BATTERY ENERGY STORAGE TESTING FOR GRID STANDARD COMPLIANCE AND APPLICATION PERFORMANCE

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ABSTRACT

Battery Energy Storage Systems (BESS) are expected to be an integral component of future electric grid solutions. Testing is needed to verify that new BESS products comply with grid standards while delivering the performance expected for utility applications. This paper describes a coordinated process that starts with individual cell testing and progresses through both large cell module and integrated system testing based on the expected utility application duty cycles and interconnection requirements. This includes discussions on required lab facilities, battery and module cycle testing, system interconnection requirement validation and application cycle performance testing.

INTRODUCTION

A number of manufacturers are in the process of introducing the first generation of new BESS products for the grid, even though the applications and standards have yet to be fully defined. The introduction of new BESS products to the electric utility market presents a number of interesting challenges. New battery technologies like lithium-ion are being incorporated into grid products for which battery efficiency and life characteristics have not been fully evaluated for utility application duty cycles. There is not even proof of product life of five years which is very low in a utility environment. In order to operate at high power and energy levels, individual cells are being packaged into large-scale packs consisting of thousands of cells in various series-parallel configurations. Managing these large-scale cell stacks requires sophisticated battery management system techniques that have not previously existed for large-scale utility applications. Operating the inverters dedicated to energy storage applications on the utility grids requires a wide variety of grid-connected and stand-alone modes while adhering to grid standards, and also presents a number of unique challenges.

Before utility customers have the confidence level to purchase and install this new generation of BESS devices, independent testing and verification is needed to satisfy the following questions:

1) Does the inverter interface conform to grid interconnection standards (IEEE 1547, IEC, etc)?
2) Does the system unit have the power and energy capacity as stated in the specifications with respect to intended applications?
3) What is the round-trip unit efficiency net of all auxiliary load requirements for the intended applications?
4) What will be the expected life of the batteries for the intended applications?
5) Does the unit operate properly and safely for a variety of contingency conditions?

By applying a rigorous test program to new BESS products, manufacturers can clearly see where their products conform or not to standards and other performance requirements. Customers are also assured that the BESS products that go through this process will meet interconnection standards and performance required for their electric grid applications.

OVERALL TEST PROGRAM FRAMEWORK

A comprehensive test program framework for battery energy storage systems is shown in Table 1. This starts with individual cell characterization with various steps taken all the way through to field commissioning. The ability of the unit to meet application requirements is met at the cell, battery cell module and storage system level.

The tests performed can be categorized as being related to application functionality, safety, performance or lifecycle. Application functionality refers to the ability of the unit to properly perform its desired control functions such as peak shaving, wind smoothing or other control cycles. The safe operation of the unit with respect to cell failures, equipment misoperation and grid interactions must also be evaluated. Performance refers to the ability of the unit to operate at rated power, energy discharge/charge and efficiency for conditions expected in the field. The life cycle tests pertain to the number of application cycles the batteries can provide before needing refurbishment.

It should be pointed out that present day battery testing on new technology has outpaced the standards development process. There are standards for photovoltaic system components, wind generation and conventional batteries. However, there are currently no IEEE, UL or IEC standards that yet pertain specifically to this new generation of integrated battery energy storage system products.

The framework presented below includes a field commissioning component. This is needed to make sure the system is properly reassembled in the field. Key application functionality and performance tests are repeated in the field to establish a baseline for periodic maintenance checks.

Table 1: Test Program Framework

Program	**Description**
Cell Characterization	Battery cell-level capacity, efficiency, cycle life and safety verification
Cell Application Performance	Cell-level testing against utility application cycle characteristics not included in standard full depth-of-discharge patterns
Stack Level	Repeat of cell testing at large-scale battery stack level
Battery Module Performance	Module level verification of battery management system safety and cell balancing functionality
Storage System Basic Operation and Safety	Unit control system respond properly and self-protecting for various equipment switching, failures and operating contingencies
Storage System Interconnection Compliance	Unit interface compliant to standards with respect to harmonics, surges, voltage events, power factor, loss of grid supply
Storage System Performance	System level verification of unit rating, storage capacity and efficiency
Storage System Extended Application Cycling	Verification of proper control logic for application duty cycles
Field Commissioning and Extended Testing	Verification unit properly installed in field and control logic performs properly

BATTERY CELL AND MODULE TESTING

Figure 1 shows the layout for a battery laboratory designed to support both cell and module testing as outlined in Table 2. It is important to support both cell and multiple-cell module testing, since the module testing also needs to factor in the electronics controlling the cells. Life cycle testing needs to be performed at the cell and module level since this involves extended time frames and putting significant wear and tear on the cells, which is not feasible for large system units containing possibly thousands of cells.

Manufacturers routinely provide test data on their cells, but not according to any agreed upon standards. There have been attempts to provide standardized tests for electric vehicle batteries through such forums and programs such as USABC [1]. However at this time there are no battery test standards for utility stationary applications.

An important aspect of testing batteries for utility applications is to test with cycle patterns that correspond to defined market applications, such as those shown in Table 3 [2]. Typically battery manufacturers only run life cycle tests at 100% or 80% of energy capacity. However utility cycles can also involve depth of discharge cycling that mix moderate (20-30%) depth of discharge combined with many small (<1%) depth of discharge events. Partial state of charge test patterns must be used to augment the full scale depth of discharge testing performed by manufacturers [3]. Figure 2 shows a utility cycle where the charge deviates plus and minus 10% about a nominal 50% state of charge target.

Figure 1: Battery Test Facility Layout

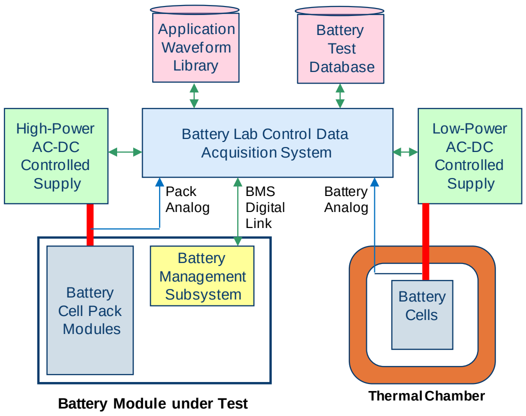


Table 2: Battery Cell and Module Test Types

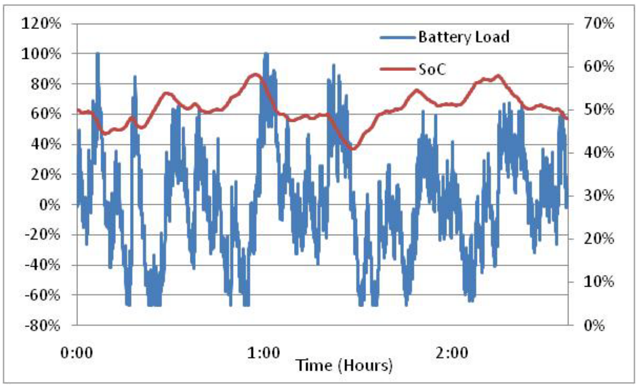
Test	**Description**
Cell Capacity	Ampere-hour and corresponding kilowatt-hour capacity
Cell Efficiency	Round-trip efficiency as function of discharge rate and cycle type
Cell Cycle Life for Standard Cycle	Number of cycles for discharge to 80% of capacity
Cell Safety	Test for possibility of fire or chemical result
Battery Module Management System	Verify BMS communication present to monitor, control and self-protect battery
Battery Module Rating, Charge/Discharge/Trip Control	Peak and nominal power rating. Check for proper charge control on cells and that alarms are properly generated
Battery Module Cell Balancing	Verify that cell state of charge properly equalized by balancing control
Battery State of Charge/State of Health	Verify that battery state of charge accurate and that loss of cell life is being tracked

Battery Module Performance of Application Cycles	Verify that cell combinations are properly controlled during variety of application duty cycles

Table 3: Utility Application Pattern Examples

Application	Characteristics
Frequency Regulation	Up and down compensation for frequency deviation on order of seconds; moderate deviations from 50% target state of charge
Peak Shaving	Daily 2-4 hour discharge during peak utilizing 80% of battery energy capacity
Wind Farm Smoothing	Compensation for minute-by-minute variation in wind farm output to control ramp rate, moderate deviations from 50% target state of charge
PV Time-Shift	Shift in solar output from mid-day to afternoon on-peak or morning on-peak period, discharge up to 2 hours utilizing 80% of battery energy capacity
PV Smoothing	Compensation for second-by-second variation in solar generation output, large deviations in state of charge from 50% target state of charge

Figure 2: Utility Application Cycle



INTERCONNECTION TYPE TESTING

Grid interconnection type testing is used to verify that the battery energy storage system properly performs its application logic and complies with grid interconnection standards (such as IEEE 1547) over its entire operating range. This testing would be performed with a test lab setup with the equipment and monitoring links as shown in Figure 3. Components of the type testing are shown in Table 4. Note that this stage of testing is focused on functionality, safety and grid standard compliance. Performance testing does not take place until type testing is complete. It is important to be able to simulate the various faults and failures that could take place in the field to make sure that alarms and trips are working properly.

Figure 3: Energy Storage System Test Facility Layout

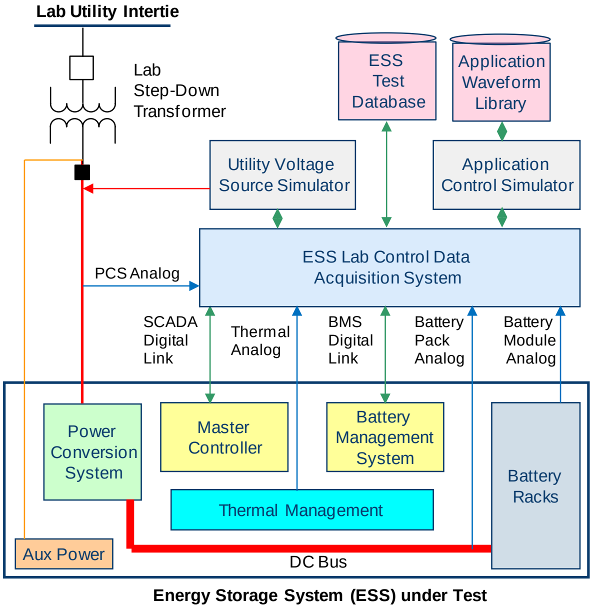


Table 4: Energy Storage System Interconnect Type Testing

Test	Description
Startup/Shutdown /Emergency Stop	Verify unit properly starts and stops with provisions met for emergency stop
Equipment Failure	Verify unit properly responds to various contingencies through generation of alarms and tripping if required
Abnormal Grid Event	Verify unit properly responds to grid voltage/frequency events, faults and grid isolation according to standards
User Interface	Demonstrate that user interface, alarms and controls operate as described in documentation
Low Power	Demonstrate that unit logic properly responds and that interconnection standards are met during low-power operation
Full Range	Demonstrate that unit logic properly responds and that interface standards are met over full rating range
Remote	Demonstrate that unit logic properly responds to remote control and SCADA interface

PERFORMANCE TESTING

Performance testing is focused on testing the integrated system unit to ascertain the unit power rating, energy capacity and efficiency characteristics. The types of performance tests that could be executed are outlined in Table 5. Round trip efficiency for a unit could vary between 65-95% depending on the battery technology and duty cycle performed.

Another aspect of performance testing is to validate the ability of the battery management system (BMS) to properly compute battery pack state of charge, state of health and cell balancing. Basic BMS functionality is still tested in the battery cell laboratory, but the scaling up to managing potentially tens of thousands of cells still needs to be verified at the large-scale integrated system level.

Application logic performance for the types of duty cycles shown in Table 3 is also evaluated at this stage in the program. The application logic can be run against typical waveforms from field deployments or based on simulation using the test setup shown in Figure 3.

Table 5: Energy Storage System Performance Tests

Test	Description
Power Rating	Validate that unit rated power (kW) conforms to vendor specifications
Energy Rating	Validate that unit rated energy (kWh) conforms to vendor specifications
Dispatch Response	Validate that unit dispatches accurately with proper speed of response
Round Trip Efficiency	Characterize unit efficiency as function of cycle type
Standby	Characterize unit losses corresponding to auxiliary power and battery parasitic loss

A realistic size of these systems installed and connected to a grid can be up to 20 MW or more, while the systems for a number of technical and logistical reasons are expected to be provided in modular configurations. The KEMA's Energy Storage Test Facility provided in Chalfont, PA is capable to handle and test the BESS modules up to 2 MW rated power charge and discharge, as an expected optimum maximum size of a module to date. Table 6 provides basic technical parameters of the test facility offered by KEMA to the industry in Chalfont, PA.

Table 6: BESS Performance Test Facility at KEMA Chalfont Laboratory

Test	Description
Maximum Power	2 MW AC
Output Voltage	100 V – 800 V, three or single phase (in steps)
Maximum Output Current	3000 A at 600 V
Charging / Discharge Source	Synchronized with local utility network
Test Area	Outdoor 100 ft. x 60 ft., Indoor 30 ft. x 20 ft.

CONCLUSIONS

This paper describes a battery energy storage system test process that starts with single cell testing and progresses through to large-scale system tests. Programs have specific aspects for the defined application. Lifetime characterization is emphasized as well. With test standards still lacking, this framework can be applied to new storage system products. Manufacturers typically perform a subset of these tests on their own as part of the product development process. However, thorough independent testing is still needed to verify vendor claims and build customer confidence for making purchasing decisions. The outcome of this process would be a series of test reports, but it is anticipated in the future this would lead to a certification process.

REFERENCES

[1] "USABC Electric Vehicle Battery Test Procedures Manual", Revision 2, January 1996, http://avt.inl.gov/energy_storage_lib.shtml.

[2] DOE/Sandia Report, "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide", February 2010, SAND2010-0815.

[3] Sandia Report, "Selected Test Results from the Neosonic Polymer Li-Ion Battery", July 2010, SAND2010-4862.