Letter Report on Testing of Distributed Energy Resource, Microgrid, and End-Use Efficiency Technologies

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Hawai‘i Distributed Energy Resource Technologies for Energy Security

Task 8 Deliverable

Letter Report on Testing of Distributed Energy Resource/Microgrid/End-Use Efficiency Technologies

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Letter Report on Testing of Distributed Energy Resource, Microgrid, and End Use Efficiency Technologies (Task 8)

This completes deliverables for Task 8.

Under Task 8.0 HNEI proposed to complete work initiated under Task **2.0,** addressing potential renewable, distributed energy resource, and micro-grid technology initiatives. Specific activities included

Subtask 8.1: Plug-in-Hybrid Electric Vehicles:
Under this subtask, HNEI proposed to procure and evaluate plug-in hybrid vehicles (PHEV) in terms of their efficacy and efficiency for the state of Hawaii market. It was proposed to purchase and convert two vehicles in order to obtain information on PHEV operation, economics, fuel use, and other attributes for this market. However, early in the program two Prius Hybrid vehicles from the Hawaii State Motor Pool become available. These vehicles were converted at no-cost to this project and included in the Hymotion Prius Conversion PHEV Demonstration program run by Idaho National Laboratories (INL). Results of the INL assessment can be found at: http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/phev/hymotion_prius_wrapup_inl-ext-11-23746.pdf.

In addition, due to the growing importance of EV and PHEV in Hawaii, HNEI conducted a detailed assessment of the use of electric vehicle technology to address integration issues associated with the high penetration of intermittent renewable energy technologies. These results have been reported under Task 7.2 Electric Vehicle Charging as an Enabling Technology.

Subtask 8.2: Use of Hydrogen for Energy Storage
Under this subtask, HNEI evaluated the use of hydrogen as part of an integrated storage system with emphasis on the use of hydrogen production to provide ancillary services support to a grid system with a high penetration of intermittent renewable generation technologies. The more energy storage available on the grid, the more intermittent renewables such as wind and solar that can be added to the grid. Currently grids use backup power generators that are at idle power setting ready to ramp up quickly to support the grid when the wind is gusting or PV arrays are subjected to cloud cover. It is postulated that using an electrolyzer as a variable load could provide the same support to the grid. Figure 1 indicates that 1 MW of storage (provided by a battery or ramping down an electrolyzer) on a grid of 100 to 200 MW capacity could contribute to a reduction of the frequency fluctuation potentially allowing additional renewables to be integrated into the system.

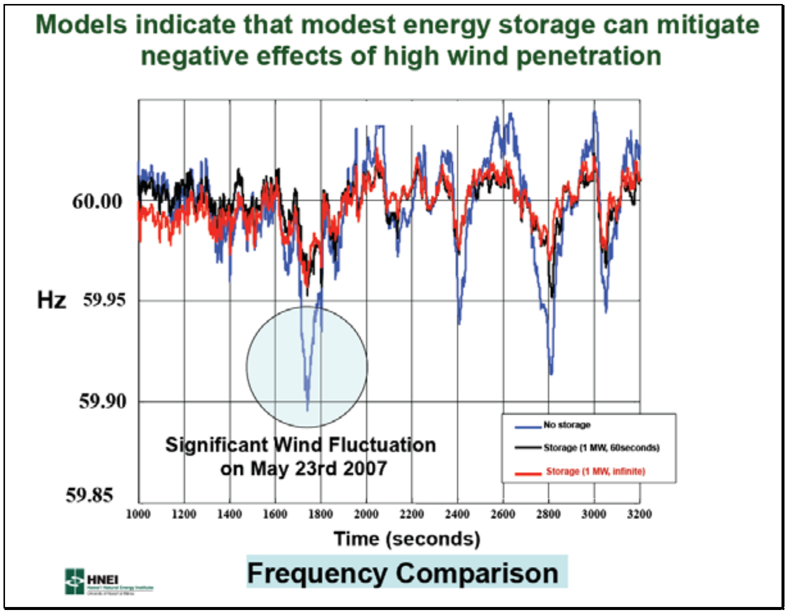

Figure 1: Effect of Energy Storage on Grid Frequency Regulation

The evaluation included identifying different operating strategies for the hydrogen energy system to mitigate system frequency excursions, displacement of fossil generation on grid, and reduced curtailment of renewable energy sources such as wind, solar and geothermal while at the same time providing value-added products that may mitigate system costs and further increase the use of renewable energy resources. The system includes an electrolyzer that operates as a controllable variable load that provides ancillary services to the grid and hardware for production of value-added products that utilize hydrogen for transportation fuels, and stationary power production. It was identified that an important component of an experimental test plan would be to evaluate the performance and durability of operating electrolyzers in a dynamically changing mode over time. HNEI sought and successfully procured funding to demonstrate this concept. The following figure provides a conceptual illustration of the hydrogen energy system developed in this subtask.

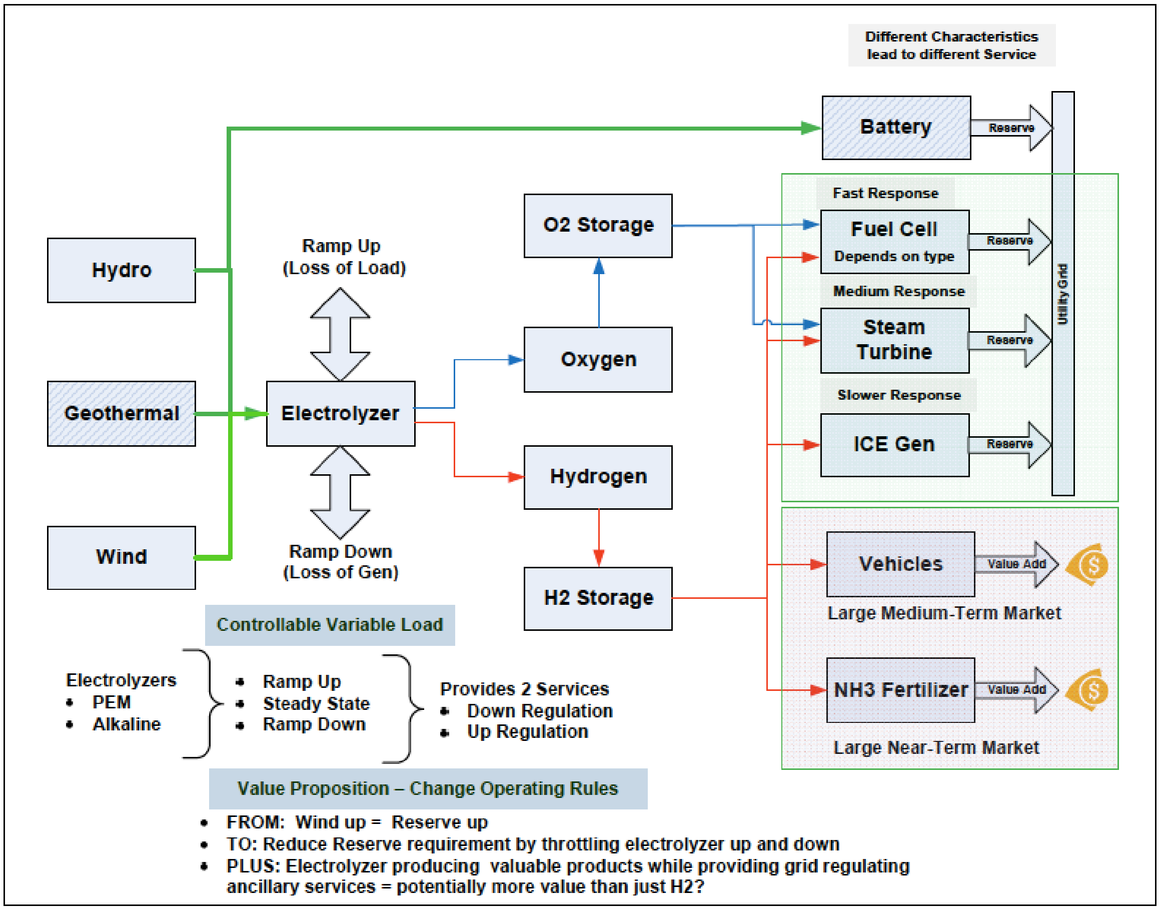

Figure 2: Hydrogen Energy System

The system has three main components. The first component is an electrolyzer that operates as a controllable load that provides ancillary services to the grid. A second component, shown in the box on the lower right of the figure, is a set of value added products that utilize hydrogen for transportation fuels and producing fertilizer. Both of these products can be manufactured using technologies that are in commercial use today. The third main component of the system, shown in the box on the upper right of the diagram, is additional grid services enabled by the hydrogen and oxygen produced by the electrolyzer. The box shows three different potential electricity generating technologies than can use the stored hydrogen to produce power for additional grid services: fuel cells, steam turbines, and internal combustion engines.

The diagram shows several items in addition to the components described above. On the far left, the figure shows different potential electricity sources for the electrolyzer. An Independent Power Producer (IPP) could utilize a portion of its power output to supply this system and produce other high value products (transportation fuel, fertilizer, and grid services) in addition to its normal supply of electricity to the grid. Alternatively, the hydrogen energy system could be utilized by intermittent power sources, such as wind or run-of-river hydro plants, to utilize off peak energy that would be curtailed in the absence of the system.

The middle of the diagram shows the resulting products from the electrolyzer - hydrogen and oxygen. These products would be stored on site and could be used for multiple uses illustrated in the diagram. Hydrogen could be used as a transportation fuel and as an input in producing ammonia for fertilizer. It could also be used in one of the power generating units that provides additional grid services. The diagram shows that the oxygen produced from the electrolyzer could be stored and used in the fuel cell or to produce steam utilized by a steam turbine.

Finally, the diagram shows a battery, which is depicted in the graph only for comparative purposes. .One alternative to the system shown in the diagram is a battery that provides grid services and it would be useful to conduct analysis to compare these different technologies. The sections below further describe the potential grid services available from an electrolyzer and stored hydrogen.

Grid Services from Electrolyzer

The electrolyzer could be operated as a controllable variable load that can potentially provide the following grid services:

- Up regulation;
- Down regulation; and
- Off peak load (relieving curtailment of as available renewable energy).

The hydrogen energy system would operate the electrolyzer at a steady state, which would be primarily determined by the steady state demand for transportation fuels. When operating at the steady state demand, the electrolyzer would have the ability to reduce its power draw (ramp down) in response to a loss of generation on the system. This capability to quickly drop power is equivalent to up regulation carried by generating units on the system. The hydrogen energy system could also provide quick-responding increases in load (ramp up) that would be useful in loss-of-load events, such as a loss of transmission lines. For this service, the difference between the maximum capacity of the electrolyzer and the steady state defines the ability of the electrolyzer to provide down regulation.

The hydrogen energy system could potentially provide these regulation services in three different timeframes of importance to system operators, which are shown in the table below.

Control Timeframe	System Use	Effect on System Operation	Primary Benefit	Preliminary Assessment
Primary (seconds)	Mimic droop response of generator	Improve reliability, potentially relax must run rules	Increase ability of system to accept variable gen	Large system needed to have significant benefit
Secondary (seconds to minutes)	Provide additional regulation to AGC	Reduce reserve requirement and stress on thermal units	Fewer thermal units committed over year and less ramping on units	Smaller system useful but used frequently
Tertiary (minutes to hours)	Used under discretion of system operator	Reduce reserve requirement and provide "last line of defense"	Fewer thermal units committed over year	Smaller system useful but used infrequently

Electrolyzers have the ability to respond very rapidly and could be operated to mimic the droop response currently provided by generating units to stabilize system frequency. By using a signal triggered by system frequency, the controllable load could increase or decrease load to counter rapid changes in system frequency. This control feature operates on a timeframe of seconds and the electrolyzer is capable of responding within this period. If the electrolyzer had sufficient capacity to provide up and down regulation, the controllable load could conceivably substitute for thermal units that are maintained online to provide these grid services. The system would also likely require additional measures to a controllable load, like additional fast starting generation, to make such a major change in operating rules. Nonetheless, by reducing the number of units operated on "must run" status, the system could potentially accept more "As Available" generation, particularly during off-peak periods when curtailment typically occurs. While the electrolyzer appears to be capable of responding quickly enough to provide grid services in this timeframe, the controllable load would need to be sizeable and highly reliable before system operators could consider relaxing must run requirements. The system would also need to consistently experience excess energy to ensure that the additional load is served by renewable generation.

The second row of the table describes how the controllable load can be used for secondary frequency control. The electrolyzer could respond to requests from the utility's Automatic Generation Control (AGC) to increase and decrease load for helping restore system frequency. This control system operates within several seconds to minutes and the electrolyzer is also capable of responding in this timeframe. With this capability, the controllable load would contribute to the system's reserves and can potentially lower the reserve requirement used in committing thermal units. By changing this operating rule, fewer thermal units would be committed over a year and potentially increase the ability of the system to accept "As Available" generation. The electrolyzer with a capacity of a few MW could be large enough to affect unit commitment but the load would be called on as needed by the AGC with little or no notice. Since AGC would call on the controllable load during a system emergency, some of the thermal units would be maneuvered less frequently. If the system emergencies were frequent, varying the electrolyzer may affect the supply of the value added products.

The final row of the table shows how the system could be used in the longer, tertiary control timeframe of several minutes to hours. In this case, the system operator would use the controllable load as a last line of defense in maintaining system stability. The controllable load would still contribute to system reserves and reduce unit commitment by system operators. The difference from the previous application is that system operators would only use the resource in an emergency and the system would produce transportation fuel with fewer disruptions.

Research questions based on these potential applications include:

1. What is the response time (ramp rate) for different electrolyzer technologies – alkaline vs. PEM?
2. How does system performance change (degrade) over time with rapid changes in output – alkaline vs. PEM?
3. What is the best timeframe (primary, secondary, tertiary) to control this asset – alkaline vs. PEM?
4. What control system is needed in order to respond to the grid system state – either in responding to AGC signals or to direct operator input?

Grid Services Provided by Stored Hydrogen and Oxygen

Stored hydrogen could be used in a fuel cell, steam turbine, or internal combustion engine to produce electricity and provide additional grid services from the system. With the fuel cell and steam turbine, the hydrogen would be combined with stored oxygen. For all three technologies, the electricity could be available to the grid from seconds to minutes and these systems could be used similarly to the quick start diesel generators currently called on by system operators to mitigate sustained ramp events from wind plants and other system emergencies. These generating assets would contribute to the system reserves and potentially reduce the reserve requirement carried by existing thermal generating units on the system.

The fuel cell could potentially be used for applications requiring faster response times. For instance, it could respond to system frequency and provide a droop response characteristic. Alternatively, the system could respond to output from a wind plant and reduce the severity of ramp events (wind smoothing). Finally, the system operator could call on the fuel cell only in an emergency. These services require slightly different capabilities from the system. The droop response characteristic requires a faster response time but may be called on less frequently. Mitigating wind plant ramps would happen on a longer timeframe and may occur more frequently. Operating the system in an emergency would also occur in a longer timeframe and the fuel cell would also be used infrequently.

Potential Grid Services from Fuel Cell (see the table below)

Grid Service	System Operation	Response Required	Frequency
Droop response	Add power quickly in response to system emergency	Fast - within seconds	Infrequent
Ramp mitigation	Add power to mitigate sharp drops in wind output	Seconds to minutes	Potentially frequent
Emergency reserve	Provide power as last line of defense in emergency	Minutes	Infrequent

Research Questions

1. What is the most cost-effective technology and grid service utilizing stored hydrogen?
2. How quickly can fuel cells provide power to grid under different conditions?
3. What control system is needed in order to respond to the grid system state – either in responding to AGC signals or to direct operator input?
4. How is performance affected by different modes of operation – infrequent, fast response vs. frequent, quick response vs. infrequent, slower response?
5. What are the economic values of the ancillary services?
6. Where would the systems be sited?
7. What infrastructure is needed to support the system?
8. What is the cost of implementing the system system-wide on the Big Island?
9. What are the policy and social barriers to implementing the system?

Value-Added Products from Stored Hydrogen– Transportation

When not being utilized for grid ancillary services, stored hydrogen can be used as a fuel for transportation.

Research Questions

1. What is the value proposition of producing hydrogen for cars/trucks?
2. What is the relationship between demand for value-added products and sizing the electrolyzer?

Subtask 8.3: PV Demonstration

HNEI continued the build-out of PV test beds including PuuWaaWaa on the Big Island, on top of Holmes Hall at the University campus on Mānoa, and at Maui College. Details of this work have been submitted in two reports under Subtask 11.1: 1) Report on PV Test Sites and Test Protocols, and 2) Report on PV System Performance at Selected Test Sites.

Subtask 8.4: Technologies for Energy Efficient Buildings

Under this subtask HNEI examined possible new technology development for residential energy management systems for demand side management, peak demand response, and installation of end use energy efficient appliances. This work was completed and a report delivered in 2009.