# Performance Evaluation Testing Protocols to Support Energy Storage Deployment in the Grid

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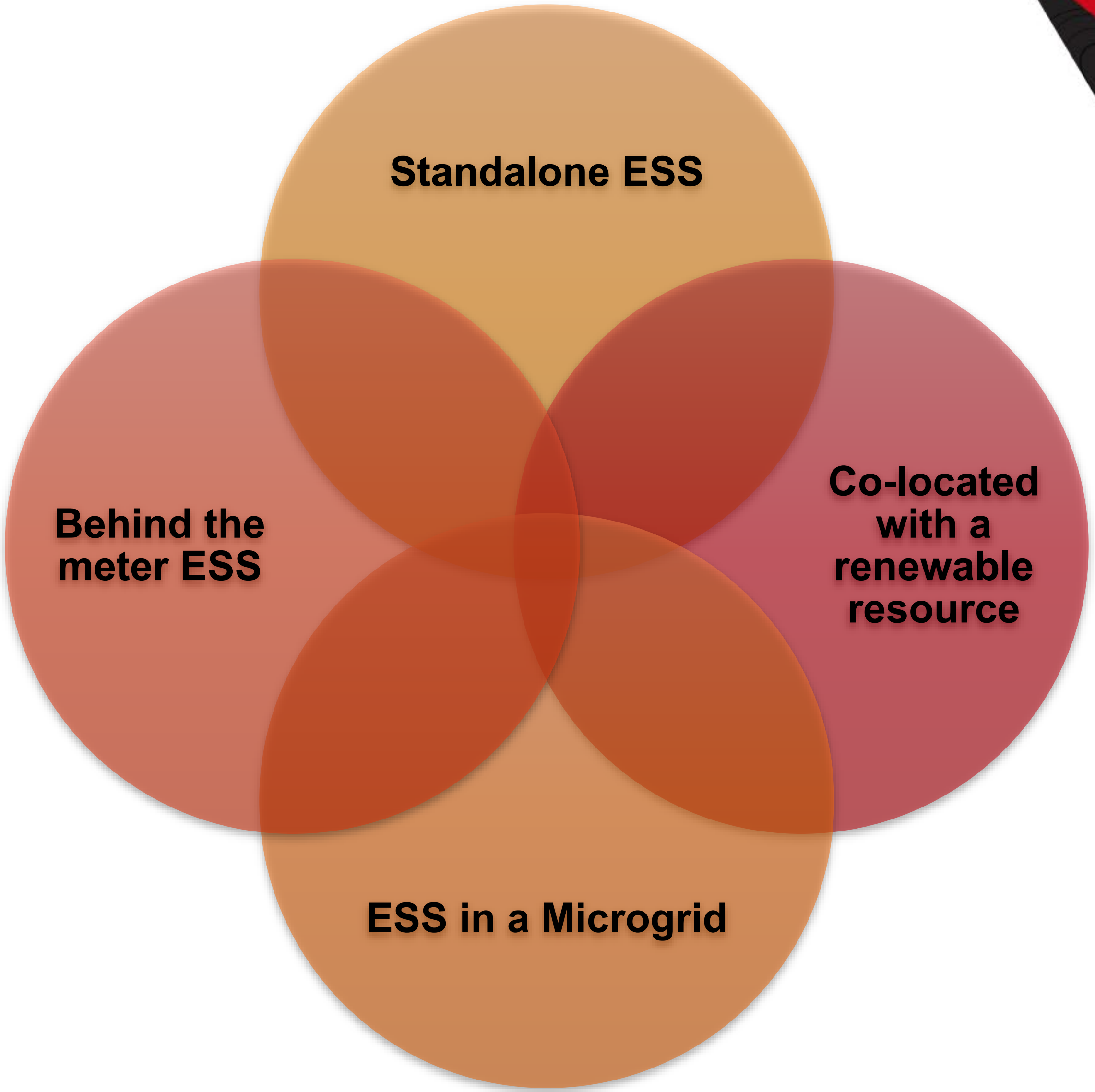
# Agenda

- Introduction
- Drivers for ESS Testing
- Different Stages of the ESS Testing
- Overview of the ESS Performance Evaluation
- Case Study
- Conclusion

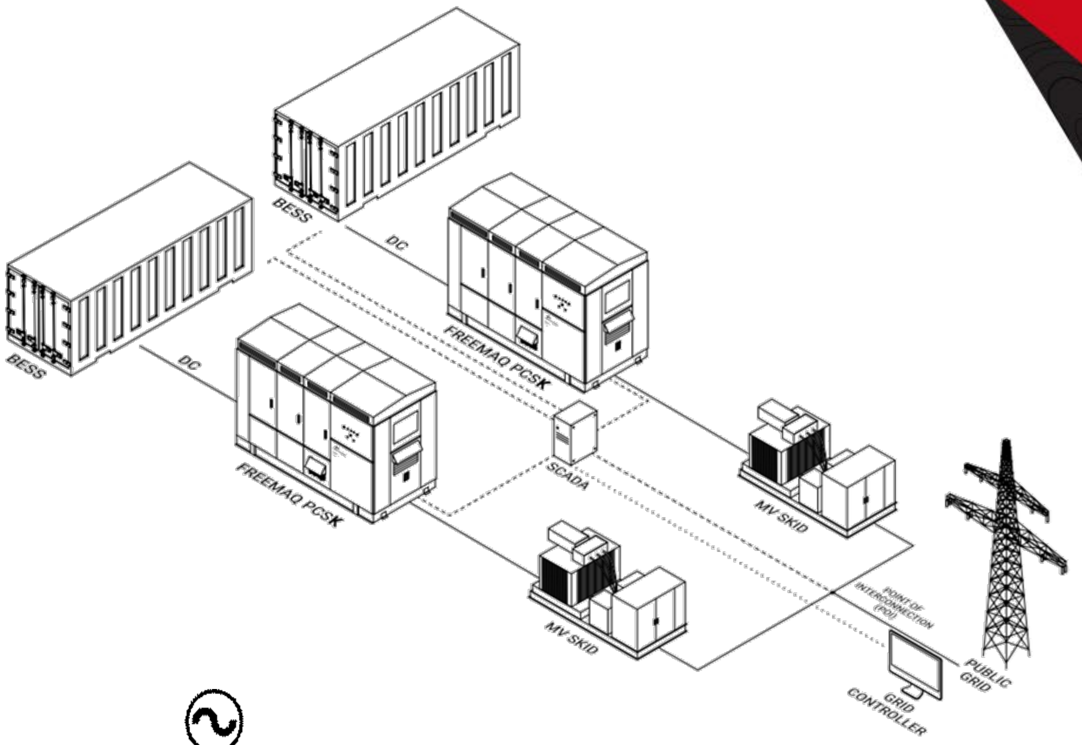
# Introduction

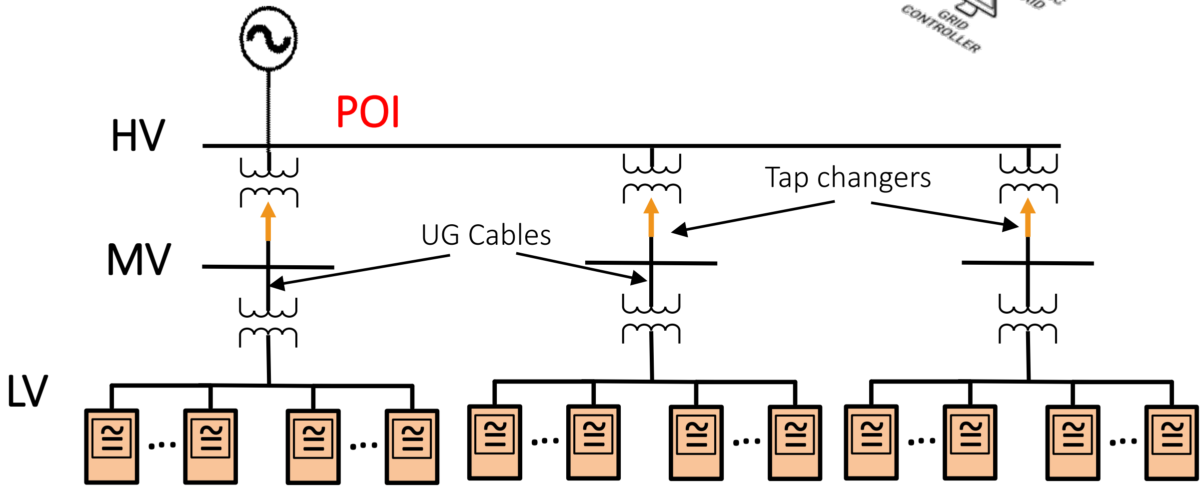
Energy storage integration into the grid has been increasing, especially as renewable generation penetration increases.



# Drivers for BESS Testing

- Scaling BESS modules into larger ratings creates greater complexity at the system level
- Component level testing does not assure system-level performance (UL Certification vs. NERC requirements)
- Requirements are evolving (New NERC Guideline for BESS issued Dec. 2020 , Revised Mar. 2021)
- Some system level performance (e.g. volt-var) may take months to confirm via conventional testing
- BESS does not typically have established processes for integration with substations and grid



# Different Stages of the BESS Testing

### Factory Acceptance

- Scaled down test
- ESS Controller
- Graphic user interface
- Equipment certification compliance evaluation
- Use case testing Not Included

### Pre-Commissioning

- Inspection type checks
- Connectivity tests
- Communication points
- Preparation (settings and config files)
- Health of P&C devices


### Site Acceptance & Commissioning

- Interconnection:
  - Start-up and Shutdown
  - Voltage and freq. ride through
  - Synchronization
- Type Tests
  - Charge and discharge
  - Capacity (duty cycle test)
  - Ramp rate and response time tests
- Application Tests
  - Volt-VAR
  - Freq-Watt

### Performance Evaluation

- Round-trip efficiency (RTE)
- Cycle charge and Capacity
- **Use case testing**
- 4-Q Power Curve (rating & stability)

# BESS SAT and Performance Evaluation Test Categories and Test Cases

## BESS Specification Verification Testing

- Nameplate data test (kW, kWh, kVA, and power factor)
- Communications, monitoring, and controls

## Type Tests

- Energy capacity and roundtrip efficiency testing
- Auxiliary power consumption testing and standby losses
- Power charge and discharge test (including active/reactive power maximum rating, and ramp rate)
- Four-quadrant operation test
- Power factor control test
- Response time tests, for active and reactive power
- Start-up and shutdown test

## Interconnection Tests

- The sequence of start-up, energization, synchronization, and grid connection for normal and trip cases
- Voltage change (connect/disconnect, and full charge/discharge)
- Power quality and harmonic distortion at PCC and POI
- Anti-Islanding (if applicable)
- Open phase condition
- Grid code compliance (site-specific)

## Application Tests

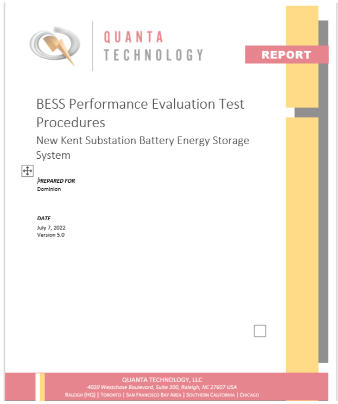
- Voltage and reactive power support
- Frequency regulation
- Power Factor Control
- Backfeed reduction
- Peak shaving
- Back-feeding
- Renewable smoothing
- Fast Frequency Response (FFR)
- Black-start and Islanding
- SOC Management
- Phase balancing
- Energy Trading

# Division of Responsibility for Performing the Performance Evaluation Testing

| ESS Developer/Integrator | ESS Owner |
| --- | --- |
| ▪ Basic Type Tests energy efficiency, standby losses, response time/ accuracy, and usable energy<br>▪ ESS Specification Verification Testing | ▪ Comprehensive ESS Type tests not covered by ESS Developer<br>▪ Interconnection tests<br>▪ Application Tests |

# Steps to develop a successful ESS Performance Evaluation testing

| Step 1 | Step 2 | Step 3 | Step 4 | Step 5 | Step 6 |
|---|---|---|---|---|---|
| Come up with the **test cases** to be performed based on the BESS spec, use cases defined for the project, as well as contractual obligations. | Develop **KPIs** and their associated metrics that can be used to define and quantify the key performance of the BESS . | Develop methods for the **data collection and data analysis** that can be used to determine the metrics of the KPIs . | **Coordinate with the BESS vendor/integrator** to review the test plan and incorporate all the comments . | **Perform KPI evaluation and ESS testing** based on the developed methods. | Compare the **test results** with the standards and grid code requirement and prepare the report. |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REPORT

BESS Performance Evaluation Test Procedures

New Kent Substation Battery Energy Storage System

PREPARED FOR

Dominion

DATE

July 7, 2022

Version 5.0

QUANTA TECHNOLOGY, LLC

3 PERFORMANCE INDICATORS AND MEASUREMENT VERIFICATIONS

Table 23. Performance indicators and measurement verification (to be measured directly)

| Measurements and Indicators | | Expected Outcome |
|---|---|---|
| Power/ Energy Rating | Guaranteed charge (Cmax) | -2 MW at 0.48 kV |
| | Guaranteed discharge (Dmax (MW) | 2 at 0.48 kV |
| | Rated charge at POI (Pmin) | - 2 at 0.48 kV |
| | Rated discharge at POI (Pmax) | 2 at 0.48 kV |
| | Maximum Reactive Power Absorption at POI | -2.5 MVAR |
| | Maximum Reactive Power Injection at POI (Qmax) | 2.5 MVAR |
| | Guaranteed Discharge Energy" below 35º C | 5.364 at 0.48 kV |
| | Rated Discharge Energy" below 35º C | 5.364 at 0.48 kV |
| | Charge Duration (at BOL) | 2 hours from 0 kWh to 5364 kWh |
| | Discharge Duration (at BOL) | 2 hours |
| | Operating voltage at PCC | 0.48 kV ±5% |
| | Operating voltage at POI | 34.5 kV ±5% |
| | Maximum design AC system Voltage | 36.5 kV |
| | Operating Frequency | 60 Hz ±5% |
| State of Charge | Max SOC | 100% |
| | Min SOC | 0% |

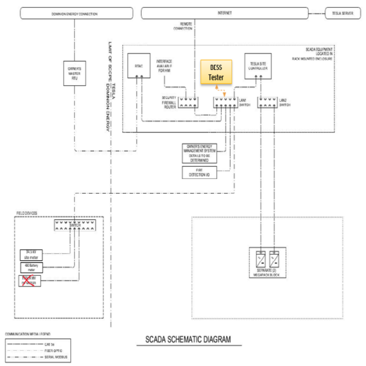
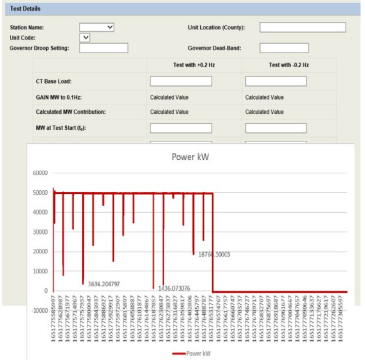


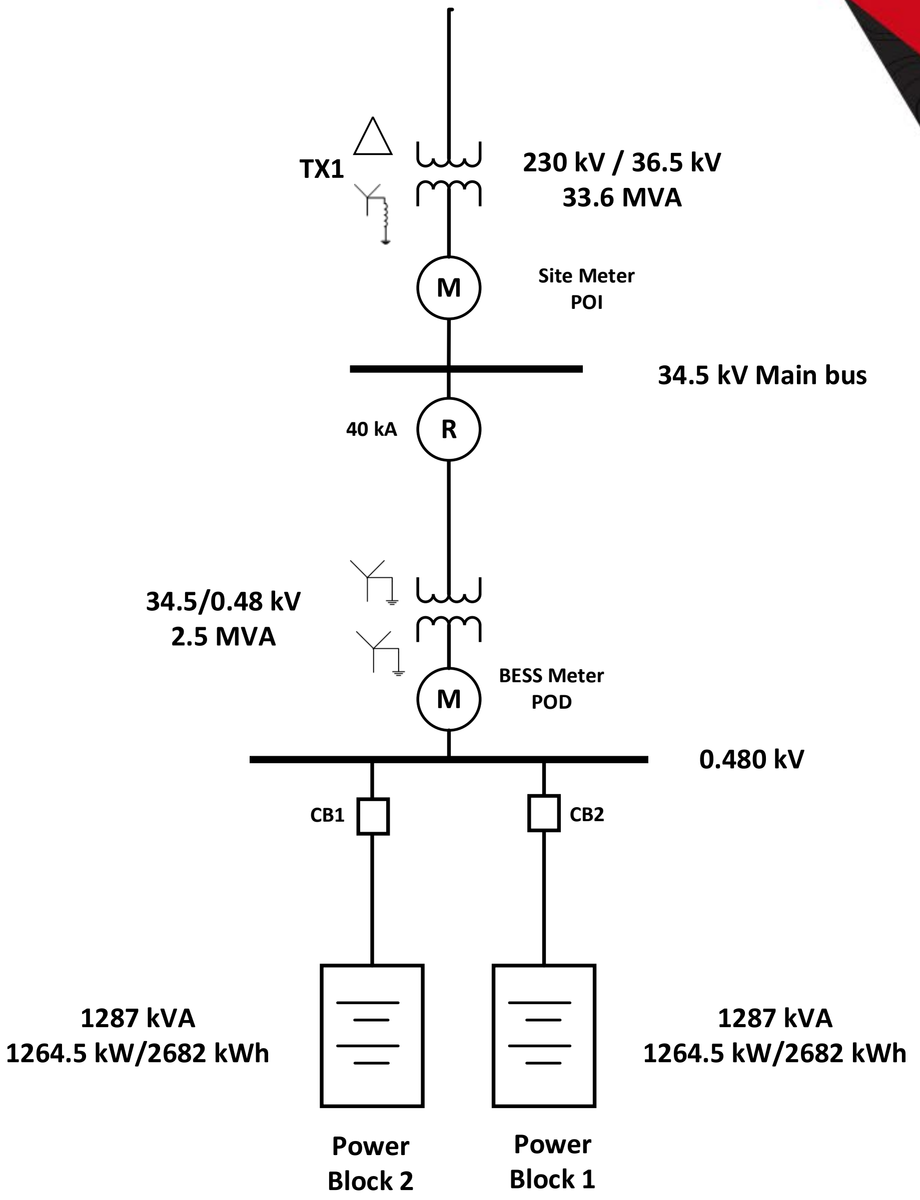

Table 1. Different test categories for performance evaluation[2]

| Testing Areas | Test categories | Responsible Party to Prepare Test Plan and Perform | |
|---|---|---|---|
| | | Tesla | Quanta |
| Interconnection tests | Start up and shut down test | | ✓ |
| | Synchronization | | ✓ |
| | Power quality (Voltage Harmonics, Flicker, | | ✓ |
| | Anti-islanding requirement | | ✓ |
| ESS Type tests | Discharge Energy Capacity Test | ✓ | ✓ |
| | Real Power Test | ✓ | ✓ |
| | Reactive Power Test | ✓ | ✓ |
| | Ramp rate and Response Time Test | ✓ | ✓ |
| | Round-trip efficiency (RTE) | | ✓ |
| | 4-Q Power Curve (rating & stability) | | ✓ |
| | Standby mode (Standby losses and Aux | | ✓ |
| Application tests[3] | Voltage control mode (voltage régulation) | ✓ | ✓ |

# Case Study

- A 2 MW/4 MWh BESS connecting to a 34.5 kV/230 kV substation.
- The primary application of the BESS: To prevent back-feeding from the distribution system into the transmission system (ESS+PV).
- A maximum gross output of 2,574 kVA / 5,364 kWh
- Limited to 2.5 MVA because of the transformer rating



# Different Test Cases Performed During Performance Evaluation Testing

## Interconnection tests

- Start up and shut down test
- Synchronization
- Power quality (Voltage Harmonics, Flicker, etc.)
- Anti-islanding requirement

## BESS Type tests

- Discharge Energy Capacity Test
- Real Power Test
- Reactive Power Test
- Ramp rate and Response Time Test
- Round-trip efficiency (RTE)
- 4-Q Power Curve (rating & stability)
- Standby mode (Standby losses and Aux power consumptions)

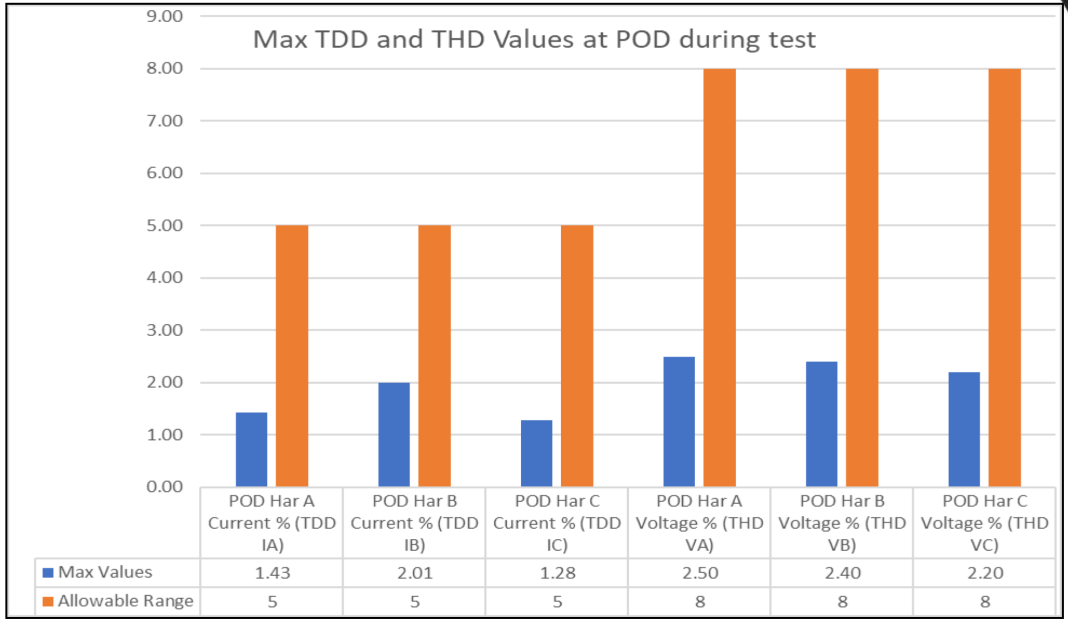
## Application tests

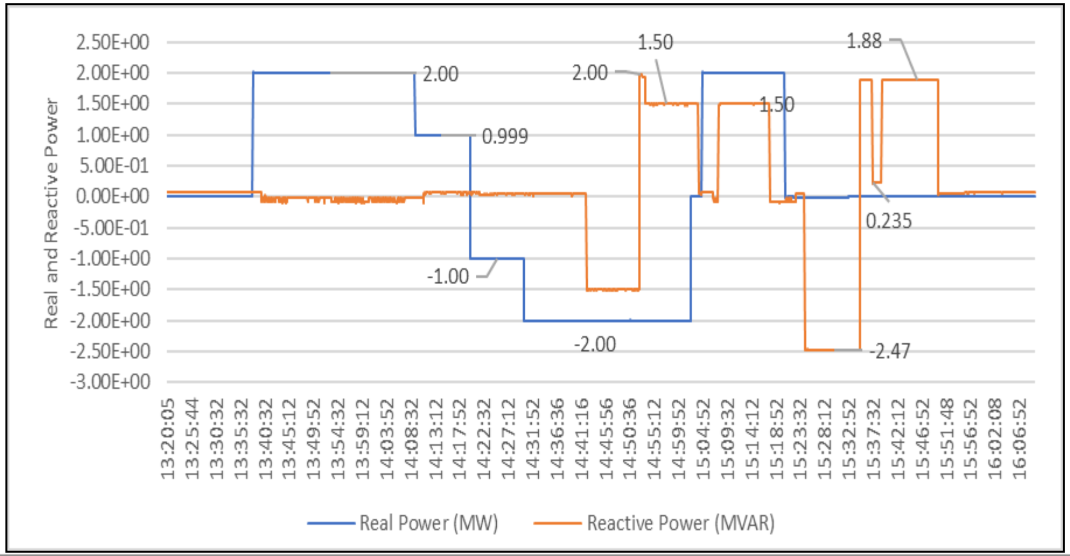
- Voltage control mode (voltage régulation)
- Site control mode
- Back feeding
- Peak shaving
- SOC management

# Power Quality Test Case

Data analysis approach for the power quality test case:

- Maximum values for each parameter were compared with the acceptable range in IEEE 519.
- Maximum and minimum values during each step when the BESS plant reached 98% of the commanded setpoints are investigated separately to evaluate the BESS power quality at certain MW and Mvar output.
- For the parameters which were outside of the acceptable range, the test results were investigated further to make sure external circumstances have not impacted the measured values or additional factors needed to be taken into consideration such as when the plant was ramping up/ down.



# Anti-Islanding Test Case

The main objective of this test was to evaluate the BESS's ability to disconnect from the grid upon loss of utility voltage (Inverters were set in the grid following).

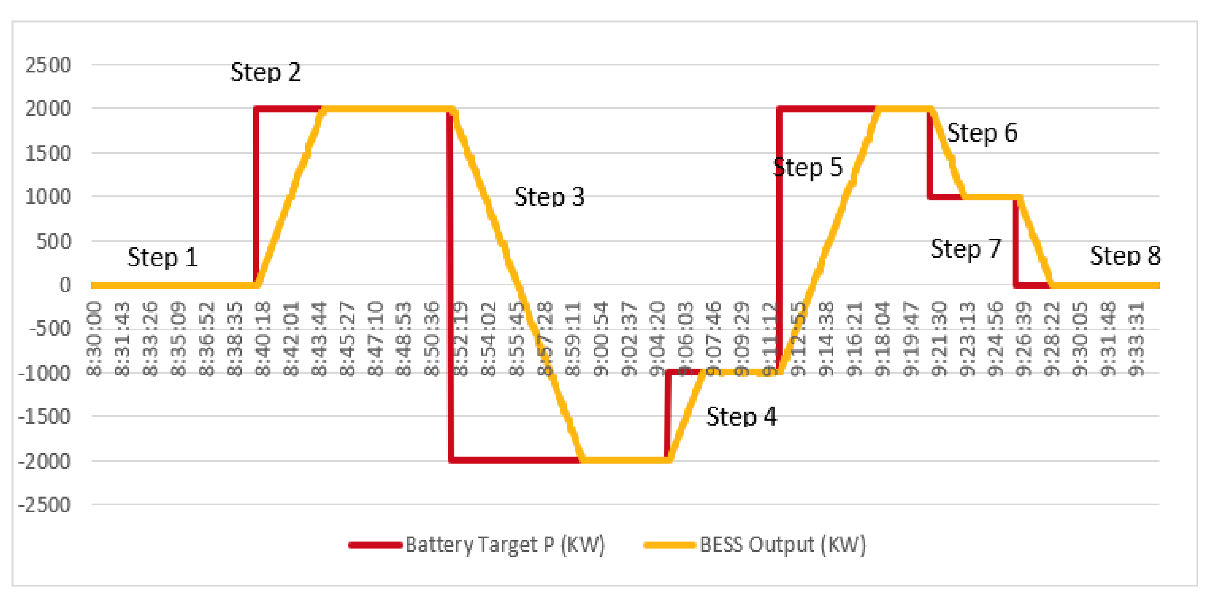
- The anti-Islanding logic in the BESS worked as expected with no issues.
- The POI recloser was opened and the BESS immediately disconnected outputs and reset the P and Q setpoints to zero.
- There was one case seen during the testing which is with the THD value that jumps to 9.3% when the POI closed. This was due to the inrush of the GSU transformer energizing and was expected. No other anomalies were observed.

# Ramp Rate Test Case– Highlighted Outcomes

**Highlighted outcomes**

•All ramp rate tests were as expected where the BESS slowly ramped the output up or down at the programmed ramp rate.

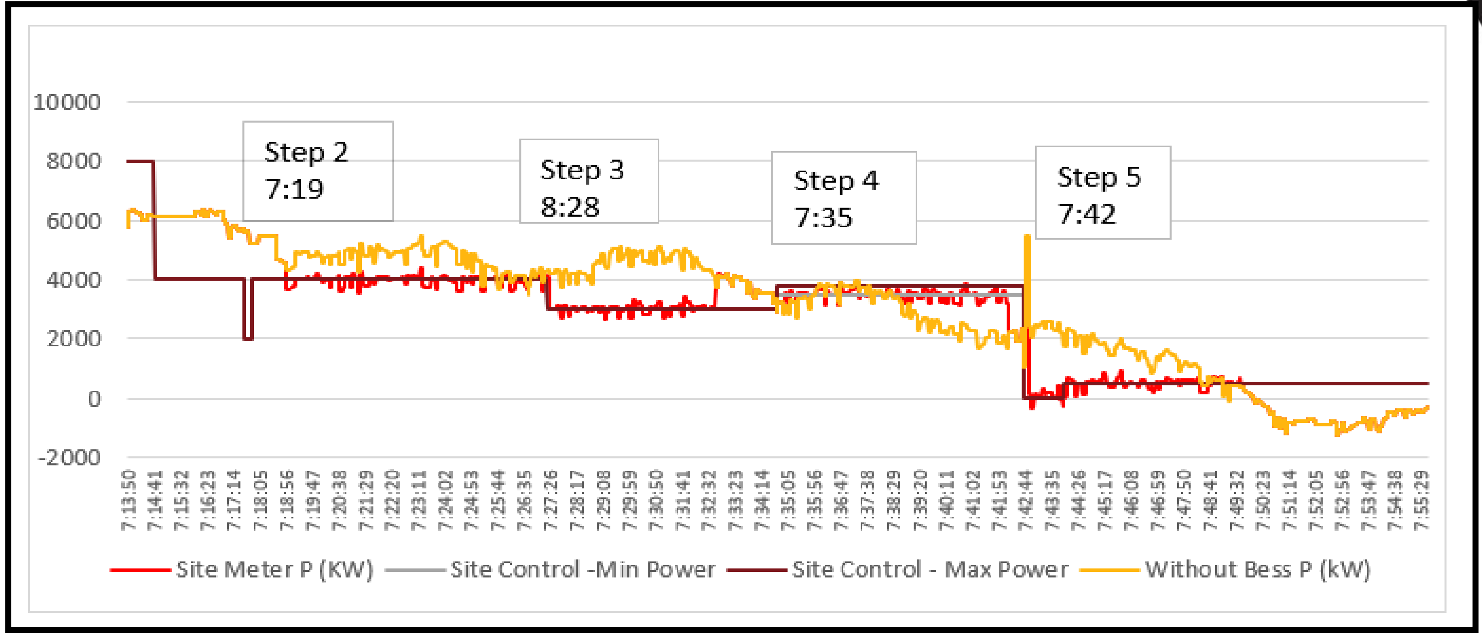
•Voltage during this test showed a variation of 1.6% of nominal and was to be expected with the changing load of charging or discharging of the BESS on the grid.




| Step | BESS Command Start Time | BESS Command Completion Time | Ramp Time in Seconds | Ramp Rate Actual kW/s | Programmed Ramp Rate kW/s | Deviation % |
|---|---|---|---|---|---|---|
| 2 | 8:40:05 | 8:44:07 | 242 | 8.26 | 8.333 | 0.822 |
| 3 | 8:51:51 | 8:59:52 | 481 | 8.31 | 8.333 | 0.203 |
| 4 | 9:05:14 | 9:07:15 | 121 | 8.26 | 8.333 | 0.822 |
| 5 | 9:11:50 | 9:17:56 | 366 | 8.19 | 8.333 | 1.635 |
| 6 | 9:21:06 | 9:23:06 | 120 | 8.33 | 8.333 | -0.004 |
| 7 | 9:26:30 | 9:28:30 | 120 | 8.33 | 8.333 | -0.004 |

# Back Feeding Test Case

The main objective of this test was to evaluate the BESS's ability to operate in back-feeding mode following the SCADA commands and setpoints limiting back feeding, both in terms of power and energy.




Commanded Power level vs Actual Power Level During Back Feeding Test Case

**Highlighted outcomes**

- Back feeding mode was successful at controlling the power level between the minimum and maximum levels set for the BESS.
- During this test, TDD and THD levels were well within the IEEE 519 standard

# Conclusion

- Comprehensive performance evaluation testing beyond generic tests by the vendor (Third-Party Testing) is crucial to ensure the BESS performs as designed and meets the specified performance criteria and it helps to discover and correct problems before the system goes "online".
- Test results showed the importance of evaluating the BESS plant under different operating conditions/modes (lower power levels or pure reactive power output) and not only the BESS maximum or minimum active power output.
- A well-configured BESS with an appropriate ramp rate and settings can avoid/reduce voltage issues or harmonic distortion at different active and reactive power outputs.