Grid Integration & Energy Efficiency

Stochastic Modeling for High Renewable Grids

OBJECTIVE AND SIGNIFICANCE: As the amount solar and storage integration increases in Hawaiʻi, accurately capturing the impact of weather variability and uncertainty is critical. In addition, with the relatively small number of generating units on Hawaiʻi's grid, correlated outages and maintenance events can significantly decrease reliability. The objective of this work conducted by HNEI, in collaboration with Telos Energy, was to develop novel methodologies and tools to properly evaluate system risk and the likelihood of capacity shortfalls in high percentage renewable grids by probabilistically simulating solar variability, generator outages, and storage availability.

The modeling tools and methods have been used regularly over the past four-years (2020-2023) to evaluate ongoing reliability concerns related to fossil plant retirements across Oʻahu, Maui, and Hawaiʻi Island and the role of solar, storage, and distributed energy resources to provide capacity grid services.

KEY RESULTS: A novel methodology to capture the impact of solar variability, generator outage, and storage availability on the reliability of high percentage renewable grids was developed. A 23-year dataset of solar irradiance and production profiles, as well as detailed probability distributions of generator outages and maintenance schedules were developed to allow application of this methodology to the Hawaiʻi grids. The methodology captures inherent solar variability, outlier weather events, and the impact of generator outages. This new analysis technique helps answer key questions for power system planning that are missed by traditional resource adequacy analysis such as:

- How much solar, storage, and thermal capacity is required to maintain grid reliability?
- What is the effect of increased forced outages and maintenance schedules on reliability?
- How much legacy thermal capacity can be retired?
- How do multi-day low solar and extreme weather events affect reliability?

BACKGROUND: Historically, production cost analyses used to model economic dispatch of utility generation sources typically focus on modeling hour-to-hour and sub-hourly solar variability across a single weather year. As battery storage is deployed in quantities that impact grid operations, the challenge of sub-hourly variability of the solar resource becomes less important. Instead, periods of challenging operations due to extended periods of low solar output may occur. When these challenging periods of low solar resources are concurrent with generator failures, unserved energy may result. This occurs when there is not enough capacity to serve load. This issue may be particularly acute for Hawaiʻi's grids, which have relatively few, large generators relative to the size of the load. This risk to system reliability is expected to become more serious as Hawaiʻi's fossil fleet ages as more frequent outages and maintenance events, increasing the likelihood of concurrent events.

Traditional power system planning evaluates weather risk and generator outages via resource adequacy analysis rather than hourly production cost analysis. This traditional resource adequacy analysis leverages stochastic, probabilistic assessments of risk (weather and generator outages), to determine the likelihood of capacity shortfalls. However, this analysis is limited because it does not capture chronological dispatch of the power grid, but instead evaluates snapshots in time, such as peak load hours. This inability to capture chronological dispatch is likely to miss significant events when evaluating systems with high levels of energy limited resources, such as battery storage and demand response.

The increasing importance of weather uncertainty and generator outages, combined with the need to accurately simulate storage and demand response, requires novel methodologies and tools to properly evaluate system risk and the likelihood of capacity shortfalls. Under this activity, a new model to capture the stochastic nature of grids with a high penetration of variable renewable generation has been developed and used to analyze capacity reliability of the Hawaiʻi grids.

PROJECT STATUS/RESULTS: To address the evolving challenges of system reliability on the Hawaiʻi grids at high levels of solar and storage integration, HNEI and Telos Energy developed and applied novel grid modeling techniques and tools to stochastically evaluate system operation across many years of historical weather data and potential generator outages. The project includes the

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development of a detailed, Hawai'i-specific, historical weather database. Weather conditions were simulated over the past 23-years using NREL's National Solar Radiation Database (NRSDB). Combining the weather data with solar PV plant-specific information – such as location, DC:AC ratios, tracking systems, etc. – resulted in unique sub-hourly power production profiles for each existing and proposed solar PV project in Hawai'i. The figure below illustrates the system-wide variability in monthly generation (top) and an example of a single year's rolling weekly average of solar generation relative to the 21-year average (bottom).

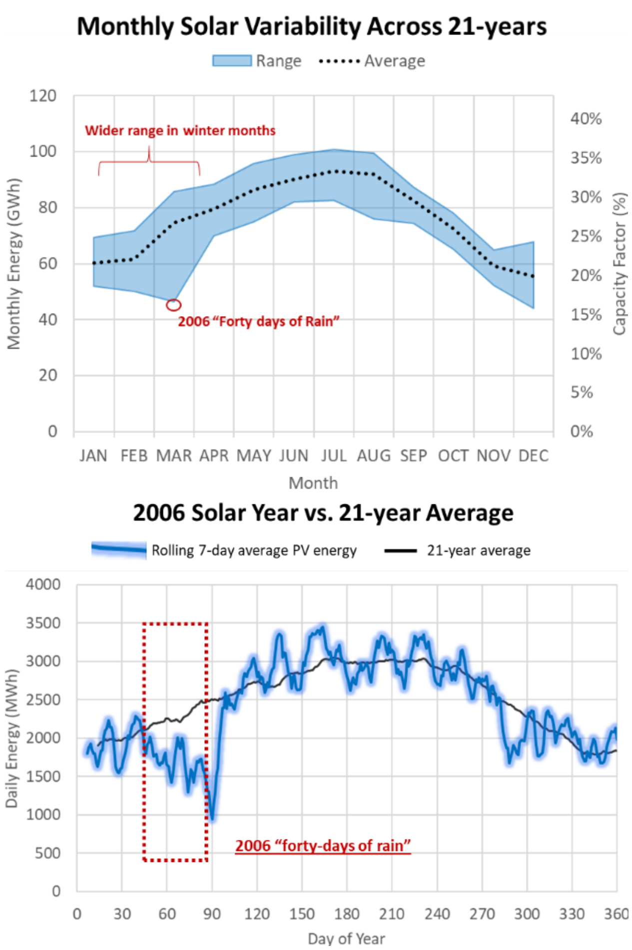

Figure 1. Monthly variability of solar power generation across 21 years (top) and the weekly average of solar generation across a year, relative to the 21-year average (bottom).

The methodology incorporates the 23-years of historical weather data for chronological solar production profiles and then simulates grid performance for those years against a series of randomly selected generator outages and maintenance events. In the analysis conducted to date, up to twelve random outage profiles were used resulting in a matrix of at least 500 Monte Carlo samples, each analyzing a full 8,760-hour year of chronological operation. The result is an analysis the calculates the probability of a capacity shortfall across over 5 million hours of grid operation.

This process allows for the calculation of conventional resource adequacy metrics, like Loss of Load Expectation (LOLE), Loss of Load Hours (LOLH), and Expected Unserved Energy (EUE), along with typical production cost metrics like cost of generation and curtailment. It also accurately captures battery utilization and state-of-charge as well as better incorporating storage scheduling, which inherently increases capacity margins in some hours (charging) in order to reduce risk in others (discharging).

Loss of Load Hours by Replication

Outage Draws →

Solar Years ↓

Solar Year	1	2	3	4	5	6	7	8	9	10	11	12
1998	0	0	5	0	0	0	0	0	0	2	0	3
1999	0	0	6	0	0	0	0	0	2	0	18	0
2000	0	0	0	2	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	2	0	0	0	1
2003	0	2	3	0	0	3	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	1	0	0	0	0	0
2006	0	0	0	0	0	0	2	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	4	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	3	0	0	0	0	0	0	0	1	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	1	0	0	2	2	0	0	0	0	11
2014	0	0	1	0	0	0	0	3	0	0	0	0
2015	0	0	0	0	0	0	3	0	0	0	1	0
2016	0	0	0	0	0	0	3	0	0	0	0	3
2017	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	1	0	0	0	0

Figure 2. Matrix of the 12 outage profiles used to calculate capacity shortfall probabilities.

In addition to the traditional resource adequacy metrics like LOLE and LOLH that only characterize the frequency of capacity shortfalls, the stochastic analysis developed under this project provides additional information, such as the size and duration of events. This ability to characterize size, frequency, and duration of reliability events offers the opportunity to tailor mitigations to meet grid needs. This allows for a more effective comparison between mitigation technologies and operational responses,

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such as battery energy storage, demand response, and fossil capacity additions for reliability. For example, battery energy storage and demand response may be preferred options to mitigate short duration events, whereas fossil generation or long-duration storage will be required for longer duration events.

The new modeling techniques and tools outlined in this report were developed to allow more accurate and higher fidelity analysis of the need for capacity and risks of unserved energy as the Hawai‘i grids transition to increasing levels of solar and battery storage. This tool is being used to evaluate issues such as the reliable retirement of fossil generators, the value of demand response, and battery storage for capacity grid services, as well as the role of long-duration storage for future power systems.

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