Hawaiʻi Natural Energy Institute Research Highlights

Grid Integration & Renewable Power Generation

Fast Frequency Response Battery on a Low-Inertia Grid

OBJECTIVE AND SIGNIFICANCE: As summarized in the "**Grid-Scale Battery Testing**" project summary, a fast responding Battery Energy Storage System (BESS) was installed and operated to provide fast frequency response on a low-inertia grid on the island of Molokaʻi. Lessons learned from that system that could impact industrial standards for metering and frequency measurement during electrical transients on low inertia grids.

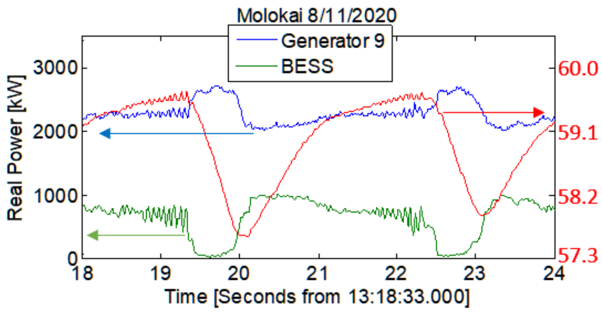
BACKGROUND: HNEI and Maui Electric entered into an agreement to install and test a 2 MW, 397 kW-Hr BESS on the island of Molokaʻi. The electric grid on Molokaʻi is ~5.5 MW (peak) with ~2.3 MW of distributed photovoltaics (PV). The significant PV penetration complicates grid operations; they automatically disconnect when the grid frequency is below a threshold, exacerbating any loss of generation, and they displace traditional generation which has natural mechanical inertia.

Because of the low system inertia, the island's grid frequency can swing quickly when relatively small electrical events occur. When those swings exceed PV disconnection thresholds, the loss of PV generation compounds the original problem. Modeling and experiments also showed that low grid inertia also means that any BESS providing fast frequency response would be required to have a response time on the order of 50 milliseconds to be effective, something that did not exist in the market. A BESS providing fast frequency response provides 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 can cause instability on low inertia grids.

HNEI funded a BESS manufacturer and an inverter manufacturer to redesign the control path to minimize the system response time as much as possible. The new controls allowed the inverter to measure grid frequency directly rather than wait to receive real power commands from the battery's controller. The redesign reduced BESS response to an event from around 300ms to within 58 milliseconds (typical) which, to the best of our knowledge, is the fastest BESS response reported to date. Live grid testing showed that the redesigned BESS effectively reduced grid instability resulting from conflicts with the island's diesel generators.

The Molokaʻi BESS has been in service since May 2017. As the system's authority (maximum allowable power response) was raised, expected power outages were increasingly avoided. Over the duration of the project, the Molokaʻi BESS has responded to many grid events. Based on historical comparisons, the BESS response has eliminated a number of potential grid outages. However, some anomalies were also amplified by the fast response. One anomaly was a fast oscillation in BESS real power and grid frequency. This oscillation was too fast to be explained as conflicts between the BESS and the diesel generators. An oscillation detector was incorporated as a patch into the BESS control software to arrest operations until the oscillations cleared. While the source of the oscillations is not fully understood, a review of laboratory data as well as high resolution measurement on the grid suggests the problem results from how the inverter measures grid frequency. There have been several oscillation events and findings that will be discussed in an up-coming paper. One notable event, that provides insights into the problem from August 11, 2020 is discussed further below.

PROJECT STATUS/RESULTS: On August 11, 2020, the BESS responded to a generator outage, supplying real power to mitigate the drop in frequency. However, instead of resolving the problem, fast oscillations in real power were detected and the BESS service was halted. This caused one of the other diesel generators to respond by sourcing more power. Less than a second later, the BESS again began to source real power until another oscillation started, causing the BESS to halt output again. This cycle repeated several times and caused the generator to exceed its power rating of 2.2 MW. This event, shown in Figure 1 below, prompted re-examination of controlled laboratory testing that had been performed on the inverter prior to installation on Molokaʻi.



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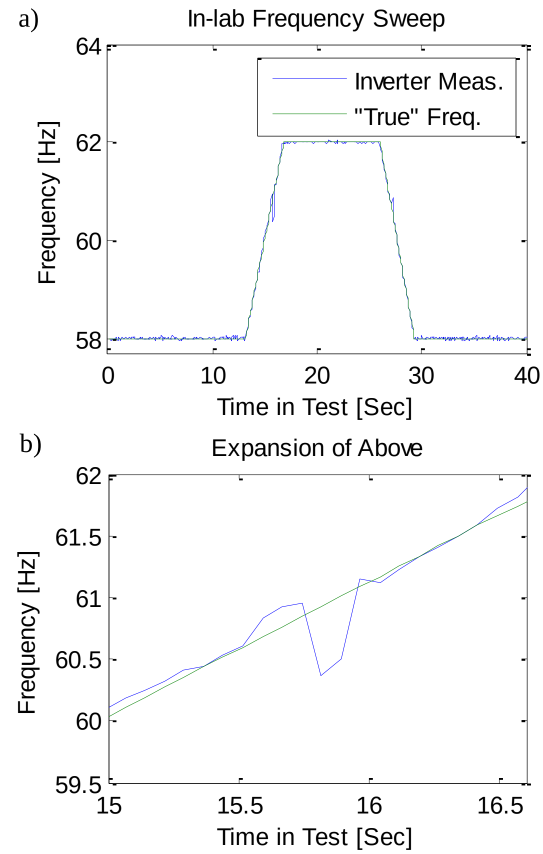
As depicted in the Figure 2 on the right, examination of the laboratory data showed some anomalous behavior. An experiment was run during which the inverter was set to absorb a constant 200 kW while the true frequency (green trace in the figure below) was held at 58 Hz for the first ~12 minutes of the test. The frequency was then ramped up gradually to 62 Hz. While ramping up, the inverter's estimate of frequency (blue trace) diverged from the true frequency. This is shown more clearly in the expanded scale in Figure 2b showing a clear difference between 60.5 Hz and 60.9 Hz. This behavior has now been observed both in the lab and field for various frequency and power combinations. Also, since grid scale inverters are not normally used to directly measure frequency, relying instead on external commands, we are not able to comment at this time about the prevalence of this issue in other types of inverters.

The oscillations shown in Figure 1 occurred when the grid frequency was just below 60 Hz with the inverter supplying ~800 kW, a point that could not be tested in the laboratory. The plausibility of such frequency measurement errors causing oscillations on a small grid in a closed-loop with a BESS is under investigation and will be reported on.



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