DNV ESS EVALUATION PROGRAM

BEST Test & Commercialization Center, Rochester, NY

1. PERFORMANCE AND DEGRADATION TESTING

DNV has developed over the last 10 years the Scorecard Qualification Test Matrix to characterize the performance and degradation behavior of a specific type of battery cell. By testing the cell performance over a 6–9-month period using a design-of-experiments approach with various test conditions, it is possible to develop a cell degradation model (digital twin) that covers a wide range of potential operating conditions. Using DNV's battery simulation software, Battery.ai, this model can then be applied to the intended customer applications and to predict the degradation behavior of the system over its lifetime and evaluate proposed warranties.

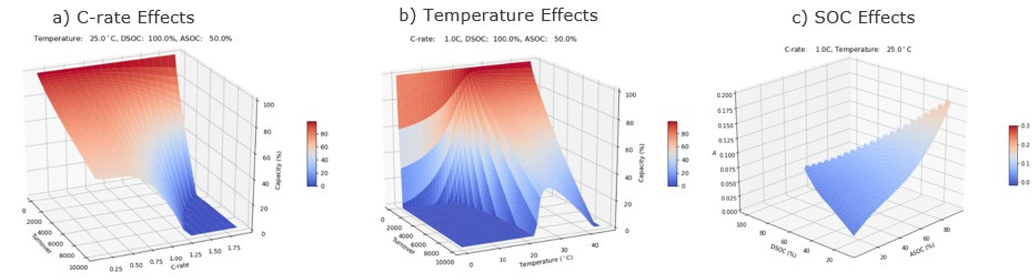

Figure 1 1: Example of Cell Model in Battery.ai

The test program for the ESS evaluation uses a special Scorecard test matrix of about 20 cell tests tailored for the specific application and includes vocational tests to duplicate the cells warranty test conditions and verify manufacturer claims. The program size depends on the number of intended applications for the storage system and can be customized accordingly.

The main components of the Scorecard cell test program are as follows:

1. Cell performance characterization at BOL, EOL and monthly intervals during degradation testing (Capacity Retention, Round-trip Efficiency, Capacity Pulse Power Characterization (CapPPC), Internal Resistance, Performance at Temperature)

2. Cell degradation cycle testing for 6 months at different c-rates, different temperatures and different SOC-windows

3. Calendar Life degradation at different SOC levels

4. Vocational tests that duplicate cell warranty conditions and specific customer use cases

With the test results, DNV can model the cell degradation behavior and evaluate the expected system life for different application scenarios and verify if the manufacturers warranties are realistic.

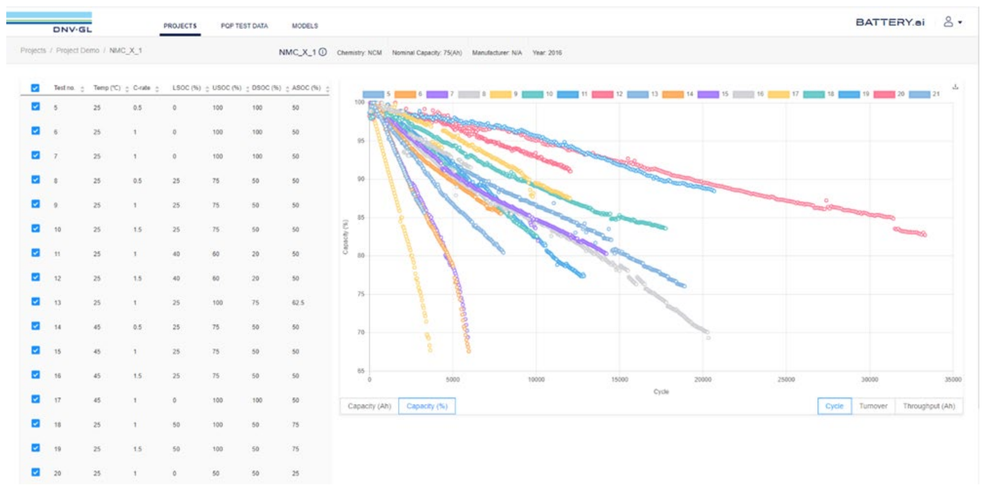

Figure 1 2: Example: Scorecard Degradation Test Results

2 FUNCTIONAL SYSTEM TESTING

DNV has developed a system test program to evaluate the function and performance of the integrated storage system, which typically consists of the battery, BMS, inverter, and control systems. The test goes beyond the test of individual components, which are typically certified to UL or other standards, and instead evaluates the overall system function, i.e. how well the components perform together.

Figure 2 1: System Testing Set-up with various Simulation Equipment

The following tests are included in the system test program:

• Precision performance measurements (performed at different temperatures), such as RTE, SOC-validation, Aux. Power consumption, Self-Discharge, AC-Envelope, etc.

• Functional verification and Full System Cycle Testing at all possible Operating Conditions

• Resilience Tests, such as Loss of Communication, Overcharge/Overdischarge, Over/Under Temperature, Ground Fault

• Accelerated Stress Tests can be performed optionally (such as Thermal cycling, Humidity Freeze, Damp Heat)

Three step program to ensure quality and performance of Residential and C&I Energy Storage Systems (ESS):

1. Performance and degradation testing of the battery cells using DNV's Scorecard Qualification Matrix
2. Complete system function and efficiency testing (battery with inverter and controls)
3. Technology review by DNV's Energy Storage Advisory team

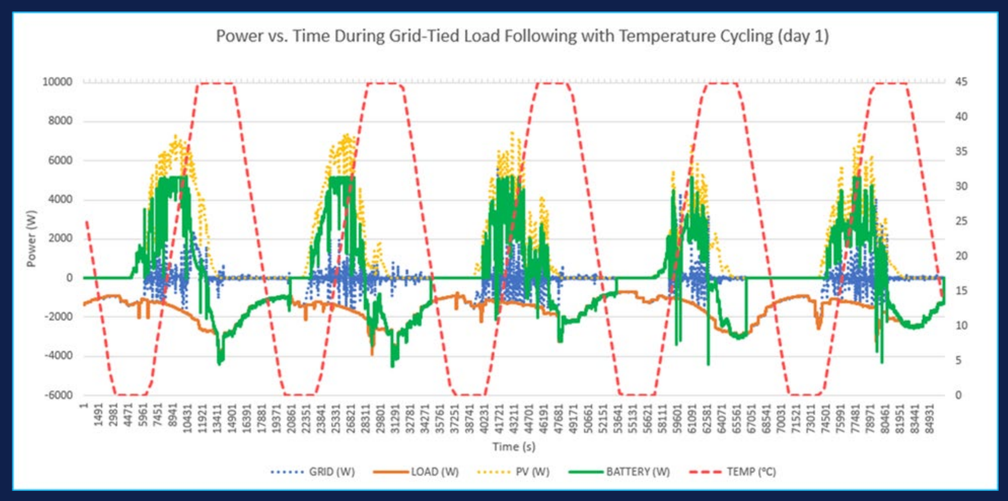

Figure 2-2: Example of Full Cycle System Testing

3. TECHNOLOGY REVIEW

DNV's Technology Review Report provides third-party verification of technical claims for a comprehensive appraisal of the battery's technology risks and methods of mitigation; performance and design of the product; and guarantees in comparison with industry best practices. To perform the assessment, DNV uses test results provided from DNV's BEST Test Center and other documentation provided by the customer, along with phone and in-person conversations.

The typical Technology Review includes the following elements:

• Business evaluation (General business, Product History, Company Financials, Sales History, IP)

• Product evaluation / review:
  - Battery cell/module/pack evaluation (description of battery technology, specification sheets)
  - Battery operation evaluation (testing results such as cell level capacity degradation data, RTE performance data, charge/discharge power performance data over various SOC/temperature/system age, battery self-consumption)
  - Inverter product overview including power quality measurements
  - Inverter performance
  - Thermal management review
  - Environmental or enclosure characteristics
  - BMS functionalities, faults, and alarms

• Review of DNV system test results and comparison to supplier specifications

• Regulatory compliance and safety evaluation

• Controls review

• Installation and integrated system evaluation

• Reliability and durability evaluation

• Manufacturing and quality review (might include a site visit, priced separately)

• Service infrastructure and warranty review

• Field history evaluation

PROJECT DURATION

The three ESS evaluation components have different lead times, with cell tests taking the longest to obtain meaningful degradation results. Cell tests should therefore be started first. An initial technology review can be conducted before the tests are completed using manufacturer supplied data, and then updated once test results are available.

DNV ESS Evaluation	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10
Performance & Degradation	Base Cell Tests						Extended Cell Tests			
Functional System Test				System Tests			Optional Stress Tests			
Technology Review Report						Init. Report			Updated Report	

Figure: Typical Project Time Line

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