Energy Storage with Staying Power

Successes from Aquion's Smart Grid Demonstration Project

Introduction

Energy storage from batteries promises to maximize distributed and renewable energy's usefulness on and off the electric grid. For example solar energy collected in the afternoon may not be available in the evening, when consumers most need it, unless batteries store the excess energy. There is a tradeoff in batteries between energy and power density versus longevity and low cost.

With its $10.4-million cooperative research agreement under the U.S. Department of Energy's (DOE) Smart Grid Demonstration Program, which provided $5.2 million, Aquion demonstrated a pilot ambient-temperature, Aqueous Hybrid Ion (AHI) battery system. The system's stability, longevity, and energy efficiency makes it an option for supporting distributed generation, reducing peak load on the grid, and helping to regulate the voltage and frequency on transmission and distribution lines. The stable and and safe battery chemistry makes it an option for off-grid, substation and community energy storage applications.

Stability

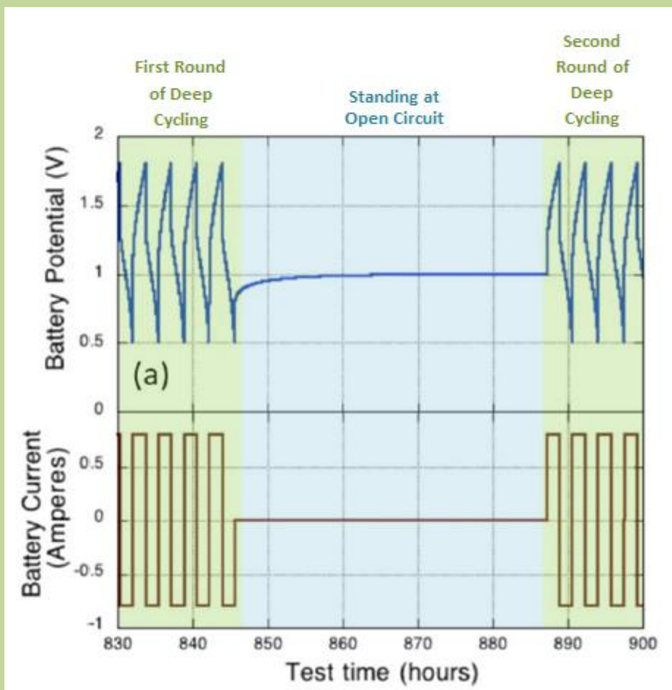
Aquion makes their battery from a combination of nontoxic materials, including salt water, a carbon composite material, and manganese oxide, an idea developed by Carnegie Mellon professor Jay Whitacre, Aquion Energy's founder. The project delivered a 1 kV, 1 kW battery system that was tested by discharging at the maximum recommended power and at 75 percent of the maximum recommended power, with the results in Table 1. Throughout all testing, the battery system's current and voltage responses were consistent, performing on par with conventional lead-acid batteries.

Mode of use	Discharge time	Energy capacity	Average Power
Light	20 hours	15 kWh	0.75 kW
Recommended	11 hours	11 kWh	1.0 kW

Table 1. Performance Profiles for Aquion Demonstration Battery

Aquion successfully delivered a laboratory scale battery developed with the DOE funding. Aquion has since developed commercial versions of its battery system that have been shown to cycle thousands of times with a high degree of stability at third-party locations, including DNV-GL and Sandia National Laboratories. Aquion's "S-Line" batteries

Figure 1. Not only did Aquion's Aqueous Hybrid Ion cell hold a steady, partial charge when it was idle, but it also performed as well after idling as before.



are 2.4 kWh, 48 V nominal modules that can be connected in parallel or serial fashion to make larger systems. Their "M-Line" series consist of 12 palletized S-Line batteries in parallel. Their capacity is 25.5 kWh, which is 88.5% of the nominal capacity. The uniformity of daily cycles in the initial demonstration project was not the only way Aquion's battery system exhibited stability. It also held its charge. To arrive at this conclusion, Aquion deep-cycled a 1.4 Ah cell 200 times over a span of 845 hours and at a temperature of 60 degrees Celsius. In other words, the cell discharged about 70 percent of its potential energy 200 times over a period slightly longer than a month. After that period, Aquion let the cell stand at open circuit—maintaining a constant, partial state of charge—for 40 hours. Then, deep-cycling began again. The cell's current and potential energy both withstood the 40 hours of idleness. Aquion observed little, if any, self-discharge during that time. Aquion also found that the cell performed equally well before and after standing at open circuit (Figure 1).

Another encouraging sign is that after Aquion's 1.4 to 1.5 V cells were placed in storage for a year (at ambient temperatures), they retained 1.1 V of their energy potential. That slow rate of self-discharge translates to 2 percent of total capacity self-discharge per month. For comparison, lead-acid batteries can have a 3- to 8-percent monthly self-discharge rate.[1]

Longevity

Because Aquion's cells maintained their charge capacity so well, they are especially long-lived. While conventional lead-acid batteries used in grid applications must be replaced every 5 years or so,[2] Aquion's battery system showed no evidence of needing to be replaced for at least a decade. It withstood the Sandia National Laboratories partial-state-of-charge test, which reveals how batteries tolerate short, powerful micro-cycles while they are only partially charged. Even after a year of rapid partial-state-of-charge cycling, Aquion's batteries did not lose any capacity or potential.

Efficiency

Cells that Aquion tested also have high roundtrip energy efficiency—or, to put it another way, they retain a high percentage of charge energy during each discharge. Aquion's coin-cell-format devices, with electrodes thinner than 100 micrometers, showed a DC-to-DC energy efficiency in lab testing of up to 95 percent, comparing favorably with traditional lead-acid batteries which have an estimated roundtrip DC-to-DC energy efficiency of 80 percent.[3]

Aquion's battery system does not pack as much potential energy per kilogram as lead-acid batteries do. They are still more energy-dense than flywheels and flow batteries, compressed air energy storage, and pumped hydro, making them a combination of an efficient use of space and a safe and reliable option. As the project ended, they were considering introducing a new composite anode system that would increase the battery system's energy density by at least one-fourth. Due to the battery reliability and safety, customers will need to compare the AHI vs. lead and lithium chemistries to make their purchase choices.

[1] Multiple variables can affect a battery's self-discharge rate, but several sources report that lead-acid batteries self-discharge at rates in the range of 3 to 8 percent each month. These sources include Thomas Crompton's *Battery Reference Book* (Newnes, 2000), a technical bulletin by C&D Technologies, and an UltraLife report.

[2] For example, Power-Sonic's batteries last about 5 years, and the Trojan L16P battery has a lifespan of 3 to 6 years.

[3] A wide range of sources—including UltraLife's report, a report by the National Renewable Energy Laboratory, a *PV Magazine* article, and a battery patent application—state that lead-acid batteries have a roundtrip energy efficiency that equals or is close to 80 percent.

Applications

Because Aquion's batteries are safe, long-lived, and affordable, they can meet the requirements of grid-scale applications such as peak shifting, load shaving, renewables support, and transmission and distribution deferral. Their energy density is lower than that of lithium batteries (making them relatively larger), but this disadvantage is offset by the inherent safety of Aquion's batteries, which do not require fire-suppression systems. Therefore, they can suit microgrid and remote off-grid applications—for which, at many scales, the cost/benefit analysis emphasizes their reliability, safety, and low cost.[4] For small- to medium-scale applications, their tolerance of temperature variations makes them ideal for balancing renewables. They can also aid in managing a building's energy use. For example, Aquion's batteries can act as a building's uninterruptible power supply or shift a factory's energy load to avoid peak demand charges.[5]

Recent Developments

Aquion opened a full-scale battery manufacturing facility in Westmoreland County, PA, in June 2014. The facility will produce 1,000 MWh of batteries each year at full production capacity and create approximately 500 jobs. In addition, Aquion has made gains through core battery chemistry and more efficient use of the battery's active materials. This has made their products even more attractive in stationary energy storage market. For example, a third-party evaluator selected Aquion's AHI batteries (rather than lead-acid or lithium-ion batteries) for use in a standalone microgrid providing off-grid electricity to the Redwood Gate Ranch in Jennfer, California, which has an average daily load of 4 kW.[6] The evaluator selected AHI batteries because of "their combination of safety, cycle life and abuse tolerance, and ability to support active management of solar generation at the ranch under a variety of conditions."[7] These off-grid applications are often economical because utility power lines do not extend to the location of the load.

Further Reading

More information about Aquion's project is available at SmartGrid.gov and in Aquion's technology performance report. To read more about the Smart Grid Demonstration Program, visit smartgrid.gov.

Under the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy and the electricity industry have jointly invested over $1.5 billion in 32 cost-shared Smart Grid Demonstration Program projects to modernize the electric grid, strengthen cybersecurity, demonstrate energy storage, improve interoperability, and collect an unprecedented level of data on smart transmission, distribution operations, and customer behavior.

[4] Aquion Energy, *Off-Grid and Microgrids*, http://www.aquionenergy.com/microgrid-energy-storage, accessed December 22, 2014.

[5] Aquion Energy, Energy management http://aquionenergy.com/applications/energy-management, accessed 1/29/15

[6] Aaron Marks, "A Look at Aquion's Latest Off-Grid Installation at the Redwood Gate Ranch," June 24, 2014, http://blog.aquionenergy.com/a-look-at-aquions-latest-off-grid-installation-at-the-redwood-gate-ranch, accessed December 24, 2014.

[7] Aquion Energy, aquionenergy.com, by request, accessed December 22, 2014.

Aquion Energy

Aqueous Hybrid Ion Battery Demonstration

With the $10.4-million cooperative research agreement Aquion received as part of the [Smart Grid Demonstration Program](), the energy storage manufacturer demonstrated a 15 kWh Aqueous Hybrid Ion battery system that is stable and long-lasting enough to support grid applications, such as firming renewables and shifting peak load. To learn more about Aquion's project, refer to their [technology performance report]().

By the Numbers

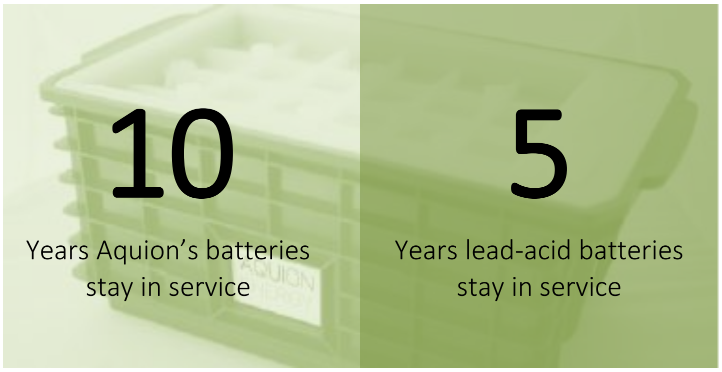
10,000
Cycles Aquion's batteries can withstand

Monthly Self-Discharge

5%
Lead-acid batteries

2%
Aquion's batteries

Lifespan during Use in Grid Applications



10
Years Aquion's batteries stay in service

5
Years lead-acid batteries stay in service

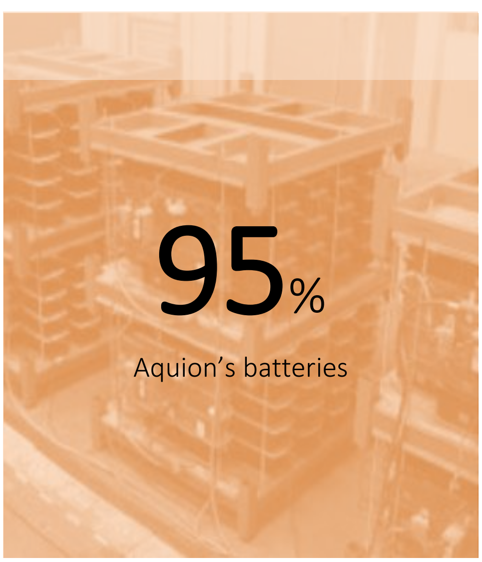
Energy Density

25 kWh/m^3
Aquion's batteries

2 kWh/m^3
Compressed air

0.3 kWh/m^3
Pumped hydro

Roundtrip DC-to-DC Energy Efficiency



95%
Aquion's batteries

80%
Lead-acid batteries

Department of Energy Cost Share

50%