Summary of KEMA Validation Report

Two Megawatt Advanced Lithium-ion BESS Successfully Demonstrates Potential for Utility Applications

Fast Response and Over 90% Roundtrip Efficiency are Verified

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The AES Corporation (AES) engaged KEMA, Inc to validate and test the use of a new battery storage technology for electric utility system applications. KEMA designed a testing program and assisted AES in conducting testing on the prototype system. The results of the test showed that the prototype unit successfully demonstrated the potential of using the device for utility applications.

The energy storage technology is based on Altairnano Lithium-Titanate material battery cells. Two 1-MW battery storage devices consisting of a lithium ion battery stack, an AC-to-DC power conversion system, HVAC unit, and a control system were mounted in a portable tractor trailer-size container. The battery stacks were composed of a series arrangement of lithium ion cell packages mounted in racks within the trailer. The battery stack was designed with enough energy storage capacity to deliver 1-MW to the grid for a duration of 15 minutes. DC to AC Power conversion was performed by commercially-available inverters with control coordinated by a programmable logic controller (PLC). The units were designed to interconnect to a three-phase 480 V electric distribution system. Hence, the intertie to the electric grid was made through a low-voltage to medium voltage distribution transformer.

Potential applications for this new technology include market-based, regulation, ramp rate regulation for distributed resources (wind, solar) and critical peak price response. One of the main features of the battery, energy storage system is that it can respond with up to full power in milliseconds to control commands. A testing program was designed by KEMA to validate the ability of the large-scale device to meet it's design characteristics and confirm the capability of the technology to perform in its anticipated applications. Hence, the program was designed to verify the unit's ability to be rapidly dispatched to various levels. The program included discrete jumps in level from idle to a peak dispatch charge level, idle to a peak dispatch discharge level, and instantaneous jumps from peak dispatch charge to peak dispatch discharge levels.

Test Methodology

The KEMA test plan for the AES battery storage system evaluation consisted of three phases:

Phase 1 – Installation, Integration and Functional Testing

Phase 2 – Battery Performance Testing

Phase 3 – Utility Application-Level Testing

The test plan developed by KEMA specified the types of tests to be conducted for each phase. The test plan was executed by AES personnel and subcontractors with guidance as needed by

KEMA. KEMA was also present at several stages of the site testing to witness key functional and performance tests. Industry-accepted standard monitoring equipment (Dranetz Power Xplorer) was used to measure the power quality and performance of the prototype units.

The purpose of the Phase 1 testing was to make sure that the two trailer units were properly installed at the substation and operating correctly before conducting performance tests. This process included a visual inspection of the installation before and after batteries were installed, basic measurements to verify component interconnections, exercising the control logic and a low-level charge/discharge test.

Phase 2 testing focused on characterizing the battery unit performance under various charge/discharge scenarios. The performance test phase utilized battery, trailer unit and 13.8 kV intertie measurements to generate the numerical results. The characterization included the energy storage capacity of the unit, the response to regulation-type signals, compliance with utility interconnection standards, battery and power conversion system efficiency, and effectiveness under typical regulation cycles.

Phase 3 tests exercised the functionality of the unit with respect to its ability to respond to external regulation control signals and properly interact with the electric grid as far as carrying out regulation sequences. The intention of Phase 3 was to confirm the ability of the device to respond to the regulation signals but was not intended to act as a long-term demonstration phase. Extended testing of the unit is continuing to be conducted through various pilot projects on actual systems.

Key Results from Performance Testing

The two battery storage system prototypes were installed and demonstrated at a substation owned and operated by Indianapolis Power & Light (IPL). The IPL test site was selected to be capable of dispatching 1-MW to a power grid in response to a regulation command. Each of the storage devices was able to operate continuously between 1-MW charge to 1-MW discharges with power dispatch response occurring within one second at a high operating efficiency. In particular, the unit demonstrated that it is well suited for scalable regulation applications based on a rapidly changing power dispatch. There were no major problems identified with the unit design concept based on field tests conducted to date. The prototype units in their current state are suitable for use in future market pilot activities designed to help better define the application requirements and demonstrate the potential of this technology.

Key performance finding related to unit performance

Energy Storage Capacity:

Maximum unit storage capacity demonstrated for this design for each of the two One-Megawatt systems in the field was approximately 300 Ampere-hours, with a capability of delivering 250 kWh at its rated output of 1000 kW in 15 minutes.

Regulation Response:

Each 1MW unit was able to dispatch at any power level between 1-MW discharge to 1-MW charge within 1 second. A number of tests were run where the unit was rapidly cycled between full discharge output and full charge input with no adverse unit or grid effects. Due to the battery and inverter technology used, response actually occurs within cycles. Power level at any dispatch level also remained constant until the unit was re-dispatched. Potential delays in the speed at which the unit can be controlled will likely be from the communications and dispatch control interface, as with any other system in this configuration.

Interconnection Requirements:

No major issues regarding interconnection requirements were identified with the substation installation. Since there are no standards pertaining to this type of device, the IEEE 1547 standard regarding distributed resources was used as reference. Interconnection criteria considered included power factor, current imbalance, harmonics, anti-islanding and voltage flicker. The unit appears as a non-voltage regulating current injection source to the electric grid, with a power factor at rated output of 0.96. The system tested well within IEEE 519 requirements for total harmonic distortion. Note that the field evaluation was based on the operation of a single 1-MW unit and the impact of a cluster of such units is still pending.

Battery and Conversion Efficiency:

Battery stack efficiency measured using cyclic charge/discharge tests (at 50% state of charge) varied from 97% at 250 kW dispatch to 91% at 1000 kW dispatch. Efficiency drops off with the power dispatch level due to internal losses that are proportional to the current squared as expected. Factoring in the DC-to-AC power conversion system, then average conversion efficiency measured varied between 93% at 250 kW dispatch to 86% at 1000 kW dispatch. This does not include HVAC or trailer auxiliary load. However, it is noted that efficiency numbers are highly dependent on the dispatch duty cycle, and need to be re-evaluated for each type of field application.

<u>*Regulation Cycle Effectiveness:*</u>

Test patterns were derived to simulate the application of the battery energy storage unit for providing regulation services. The patterns were based on 4-second intervals that would be typical of this type of application. Field tests based on these test waveforms were run for up to four hours. No major issues were identified with the units being able to respond to the dispatch signals. The trailer HVAC unit was able to properly manage the thermal load for the extended test period.

Conclusions

The battery storage system unit prototypes developed by the AES Corporation and their suppliers, Altairnano and Parker SSD successfully demonstrated the potential of using the new battery technology for utility applications. There were no inherent design limitations identified in its application within the designed 1-MW power handling range. Unit efficiency is relatively high, with application efficiencies in the low 90% range possible. The unit design should also be able to accommodate typical utility interconnection requirements as well. In particularly, it was demonstrated that the units could be operated to provide regulation services that require rapid dispatch capabilities.

Based on the testing performed to date, the units passed the initial demonstration and validation requirements. For the next steps of the prototype units, KEMA recommends that additional application-oriented field-testing be conducted to continue to verify the potential of the technology to respond to utility application requirements. Since the technology is new, it is noted that there currently are no reference standards in place to compare units against industry standards. Hence, further, long-term demonstrations of the units are recommended that will allow for integration of these types of resources in utility markets. However, from the results witnessed to date, the prototype battery storage platform developed by the AES Corporation provides a mechanism for gaining the real field knowledge needed to move this application area forward to the next stage of demonstration.