OBJECTIVE AND SIGNIFICANCE: The AES Hawai‘i coal plant, the largest power plant on O‘ahu is scheduled to retire in 2022. This retirement will decrease the amount of dispatchable fossil capacity available to the utility by more than 10%. The objective of this study was to evaluate the ability of proposed solar + storage resources to maintain grid reliability with the pending AES coal plant retirement. The results of this analysis are being briefed to the Hawai‘i Public Utility Commission (PUC) and other stakeholders and are expected to have important implications for power system planning and policy for O‘ahu.

KEY RESULTS: Stochastic analysis, using the tools developed by the HNEI-Telos Energy team (see project summary “Stochastic Modeling for High Renewable Grids”), that included the annual variability of the solar resource over 21 years and a variety of fossil plant outage profiles was conducted. It was determined that the AES retirement is likely to increase reliability risks, with increased likelihood of loss of load events (LOLE). This could occur even if Stage 1 solar + storage resources are fully deployed and would be considerably worse if there are delays in project commissioning. However, reliability is maintained or even improved once Stage 1 and a relatively small fraction of the Stage 2 solar + storage projects are completed. While standalone storage was found to effectively mitigate the reliability concerns, other potentially less costly solutions were also identified.

BACKGROUND: As the Hawai‘i grid transitions to higher percentages of renewable energy, new resources are being integrated to not only provide renewable energy, but also to provide the grid services conventionally provided by AES and other fossil generation. Combining solar and battery storage resources allows solar energy to be shifted from the middle of the day when there is surplus renewable generation to evening peak load hours after the sun has set. This allows the dispatchable hybrid solar + storage projects to replace and retire conventional fossil generation such as the AES coal plant. The ability of the O‘ahu grid to replace large amounts of energy currently supplied by thermal generation with energy supplied by solar + storage systems without significant curtailment is described in more detail in the “Curtailment and Grid Services with High Penetration Solar + Storage” project summary. The inclusion of storage into these systems offers the opportunity for them to provide grid services, one of which is capacity – or the ability to provide energy when it is required for reliability. However, there are limitations that arise due to the reliance on the variable solar resource, energy limitations of the storage, contractual limitations for battery charging, and uncertainty of generator outages.

The AES coal plant is an independent power producer with a long-term Power Purchase Agreement (PPA) with Hawaiian Electric Company (HECO) that expires in 2022. HECO does not plan to renew the PPA. In addition, SB 2629 enacted in 2020 bans coal-fired generation in Hawai‘i after 2022, ensuring the AES retirement. Given the relatively short timeframe, the most likely replacement resources are the announced Stage 1 solar + storage projects (137 MW of solar, 548 MWh of storage), potential standalone battery storage, and demand response.

The Stage 1 projects were originally proposed to be completed in 2022, concurrent with the AES retirement. However, as of October 2020, some of the projects are delayed between 6-13 months, potentially pushing out their availability to after the legislatively mandated AES coal retirement. An additional 287 MW of solar, 1,275 MWh of battery storage was awarded in the “Stage 2 RFP” that could also provide replacement capacity for the AES retirement, but most of these projects, as proposed are not expected to be online until 2023 or later. As a result, the timing of the AES retirement and replacement solar + storage projects could jeopardize system reliability in the short run.

To overcome this concern, HECO has awarded – also through the Stage 2 RFP – a PPA for the 185 MW battery energy storage project to be located in Kapolei. This project is being developed as a direct replacement for the AES capacity. However, given the amount of solar + storage resources going in through the Stage 1 and Stage 2 renewable procurements, there may be significant surplus of capacity available shortly after the AES retirement.

It is therefore important to understand the extent to which hybrid solar + storage resources can reliably
replace fossil generation, while also considering the technical and contractual limitations of the resources. The Stage 1 projects consist of four solar + storage hybrid projects, totaling 137 MWac of capacity. These hybrid projects are DC coupled, where the battery storage and solar PV share a common DC:AC inverter and grid connection (see figure below). As indicated in the figure, each of the Stage 1 projects has an overbuild of the PV panels of approximately 40% and includes 4 hours of storage relative to the nameplate rating of the plant. Energy generated by the plant can go directly onto the grid or via the battery, but the total output of the plants at any given time is limited to the AC rating of the plant.

**Solar+Storage, DC-Coupling**

In addition, contractual restrictions on the operation of the Stage 1 projects requires charging of the battery to come predominately from the solar resource, as opposed to the grid, for the first five years of the project. These restrictions intended to secure the maximum benefit from the federal investment tax credit have been included in the analysis.

As described in the “Stochastic Modeling” summary, novel modeling techniques were developed to accurately account for the chronological operations of storage, solar variability, and generator outages. This new stochastic methodology combines the disciplines of resource adequacy analysis with operational production cost modeling to better simulate grid reliability with high penetrations of solar, storage, and demand response. These methodologies have been applied to the O‘ahu grid to determine if solar + storage systems could maintain reliability when AES is retired.

**PROJECT STATUS/RESULTS:** The stochastic methodology previously described was used to evaluate the reliability of near-term changes on the O‘ahu grid, specifically the retirement of the AES coal plant and successive buildout of large amounts of utility-scale solar + storage resources. Six levels of solar + storage buildout, up to an additional 426 MWac of solar with 1,833 MWh of battery storage, representing the full buildout of recently awarded Stage 1 and Stage 2 projects were evaluated.

Each case was analyzed across 252 random draws (replications) of chronological dispatch, representing 21 years of solar data and 12 outage profiles. The output of the analysis included the number, the magnitude, and the duration of the capacity shortfall events that occur when there are not enough available resources to serve load. This methodology was repeated across eight cases, one of which represents the current system (Base Case), one with AES retired without any replacement capacity, and the six additional cases with AES retirements and incremental additions of solar + storage resources up to the equivalent capacity of the Stage 2 buildout.

The matrices on the following page summarize the number of hours of unserved energy for two of the eight cases, the Base Case, and a case assuming the AES retirement and full buildout of the Stage 1 projects. For each case, the number of hours of unserved energy for each of the 252 random draws of solar and unit outages are shown. As the matrices indicate, many draws do not have any capacity shortfall events, but on average, the number of hours with outages increases by 82% when AES is retired and only replaced with Stage 1 resources.

Interestingly, the results summarized in these matrices indicate that even with an increased reliance on solar-based resources, there is no clear dependence on which year of solar data is used. This suggests that, at this level of solar + storage integration, annual weather variability, and extreme weather events do not significantly affect system reliability. As discussed in more detail below, the results show that even in years that do have capacity shortfalls, the majority of outages are only between 1-4 hours durations.
In contrast to the lack of dependence on the solar year, a strong dependence on the outage draw is indicated. While the total amount of outages used as input to the analysis was consistent across the random draws, the timing and characteristic of the outages changes across the random samples. This is strong evidence that the timing and correlation of fossil generator outages is the primary cause of capacity shortfall events.

For each case, the results of the 252 random draws are summarized into a single metric, the average LOLE value across all the draws. Additional metrics are quantified, including loss of load expectation (LOLE), which summarizes average days per year with a capacity shortfall event; loss of load hours (LOLH), which summarizes the average number of hours per year; and expected unserved energy (EUE), which provides an average amount of unserved energy (MWh) per year. The figure below shows the average LOLE for each of the eight cases. LOLE (y-axis) is plotted against increasing solar + storage adoption (x-axis). Low values represent lower risk of capacity shortfall. The dot on the lower left y-axis represents the Base Case, the current system before the AES retirement and without additional solar + storage. The line represents system reliability after the AES retirement with increasing amounts of solar + storage.
It should be noted that while the LOLE metric provides a quantitative measure of system risk, the absolute number is very sensitive to changes in assumptions. Because the O‘ahu grid is a small system, changes to the underlying outage rates and planned outage schedules can significantly change the reliability metrics. It is therefore important to use consistent assumptions across the cases and evaluate the relative differences across cases rather than focus on the absolute level of reliability.

While the figure on the previous page highlights unacceptable reliability with the AES retirement without additional solar + storage, much of that loss of reliability is recovered with the installation of the Stage 1 solar + storage. The figure below with an expanded y-axis allows better comparison of the current system against the solar + storage replacement cases. As shown, relative to AES retirement without the addition of solar + storage, while much of the loss in reliability caused by the retirement of AES is recovered when the Stage 1 projects are included, the modeled reliability is still nearly twice that of the original baseline condition with AES operating. The chart also shows that partial deployment of the Stage 2 projects in addition to the Stage 1 is sufficient to bring the system back to the same level of reliability.

This finding is important. It indicates that, with close to a one-to-one capacity swap, the hybrid solar + storage resources can be effective and reliable replacement resources for a coal fired generator. While solar + storage resources can reliably replace baseload coal, the system will need more capacity than just the Stage 1 projects. The results show that 166 MW of solar + storage (13% more than Stage 1) is sufficient to replace 185 MW of fossil generation (8% less capacity). In this analysis, because solar + storage systems are highly modular, made up of many discrete components, the analysis assumed there is no failure mode likely to cause a major loss of production like a steam turbine generator that can lose 185 MW of capacity in a single outage. More investigation of potential transmission-related outages is needed to determine if there is risk of single failure modes that could create an outage of a full solar + storage facility. The potential for solar + storage outage rates would increase the reliability risk and require even more capacity to replace AES.

In summary, with the addition of as little as 30% of the Stage 2 solar + storage projects, capacity shortfalls are eliminated altogether. This indicates that with Stage 2 implementation, there is sufficient surplus capacity available to the grid, negating the need for a standalone battery.

On the other hand, the results also indicate that project cancellations or delays in the Stage 1 projects would increase reliability risk, potentially significantly. For example, if 50 MW of projects are delayed, which represents only one of the Stage 1 projects, the projected probability of a capacity shortfall doubles. This clearly shows the need for a mitigation plan to ensure project delays do not further erode reliability.
Conventional resource adequacy metrics currently used by the utility are limited, typically reported only as the probability of a capacity shortfall event (LOLE). Additional information that characterizes the size, frequency, and duration of capacity shortfalls is important to ensure mitigations are right sized for the reliability needs of the system. This allows the use of energy limited resources like demand response and battery energy storage to provide key grid services. These additional metrics are accessible via the stochastic analysis used for this work.

The figure below provides a probability distribution for capacity shortfall durations for the Base Case and the full build out of the Stage 1 projects with AES retired. The figure on the left shows the probability of an outage of a specified duration while the figure on the right shows the cumulative probability function. These results show that nearly all events, with Stage 1 installed, are four hours or less, with more than half of all shortfall events limited to less than two hours. This means that a short duration energy storage or demand response resource, used sparingly, can effectively improve reliability, eliminating the need for additional fossil generation.

The ability of limited energy standalone batteries and demand response was evaluated to quantify their ability to mitigate these short duration reliability risks. A series of simulations were conducted adding incremental demand response and battery storage capacity to the system. This was done assuming 50% of Stage 1 projects were installed and again assuming full buildout of the Stage 1 solar + storage.

- **Standalone Storage:** The standalone storage was configured to represent the proposed Kapolei energy storage project, at 185 MW, 565 MWh (3-hour duration). A scaled down, 60 MW configuration, was also evaluated. Neither configuration was assumed to have restrictions on charging.

- **Demand Response:** Two types of demand response programs were evaluated. One program, which represents limited flexibility, evaluated 60 MW of demand response with 1-hour duration (60 MWh per day), a maximum number of 40 calls per year, and could only be utilized on weekdays from 8am to 9pm. This is indicative of HECO’s current “Fast DR” program. A more flexible demand response option with energy duration to 2-hours (120 MWh), and no time of day restrictions was also evaluated.

Results of these cases indicate that even a modest amount of new resources can substantially improve reliability. With Stage 1 fully deployed, a 60 MW demand response or energy storage asset would make the grid twice as reliable as the current system. Even with only a 50% partial buildout of Stage 1, approximately 60 MW of battery or demand response would significantly improve reliability compared to the PV + storage alone, although more would be required to reach current reliability levels. This finding is important, as it indicates that at current levels, solar + storage, demand response, and battery storage all provide approximately 1-for-1 replacement capacity for fossil generation and are roughly equivalent from a capacity perspective.
Across both cases, the addition of 185 MW of standalone storage is significantly more capacity than is required to meet reliability requirements.

However, it should be noted that the 1-for-1 equivalency of energy limited resources will not continue indefinitely. Saturation of these resources is likely and their ability to replace fossil will diminish at higher penetration levels of solar + storage. The capacity value of energy limited resources at very high penetration is evaluated further in the “Capacity Value of Storage with High Penetration of PV and Storage” project summary.

These results show that these additional resources for reliability are rarely called on, indicating that a resource that is only available several days a year can yield significant reliability benefits (see left figure below).

One of the most important factors impacting reliability of a power system is the expected outage rates of the generating equipment. This is especially true for small, islanded power grids where concurrent outages of generators can have a large effect on reliability. This applies to both planned maintenance and unexpected failures (forced outages). O‘ahu’s installed capacity is 44 years old on average, with 260 MW of capacity over 60 years old. In addition, the older steam generator technology was not designed to cycle and ramp regularly in response to wind and solar variability.

In 2016, there was a significant increase in the maintenance and forced outage rates for the HECO fleet, which is presented in the figure on the right. While this step change can be attributed to increased outages due to newly imposed environmental constraints, it’s important to continue to track these data. The results presented previously assumed a 12-year average for forced and maintenance outage rates. Additional cases using the more recent 5-year outage rates have been initiated. Based on results to date, key results and trends do not change. This has implications for future planning. HNEI is working closely with HECO to address these changes in outages.

These results have important implications for power system planning and policy for O‘ahu. Even with full buildout of Stage 1 solar + storage resources, the AES retirement could increase reliability risks. Recently announced delays of Stage 1 projects indicate buildout of Stage 1 by the time AES is retired may be under 100MW. By the time Stage 2 is deployed, the AES retirement reliability risk is fully mitigated.

While standalone storage would effectively mitigate the reliability concerns other solutions may be in the best interest of ratepayers. These may include:

- Accelerate Stage 1 and Stage 2 projects through incentive payments, streamlined permitting, and/or increased engineering budgets;
- Temporarily continue operation of AES, beyond the current PPA term and legislative mandate;
• Adjust maintenance schedules in 2023 by deferring planned outages and other elective maintenance;
• Increase energy efficiency, demand response, and behind the meter storage deployment;
• Contract temporary diesel gensets; and
• Temporarily adjust the reliability criteria, update involuntary load shedding schemes, and make outages as least disruptive as possible.

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