# Molokai: Battery Energy Storage for Grid Stability


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***NELHA Energy Storage Conference***

**December 5, 2018**

**Kona, Hawaii**

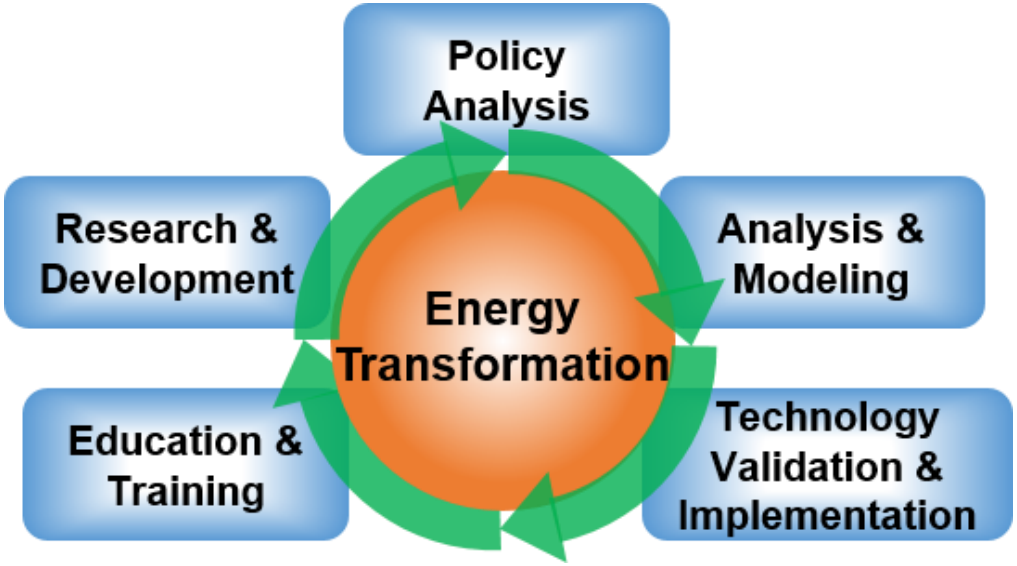
HNEI
Hawai'i Natural Energy Institute

University of Hawai'i
MANOA

# Hawaii Natural Energy Institute (HNEI)

***Organized Research Unit in School of Ocean and Earth Science and Technology***
***University of Hawaii at Manoa***
***Founded in 1974, established in statute in 2007 (HRS304A-1891)***

- Directed by statute to coordinate and undertake the development of Hawaii's abundant natural energy resources in order to …diminish Hawaii's dependence on fossil fuels
- Building international collaboration to facilitate transfer of Hawaii's lessons learned to other Asia-Pacific regions. Currently active in Japan, Thailand, Vietnam, and Korea



# Grid Scale BESS Projects (HNEI)

Conduct experiments to assess/optimize BESS performance and lifetime for high value grid applications

**Haw'i 10 MW Wind farm at Upolu Point Hawaii Island (1MW)**

- Frequency regulation and wind smoothing (6 years, > 8400 cycles)

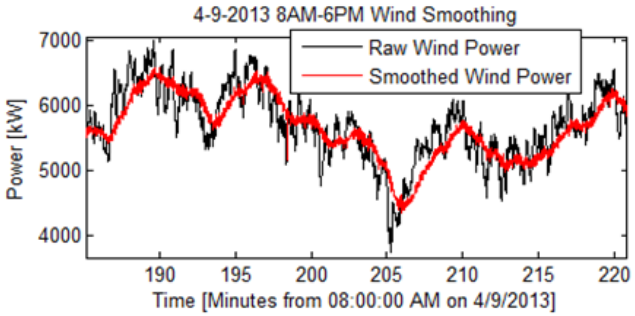
**Campbell Park industrial feeder with high penetration (1MW)**

- Power smoothing, voltage and VAr support

**Molokai Secure Renewable Microgrid (2MW)**

- Operating reserves, fault management, and frequency regulation


photos courtesy of Altairnano



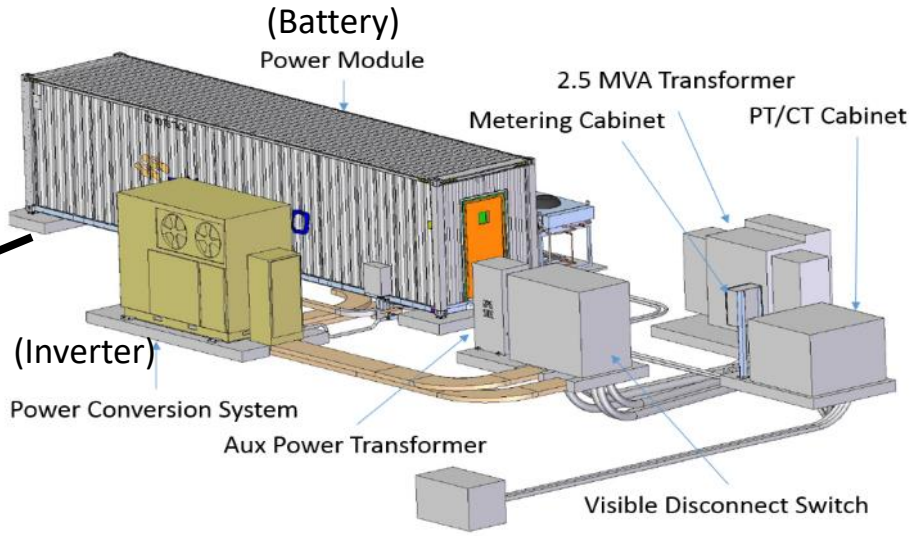

**Power smoothing at Hawi wind farm**


[1] Stein, K.; Tun, M.; Musser, K.; Rocheleau, R. Evaluation of a 1 MW, 250 kW-hr Battery Energy Storage System for Grid Services for the Island of Hawaii. *Energies* **2018**, *11*, 3367.

[2] Stein, K.; Tun, M.; Matsuura, M.; Rocheleau, R. Characterization of a Fast Battery Energy Storage System for Primary Frequency Response. *Energies* **2018**, *11*, 3358.

# Moloka'i Island 100% RE Grid Initiative

- Existing 4.5MW Molokai electric grid is powered by diesel generators with over 2MW of distributed PV.
- Relatively small disturbances can trip PV units causing automatic load shedding and customer outages
- Initial Project Goals: Integrate a fast-acting BESS to improve grid reliability. Develop interconnection and controls for a 2MW/375KWh fast-acting BESS.
- Current Project Goals: Develop sufficient understanding of Molokai grid operation to optimize value of BESS with other grid systems including dynamic load bank and proposed PV-battery system from New Energy Partners.

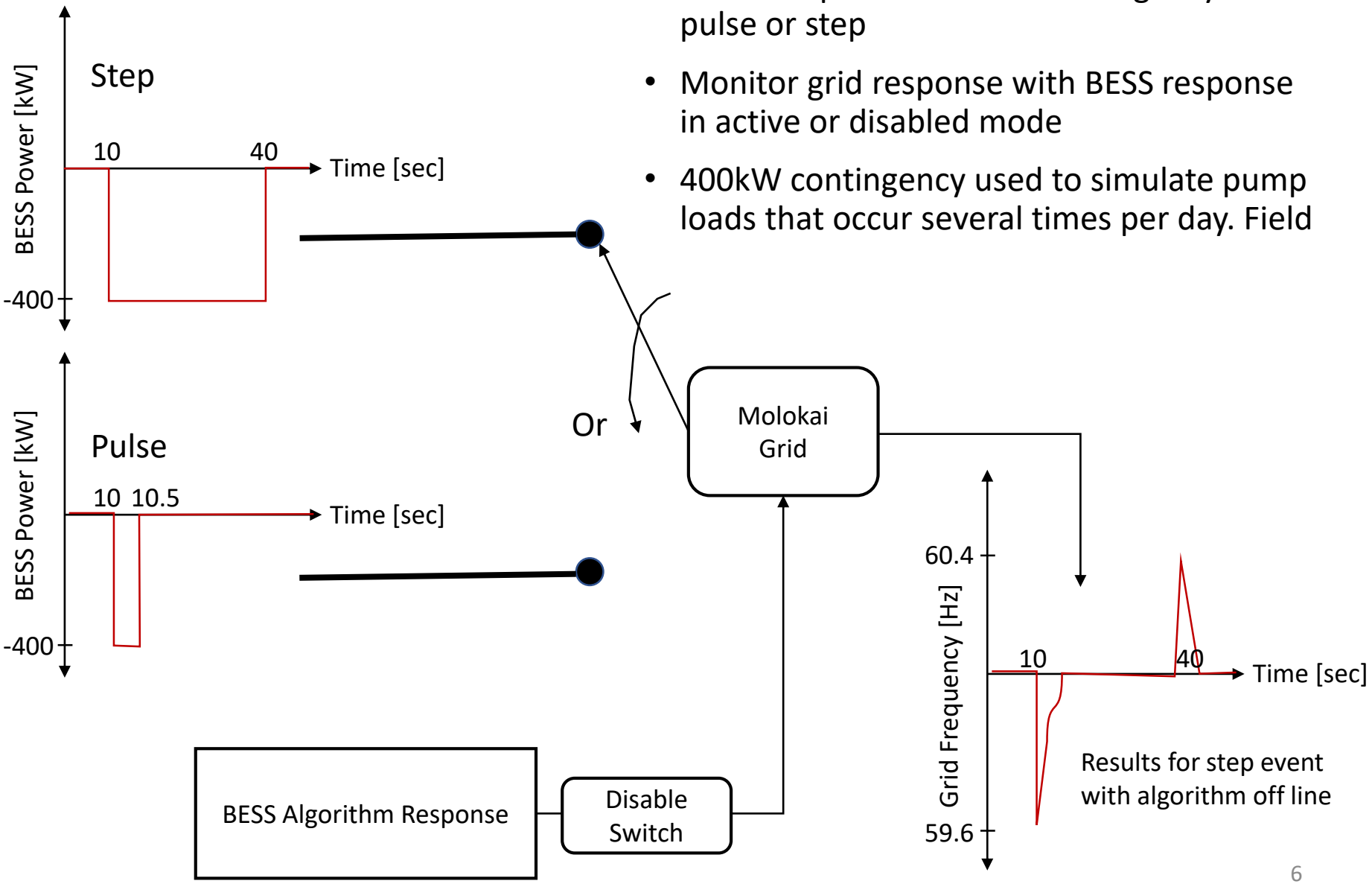


# Project Timeline

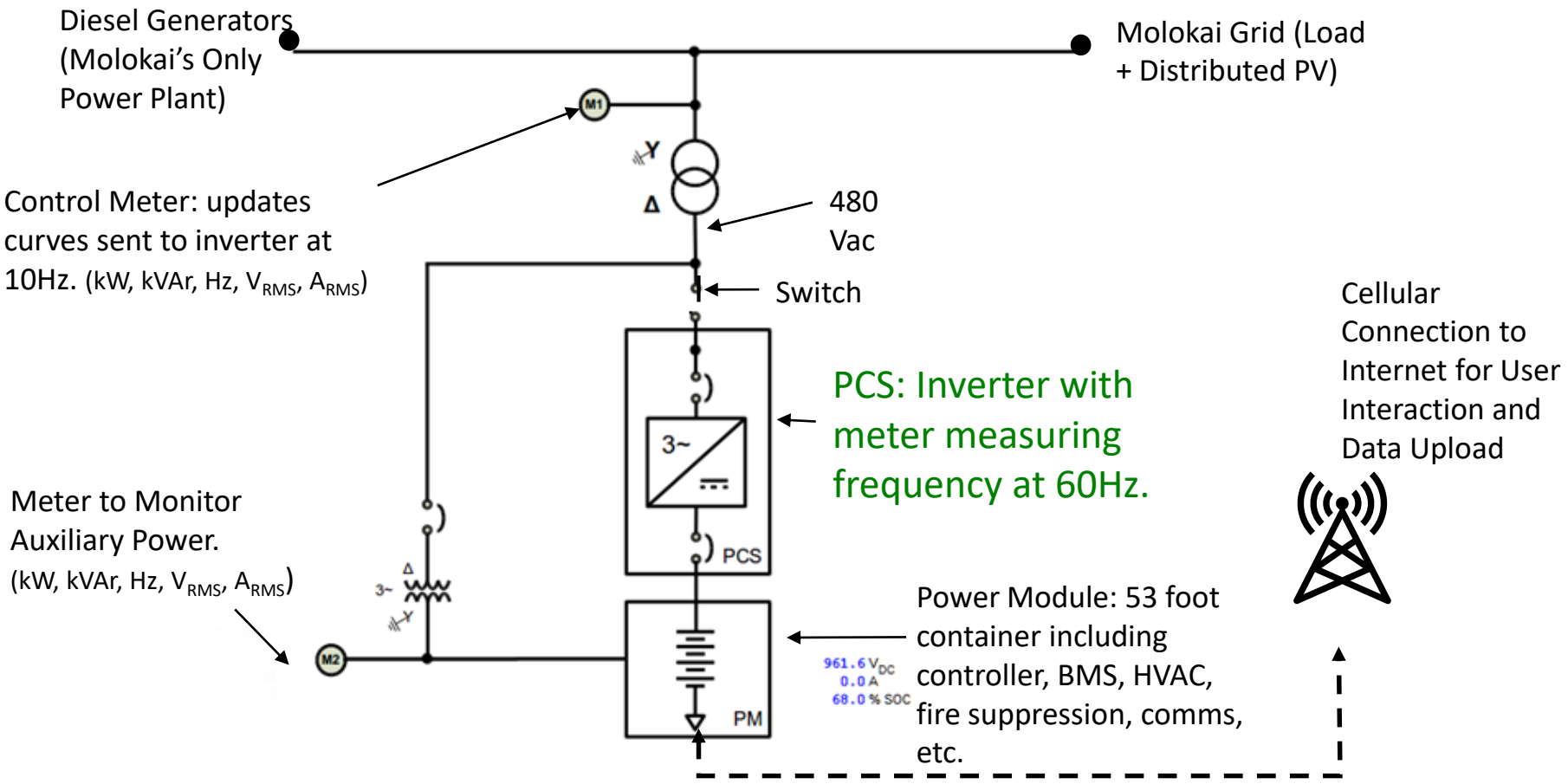
- 2011: ONR funding for 3 BESS projects in the Hawaiian archipelago.
- 2011: Memorandum of Agreement with MECO for BESS on Molokai
- 2014: Community meetings on Molokai to gain community acceptance
- 2015: 2 MW Li-ion titanate BESS was installed on Molokai (August)
- 2015: Testing confirmed that BESS response (as installed) was too slow and destabilized grid.
- 2016: Testing confirmed modified controls mitigated grid contingencies for loss of load and loss of generation)
- 2016 – 2018: Testing of BESS with incremental increase in "authority". Increased maximum response from 100kW to 500kW.
- 2018: MECO operates BESS with an authority of 750 kW. Results being analyzed
- Ongoing: High fidelity grid modeling in PSCAD to optimize coordination of all grid resources on Molokai.

# Molokai BESS Commissioning

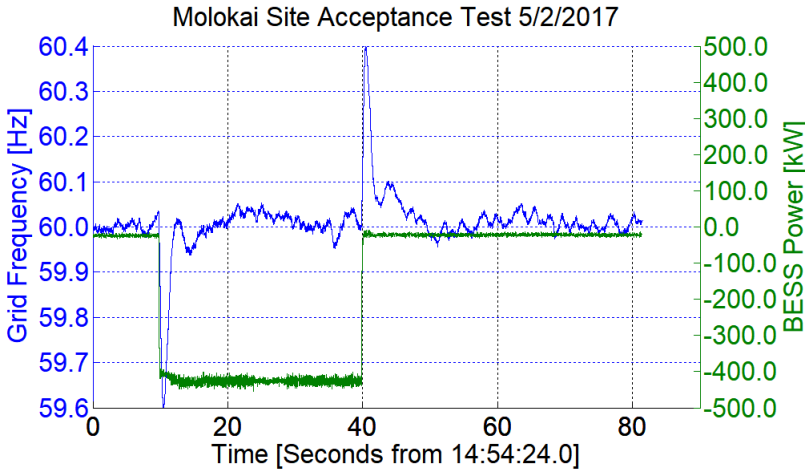
- BESS setup to simulate a contingency – pulse or step
- Monitor grid response with BESS response in active or disabled mode
- 400kW contingency used to simulate pump loads that occur several times per day. Field

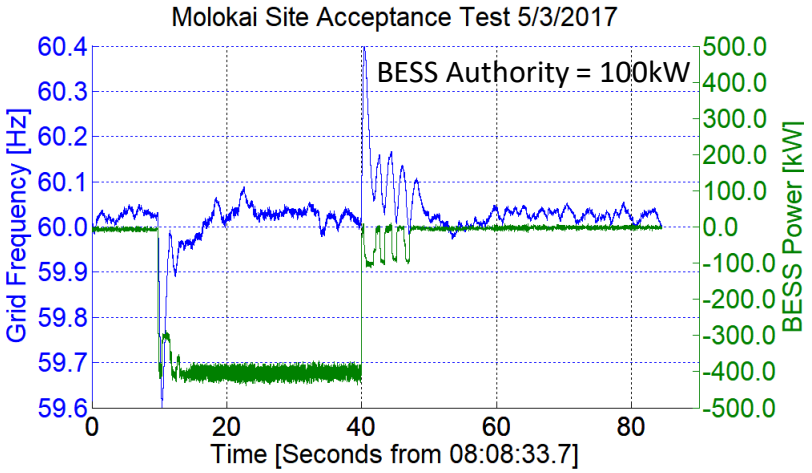


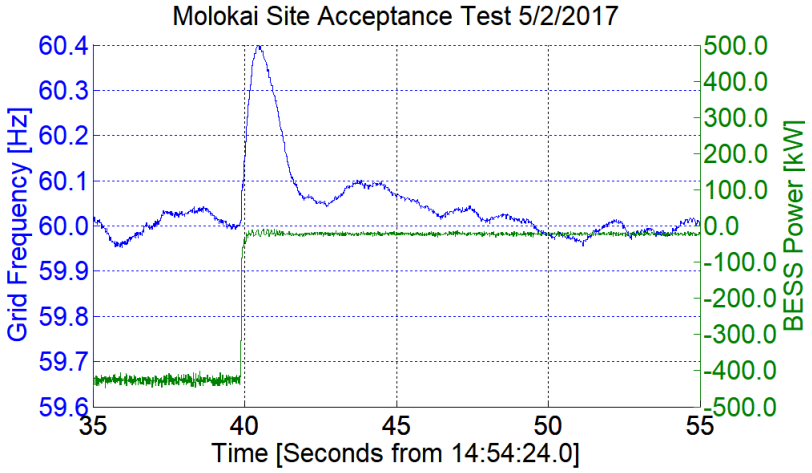
# Molokai BESS Interconnection

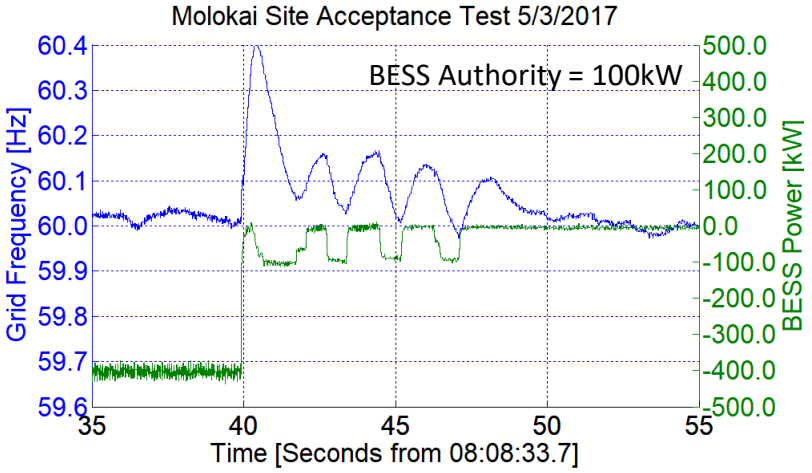


# Molokai BESS with 100kW Authority and Original Algorithm



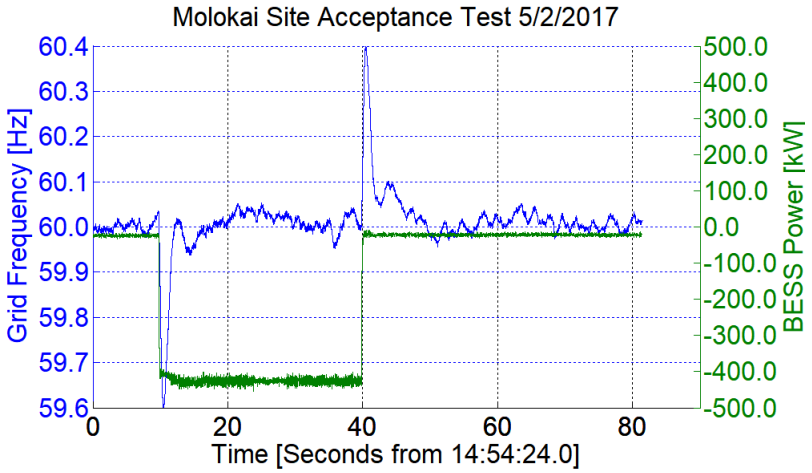



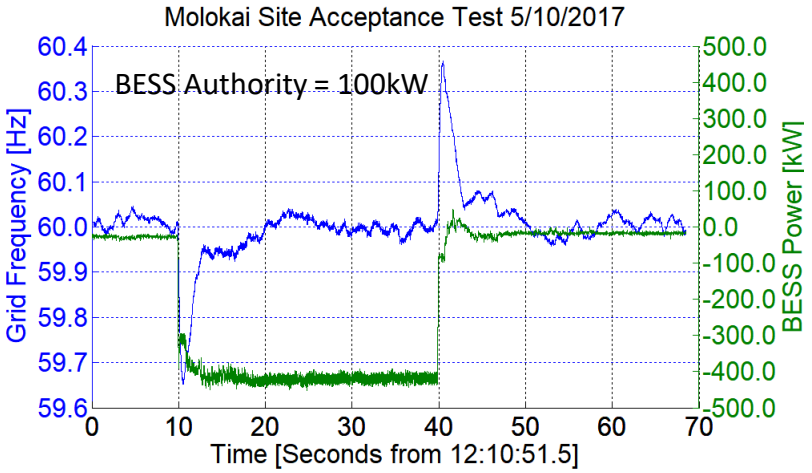



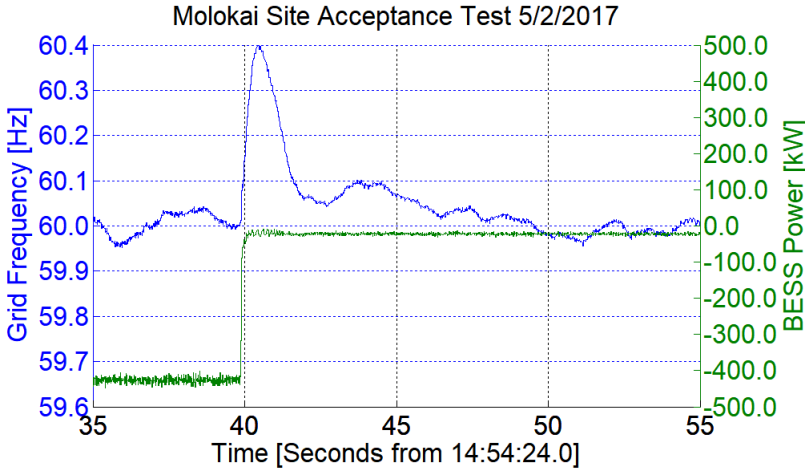



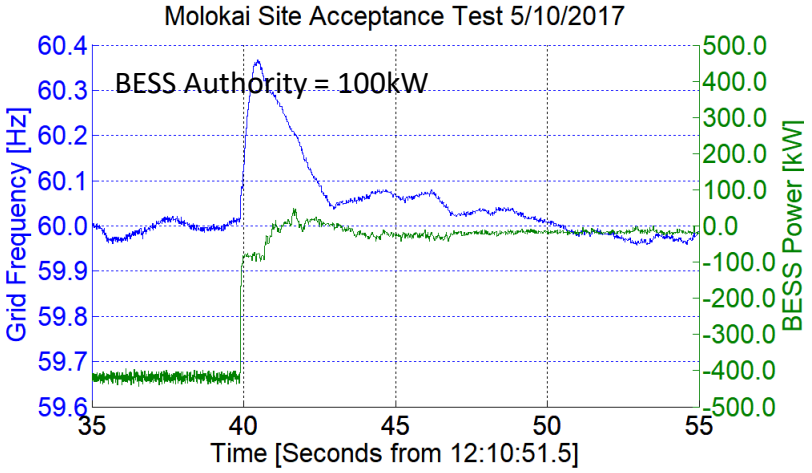

Expansions (bottom) show response at up-step

# Molokai BESS with 100kW Authority and Fast Response



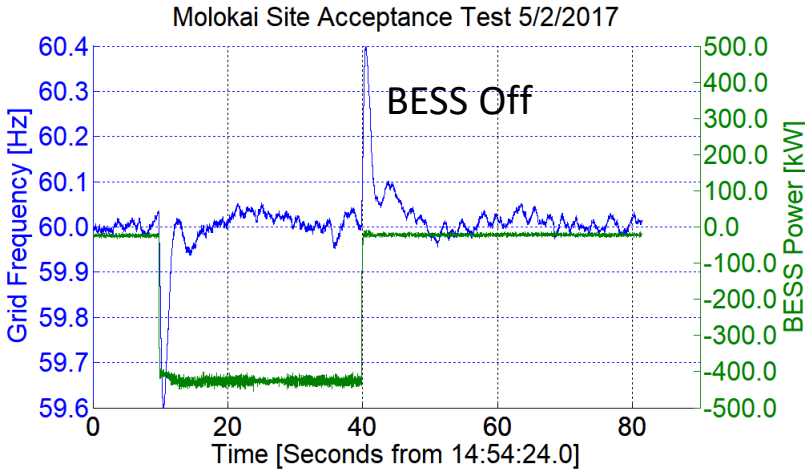



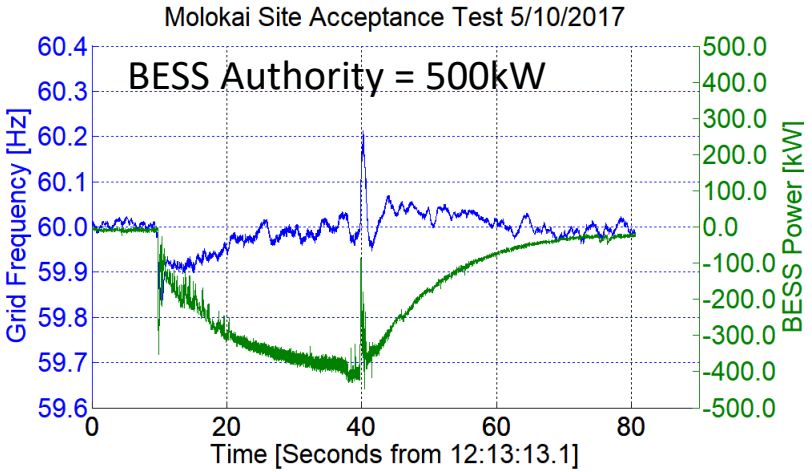



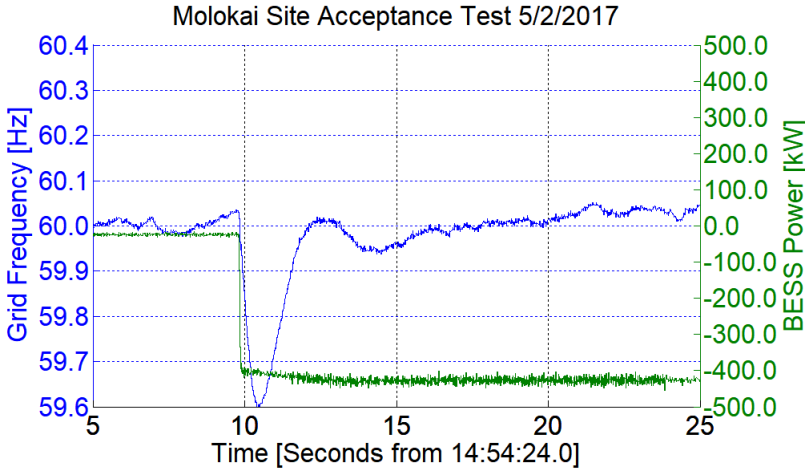

Expansion (bottom) shows response at up-step

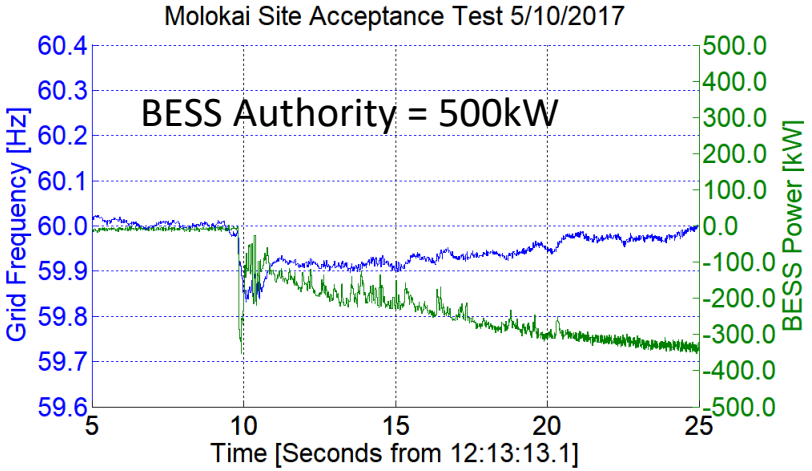
# Impact of BESS with 500kW Authority and Fast Response

Expansions (bottom) show Down-Step



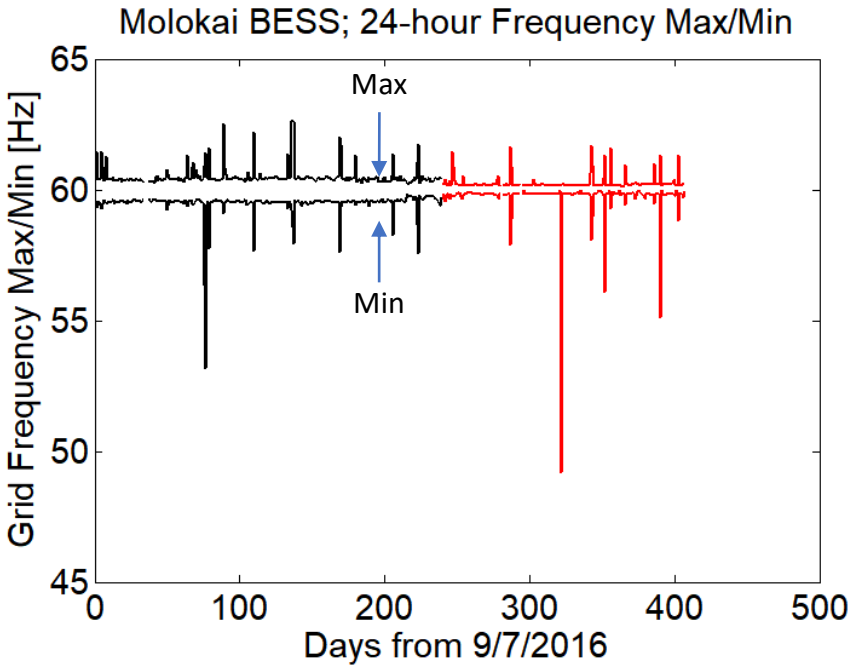



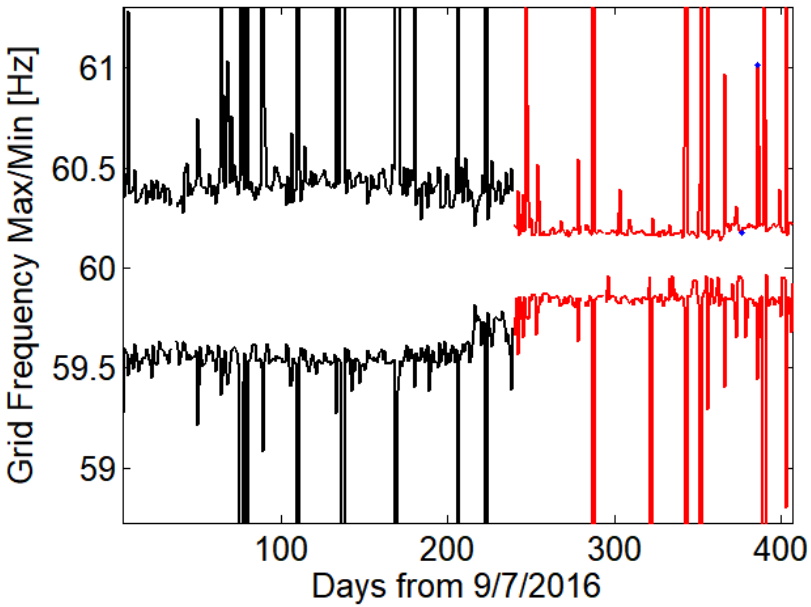




500kW fast response significantly reduced frequency fluctuation

# Molokai: Frequency Extremes

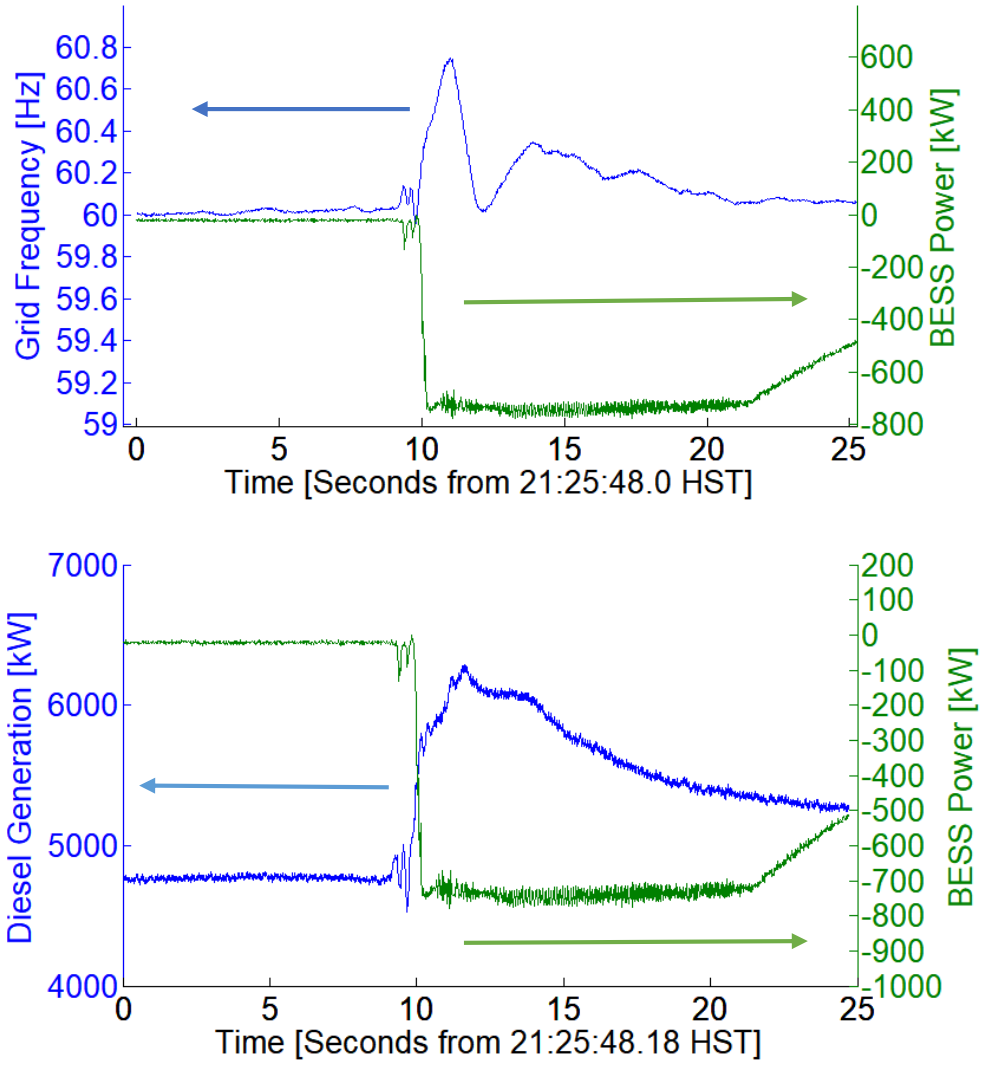



Black: BESS Offline  Red: BESS Online

Legacy PV trips at 59.3Hz and 60.5Hz

# BESS-Generator Interaction




- Fast generator ramp (bottom blue) in response to grid event causes over-frequency event (blue top)
- BESS responds to over-frequency by absorbing excess real power (green).
- BESS uses full authority of 750kW which was helpful but likely less than optimal
- BESS and generators taper off gradually as system returns to stead-state.
- PSCAD models under development to more fully understand generator-BESS dynamic.

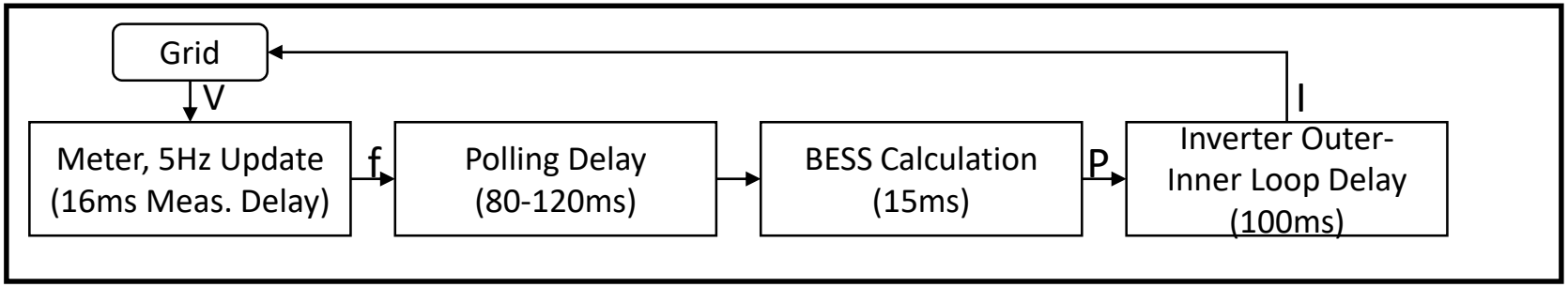
# Summary

- Modeling and initial testing showed that as procured response of 200-250ms would destabilize the Molokai grid especially when operated with lower inertia generator schemes
- Control algorithm and hardware was modified to reduce BESS response time to less than 60ms (typ.)
- Live testing on Molokai grid with incremental increases in BESS authority has shown increasing value to the grid
- After extensive observation and collaboration with the utility, the BESS now has authority to respond with 750kW
- Installation of additional high-speed measurements and PSCAD modeling underway to further optimize the interaction of the BESS with existing generation
- Model will be of value for future integration of utility scale PV-BESS (load shifting) by New Energy Partners

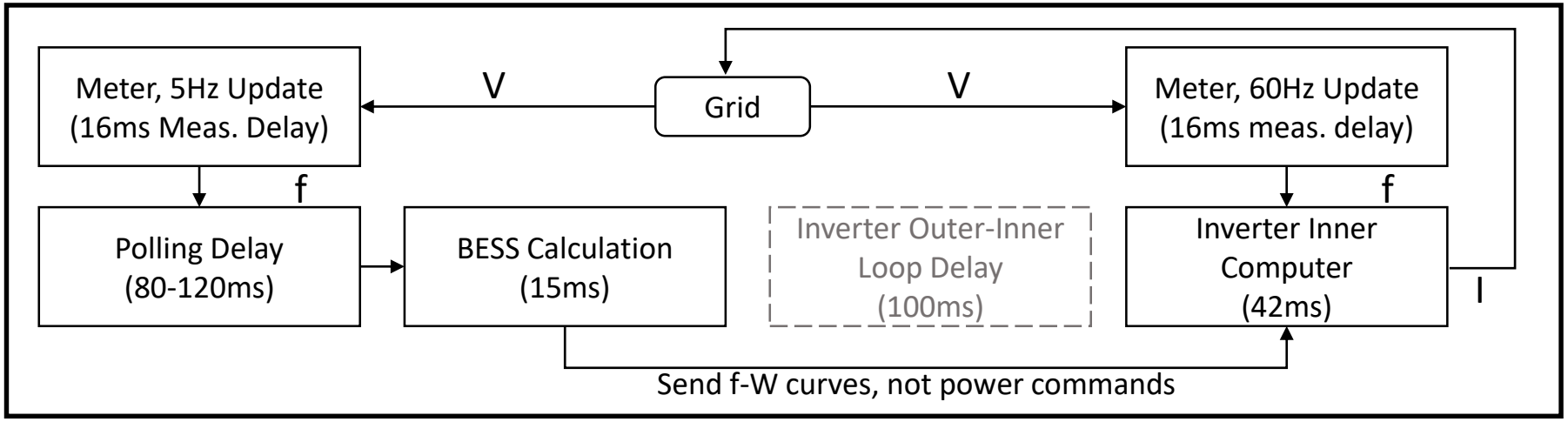
# Reduction of BESS Response Time

## Re-engineer data acquisition and processing architecture

Legacy Architecture: 211 to 251ms, depending on polling delay




Modified Architecture: <58 to 101ms max. depending on inner computer thread availability




"V" represents 3-phase voltage; "f" represents grid frequency;
"P" represents real power command; "I" represents current