Hawaiʻi Natural Energy Institute Research Highlights

Grid Integration & Renewable Power Generation

Grid-Scale Battery Testing

<u>OBJECTIVE AND SIGNIFICANCE</u>: This summary highlights the findings from the evaluation of three grid-tied Battery Energy Storage Systems (BESS) each addressing different issues arising increasing renewable energy penetration levels. The three BESS in this study facilitated the discovery of benefits as well as a number of unexpected adverse consequences arising from this relatively new technology on isolated grids.

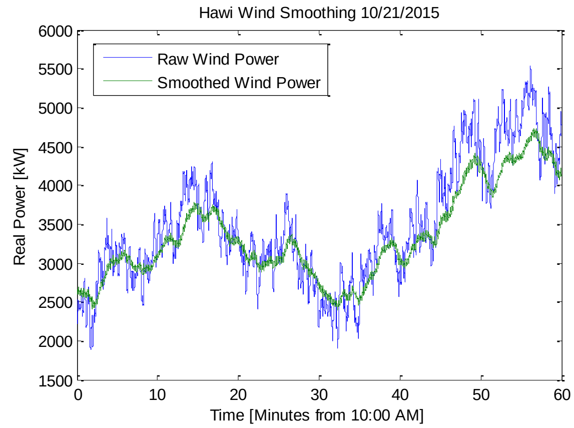
<u>BACKGROUND</u>: HNEI entered into agreements with electric grid utility companies on the Big Island of Hawaiʻi, Oʻahu, and Molokaʻi to install and test three BESS. Under the agreements, HNEI procured the systems and developed control algorithms. Ownership was transferred to the utilities after commissioning while HNEI retained multi-year data access and testing rights. The first system was installed on the Big Island at a windfarm in the town of Hawʻi, the second on an industrial circuit with high PV penetration on Oʻahu, and the third on the island of Molokaʻi at its only power station.

The three BESS were designated to test different grid services. The first 1 MW, 250 kW-Hr BESS was installed on the Big Island of Hawaiʻi and provided either frequency response or wind power smoothing to the 180 MW (peak) grid that hosts 119 MW of renewable capacity. A second 1 MW, 250 kW-Hr BESS installed on Oʻahu demonstrated power smoothing and voltage regulation on a highly variable industrial circuit with large loads and significant PV penetration. A 2 MW, 397 kW-Hr BESS was installed on the island of Molokaʻi and demonstrated fast frequency response on a low-inertia 5.5 MW (peak) grid hosting about 2.3 MW of distributed PV.

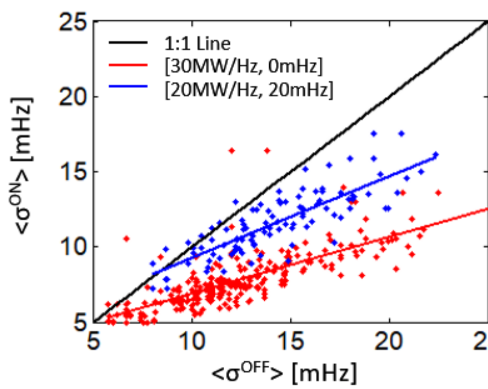
<u>PROJECT STATUS/RESULTS</u>:

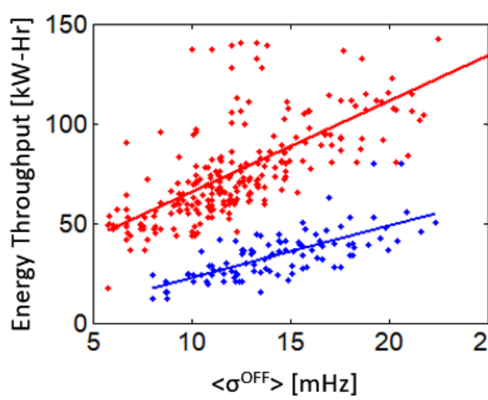
<u>Hawaiʻi ("Big Island") BESS:</u>

The Big Island BESS showed significant durability. After 7,500 equivalent full cycles over ~7 years of service the system still operates to specification with only minor repairs. While providing wind smoothing, there were several events where the BESS acted in opposition to the grid's frequency regulation needs so the work focused on use of the BESS for frequency regulation. The chart below shows an example of the BESS absorbing power in the beginning and at the end of an under frequency event.



While providing frequency response, the BESS signficantly reduced grid frequency variability (top chart below). The use of deadband allowed the BESS to provided strong grid service while minimizing cycling. Cycling was characterized by measuring energy throughput of the BESS. Energy throughpout with and without deadband is shown in the bottom chart below. The nomenclature, $\langle\sigma^{OFF}\rangle$ indicates the mean variability of grid frequency for a 20-minute period just before the BESS was turned on for another 20 minutes, whose variability is denoted as $\langle\sigma^{ON}\rangle$.





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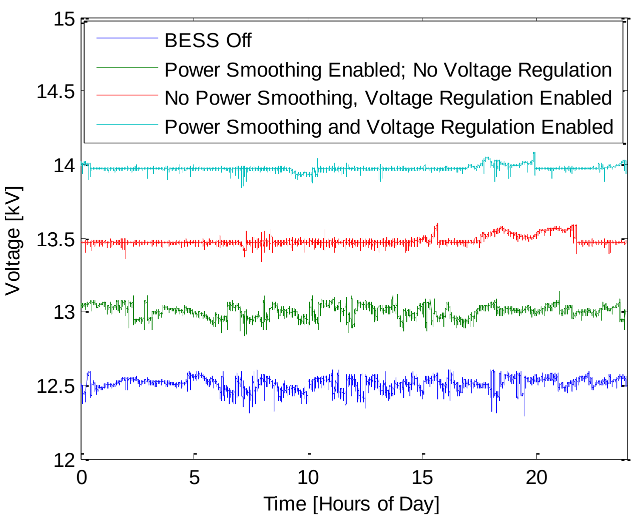
Island of O‘ahu BESS

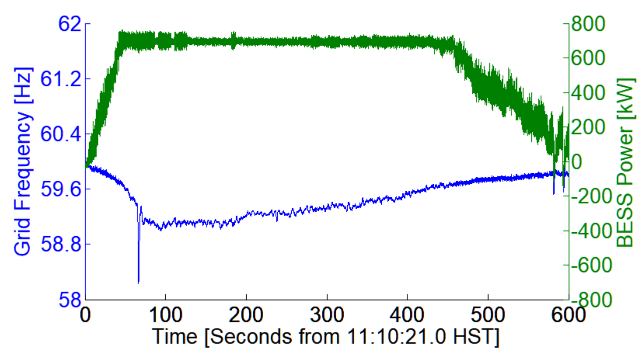
The figure below shows the impact of the O‘ahu BESS on an industrial circuit’s voltage. 500V was artificially added to these traces to avoid overlapping. The variability of the blue and green traces was about 40V when the BESS was offline or only providing power smoothing. The variability dropped to 30V for when the BESS is providing voltage regulation by adjusting its reactive power (red line). When both power smoothing and voltage regulation are used, the variability drops to less than 20V. The voltage regulation service reduced the substation’s load tap changer operations by about 80%. However, the voltage regulation doubled the power consumption of the BESS from 20 kW to 40 kW and excess heating caused isolation faults in the BESS system. This BESS was idle for a number of years prior to installation. Moisture absorbed in the capacitors needed to filter harmonics was the cited cause of an early failure of the system.



Island of Moloka‘i BESS

The Moloka‘i system provided several significant insights into the limits of fast frequency response BESS on small, low inertia electric grids. Due to the low system inertia, the grid frequency can swing quickly when relatively small electrical events occur. When those frequency swings breach PV disconnection thresholds, this new contingency compounds the original problem. Early testing also showed that, due to the low inertia, fast frequency response required the BESS to have a response time on the order of 50 milliseconds, something that did not exist in the market. A BESS providing fast frequency response sources real power to the grid when the grid frequency is low and absorbs real power from the grid when the frequency is high. Latency in this process caused instability on the low inertia grids. This result has important implications for use of BESS on any low inertia system.

The BESS generally provided helpful support, as shown in the figure below where the BESS responded to a frequency drop and then slowly handed the control back to the thermal generators. A review of the data indicates that the BESS likely prevented a number of outages, although there were some anomalies that caused enough concern to the utility so that the 2 MW BESS was limited to 1 MW or less. Specifically, high-resolution voltage data suggests that the cause of these anomalies is related to frequency measurement errors that might also occur in other inverters (e.g., grid-tied PV inverters) on low inertia grids. Several grid meters from disparate manufacturers show a strong drift in measurement sampling times during grid contingencies, such as faults. This topic is currently being documented in a paper.



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