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Washington Clean Energy Fund: Energy Storage System Performance Test Plans and Data Requirements

April 2017

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

This report documents the test plans, including detailed duty cycles, used in evaluating the technical performance of five energy storage systems (ESSs) sponsored by the Washington State Clean Energy Fund (CEF). These ESSs were installed at three participating utilities' (Avista, Snohomish Public Utility District or SnoPUD, and Puget Sound Energy or PSE) designated sites. Under each test plan, a number of baseline and use case tests are defined. This report documents the test plan for each utility, including duty cycles, data and performance reporting requirements.

Baseline tests defined in this report mainly focus on determining an initial or reference performance for each ESS, which may be compared with the performance at any later time to assess the state of health of the ESS. Parameter values of a given ESS obtained from baseline tests are applied for different modeling purposes and use case tests. The stored energy capacity test is the first test conducted in the baseline test program, which generates data to calculate round trip efficiency (RTE). The response time and ramp rate tests provide the time required for an ESS to change from zero to full charging/discharging rate and hence the ramp rate, which is important in understanding ESS performance for applications calling for fast response. Internal resistance testing of ESS cells is also conducted in conjunction with the response time and ramp rate tests. Finally, the baseline tests include frequency regulation (FR) and peak shaving (PS) tests based on real-world duty cycles.

Upon completion of the baseline tests, use case tests are conducted at each of the storage sites with duty cycles developed to meet the site-specific criteria and conditions. Figure ES.1 presents an overview of the use cases and applications to be performed and measured/analyzed in coordination with Pacific Northwest National Laboratory (PNNL). "Y" means the service is currently included as part of the use case analysis project. The use cases are grouped according to their intended target benefits within the electric infrastructure topology (e.g., transmission versus distribution). Although an ESS may be located on the low-voltage side of a substation that provides power to a distribution feeder, a use case that addresses bulk power services could still be provided and would be grouped under the transmission or bulk-power benefits. Use cases for ESS applications deep into the distribution circuit would be categorized under the distribution system cases.

Use Case and application as described in PNNL Catalog	Avista	PSE	Sno – MESA1	Sno – MESA2	Sno - Controls Integration
UC1: Energy Shifting					
Energy shifting from peak to off-peak on a daily basis	Y	Y	Y	Y	
System capacity to meet adequacy requirements	Y	Y	Y	Y	
UC2: Provide Grid Flexibility					
Regulation services	Y	Y		Y*	
Load following services	Y	Y		Y*	
Real-world flexibility operation	Y	Y		Y*	
UC3: Improving Distribution Systems Efficiency					
Volt/Var control with local and/or remote information	Y		Y	Y	
Load-shaping service	Y	Y	Y	Y	
Deferment of distribution system upgrade	Y	Y			
UC4: Outage Management of Critical Loads		Y			
UC5: Enhanced Voltage Control					
Volt/Var control with local and/or remote information and during enhanced CVR events	Y				
UC6: Grid-connected and islanded micro-grid operations					
Black Start operation	Y				
Micro-grid operation while grid-connected	Y				
Micro-grid operation in islanded mode	Y				
UC7: Optimal Utilization of Energy Storage	Y	Y			Y

Figure ES.1. Washington CEF Use Case Matrix

The remainder of this report defines the baseline and duty cycle tests for each utility, and defines data requirements and templates for reporting performance results of the tests. Reporting the results using these templates will make it easier to understand the performance of a given ESS in a concrete and simplified manner. These test plans will guide the work conducted in support of the Washington CEF but the procedures and duty cycles have broad application for evaluating any ESS. These duty cycles are technology agnostic and can be applied to ESSs of varying chemistries and power/energy capacities.

Acknowledgments

We are grateful to Dr. Imre Gyuk who is the Energy Storage Program Manager in the Office of Electricity Delivery and Energy Reliability at the U.S. Department of Energy and Bob Kirchmeier who is a Senior Energy Policy Specialist in the Clean Energy Fund Grid Modernization Program of the Washington State Energy Office. Without their organizations' financial support and their leadership, this project would not be possible.

Acronyms and Abbreviations

AC	alternating current
ACE	area control error
API	application programming interface
BMS	battery management system
DAS	data acquisition system
DERO	Distributed Energy Resources Optimizer
DC	direct current
DOD	depth of discharge
ESS	energy storage system(s)
FR	frequency regulation
HVAC	heating, ventilation, and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
kW	kilowatt(s)
MW	megawatt(s)
MWh	megawatt hour(s)
OCV	open circuit voltage
PCC	point of common coupling
PCS	power conversion system
PFC	power factor correction
PM	performance metrics
PRT	Pattern Recognition Technologies, Inc.
PS	peak shaving
PSE	Puget Sound Energy
Rp	rated power
RMSE	root mean square error
RTE	round trip efficiency
PNNL	Pacific Northwest National Laboratory
SAT	site acceptance test
SOC	state of charge
SOH	state of health
Wh	watt hour(s)

Contents

Figures

Tables

1.0 Introduction

Under the energy storage deployment and demonstration project sponsored by the Washington State Clean Energy Fund (CEF), Energy Storage Systems (ESSs) installed at three participating utilities' (Avista, Snohomish Public Utility District or SnoPUD, and Puget Sound Energy or PSE) designated sites are undergoing a number of baseline and use case tests. This report documents the test plans, including duty cycles applied to conduct these tests, the data requirements for each test, and the performance reporting requirements.

The Washington CEF comprises five battery storage systems sited at three utilities' service areas in Washington State. Avista Utilities has deployed a 1 megawatt (MW) / 3.2 megawatt-hour (MWh) UniEnergy Technologies (UET) vanadium-flow battery system in Pullman, Washington. Puget Sound Energy deployed a 2 MW / 4.4 MWh lithium-ion/phosphate ESS at a substation in Glacier, Washington. SnoPUD deployed two 1 MW / 500 kWh lithium-ion battery systems at a substation in Everett, Washington. At another substation in Everett, SnoPUD deployed a 2 MW / 8 MWh vanadium-flow battery built by UET.

To conduct analysis on the test results and to report on ESS performance, data is collected from utilities in various temporal resolutions appropriate to the test. Main data points include charge/discharge control signal issued to the ESS, actual charge/discharge power and energy, state of charge (SoC), direct current (DC) voltage and current. Data on auxiliary consumption and power in and out at the transformer connecting the ESS to the grid are also collected as available to determine efficiency at the point of coupling.

Baseline tests mainly focus on determining initial or reference performance of the ESS, which may be compared with the performance at any later time to assess State of Health (SoH) of the ESS. Parameter values of a given ESS obtained from baseline tests are applied for different modeling purposes and use case tests. The stored energy capacity test is the first test conducted in the baseline test program, which generates data to calculate round trip efficiency (RTE). The response time and ramp rate test provides the time required for an ESS to change from zero to full charging/discharging rate and hence the ramp rate, which is important in understanding ESS performance for applications calling for fast response. Internal resistance testing of ESS cells is also conducted in conjunction with the response time and ramp rate tests.

Following these initial tests, two additional tests are conducted to assess ESS performance in different real word applications. The peak shaving (PS) test is conducted to assess ESS performance in relevant energy intensive applications – e.g., system capacity, energy shifting, congestion relief. The duty cycle of a PS test consists of a fixed duration of charging operation followed by different durations of discharge operation and two floating periods over 24 hours. A frequency regulation (FR) test is conducted to assess the ability of a given ESS to track a reference signal using an energy-neutral frequency signal over 24 hours with values changing every 1-4 seconds. Duty cycle RTE is determined for each of these duty cycle tests. A SOC excursion test is conducted from the FR test results. Stored energy capacity tests are repeated after duty cycle tests and use case tests to determine energy capacity stability.

Upon completion of the baseline tests, use case tests are conducted at each of the storage sites with duty cycles developed to meet the site-specific criteria and conditions. Figure 1.1 presents an overview of the use cases and applications to be performed and measured/analyzed in coordination with Pacific Northwest National Laboratory (PNNL). "Y" means the service is currently included as part of the use case analysis project (UCAP). The use cases are grouped according to their intended target benefits within the electric infrastructure topology (e.g., transmission versus distribution). Although an ESS may be located on the low-voltage side of a substation that provides power to a distribution feeder, a use case that addresses bulk power services could still be provided and would be grouped under the transmission or bulk-power benefits. Use cases for ESS applications deep into the distribution circuit would be categorized under the distribution system cases.

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Load-shaping service	Y	Y	Y	Y	
Deferment of distribution system upgrade	Y	Y			
UC4: Outage Management of Critical Loads		Y			
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Black Start operation	Y				
Micro-grid operation while grid-connected	Y				
Micro-grid operation in islanded mode	Y				
UC7: Optimal Utilization of Energy Storage	Y	Y			Y

Figure 1.1. Washington CEF Use Case Matrix

Use Case 1 covers two forms of energy shifting. One is the energy arbitrage application that leverages the difference between peak and off-peak electricity prices. Duty cycles for energy arbitrage applications at different sites are developed through optimization runs to maximize arbitrage revenue using historical electricity price data and ESS parameters. The other application is based on the value of system capacity benefits defined by an incremental investment in a peaking resource that could be avoided through an investment in an ESS system to meet adequacy requirements. The capacity test could be tested through a day-ahead firm commitment and then dispatched at scheduled power for a minimum duration (e.g., 2-4 hours during peak periods).

Use Case 2 focuses on grid flexibility applications, namely regulation, load-following, and ramping services. Duty cycles for these tests are calculated based on either standard frequency regulation signals or internally generated by the participating utility based on Area Control Error (ACE), as applicable.

Use Case 3 includes Volt/VAR control, load shaping, and distribution system deferment services to improve distribution system efficiency. ESS VAR dispatch requirement for Volt/VAR control tests are determined based on the reactive demand of the feeder. Load shaping service can be demonstrated either as a demand limiting strategy that is relevant to deferment of a distribution system upgrade, or as a load smoothing strategy that would limit the rate change (dP/dt) of the power demand in the circuit, which is relevant to integration of intermittent renewable resources.

Outage management of critical loads using ESS is defined as Use Case 4. This test could either be simulated or actually performed by interrupting services to one or more customers, if feasible.

Use Case 5 involves testing of ESS application to support conservation voltage reduction (CVR) control strategies by responding to commands issued by a Distribution Automation System (DAS). This test should be coupled with an additional energy shifting strategy to test performance under different SoC conditions.

Use Case 6 comprises micro-grid oriented operations of ESS in grid-connected and islanded mode. Reliable transfer between modes, outage management of critical loads in islanded mode and black start capability test are a few major applications to be tested in this use case, if feasible.

Use Case 7 bundles a set of services from all use cases and co-optimizes them to determine the maximum value of energy storage on a daily basis.

Use case-based duty cycles were defined using one of three approaches. Under the first approach, time series-based duty cycles define exact charge and discharge commands with respect to time based on analysis of historic time series data (e.g., wholesale electricity price). Additional analysis (e.g., dispatch optimization based on runs of the battery storage evaluation tool or BSET) may be necessary to define the optimal charging and discharging profile. Days of the week and time of day are matched to ensure that battery output levels are realistic given real-time grid conditions. Second, set point-based duty cycles are based on parameters established by utilities. For example, Volt-VAR control testing could be conducted by setting the power factor target to unity and relying on the inverter to provide reactive power as needed to achieve the predefined set-point based objective. Some of the use case tests may be conducted using both time-series and set point-based approaches, for example, load shaping in use case 3. The final test approach is to follow utility-defined approaches. For example, the utility may define microgrid operational goals and the energy storage duty cycle will reflect the utility's operational plan. Figure 1.2 shows how each of these approaches align with the use cases tested as part of this project.

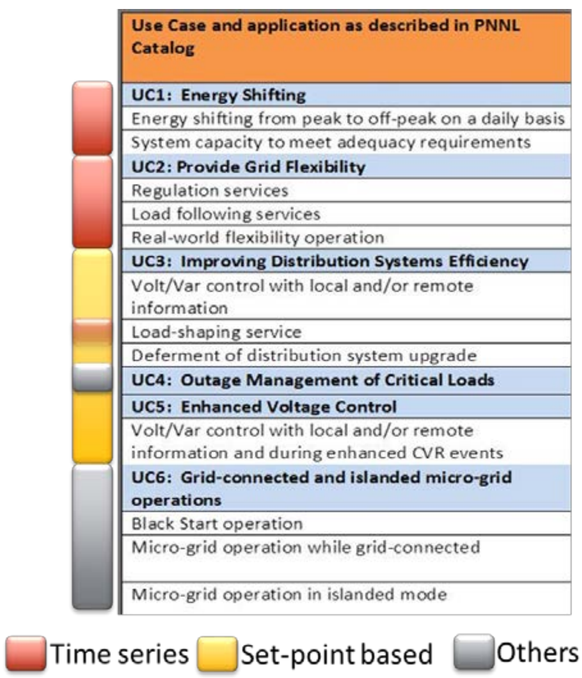


Figure 1.2. Bases of Conducting Use Case-Based Duty Cycles

The remainder of this report defines the baseline and duty cycle tests for each utility. The report also defines data requirements and templates for reporting performance results of the tests. Reporting the results using these templates will make it easier to understand the performance of a given ESS in a concrete and at-a-glance manner.

2.0 Avista Test Data Requirements and Expected Timeline

2.1 Data Requirements

The following data are requested from Avista during testing.

Alternating Current (AC) Side:

- The control signal to the ESS, which would simply be a power signal – charge or discharge at a certain power
- Actual power and energy delivered or absorbed by ESS – both in and out of transformer and in and out of PCS
- ESS state of charge – this may be communicated to the power conversion system (PCS) by the direct current battery management system (BMS).
- Voltage and current at the ESS level to determine RTE and ESS internal resistance
- PCS Temperature - locations as available

DC Side:

- Power and energy – we could use voltage and current data to calculate these
- Voltage
- Current
- SOC
- Electrolyte temperature

Optional Data, DC Side:

The AC and DC current in each parallel string, referred to as AC battery 1 and AC battery 2 in UniEnergy Technologies (2015) would also be useful. Especially for internal resistance measurements, this would allow determination of internal resistance for each string and for each module within the string.

When the ESS powers the auxiliary loads, it is not necessary to have the auxiliary load data. At present, auxiliary power is provided separately from the grid.

When the ESS does not power auxiliary loads, the electricity required to power auxiliary loads should be measured separately. Auxiliary power is a catch-all for multiple items: heating, ventilation and air conditioning (HVAC) for the battery container, lighting, communications, battery heating with heater blankets or active cooling with circulating coolant. In either case, it would be useful to have auxiliary power data. Requested data are summarized in Table 2.1.

Table 2.1. Data Requested from Avista

Test	Data Frequency[1]	Critical Data	Optional
Stored Energy Capacity Test	Every 5 minutes	Watt (W), watt-hour (Wh), current, volts (AC and DC), SOC, PCS and DC battery temperature, and auxiliary power consumption (if powered by a separate line)[2]	Cell/stack/battery container voltage, AC and DC current in each parallel battery, cell/stack/container temperature, auxiliary power (if ESS supplies it), pump flow rates for each AC battery, heat exchanger load for cathode, pressure drop across each stack in the containers.
Response Time and Ramp Test	Every second	Same as above	Same as above
Internal Resistance Test	Every millisecond (ms) for first 10 ms, every second for rest of the pulse, every 5 sec for first minute of rest, every minute for remainder of rest time	Same as above	Same as above
Peak Shaving (PS) Duty Cycle	Every 5 minutes during operation, every 15 minutes during rest	Same as above	Same as above
Frequency Regulation (FR)	Every 2 seconds	Same as above	Same as above
Capacity Stability Test	Every minute	Same as above	Same as above

2.2 Baseline Testing

The ESS will be subjected to baseline tests to determine beginning of life reference performance. These tests will allow the research team to determine ESS degradation during operation by repeating these baseline performance tests. Tests developed by the U.S. Department of Energy (DOE) Office of Energy (OE) sponsored working groups will be used with modifications as appropriate. The DOE-OE published document will be referred to as the protocol in this work (Bray et al. 2012). Language that describes baseline testing steps are taken directly from Bray et al. 2012 without modification.

Baseline testing consists of baseline performance or reference performance tests to determine the initial performance of the ESS. This reference performance test can be repeated at any time to assess the state of health of the ESS. Duty cycle testing will involve subjecting the ESS to PS and FR duty cycles to determine the performance of the ESS for these two extreme use cases. PS is an energy intensive application, while FR involves exercising the ESS around a narrow SOC range using an energy neutral signal of 1-4s frequency, with the ability of the ESS to follow the signal being of great importance. It should be noted that while the FR duty cycle is energy neutral, the RTE of the ESS will result in a deviation of the SOC from the starting SOC.

[1] All data provided every 10 seconds.
[2] Currently, auxiliary power is provided by the grid. There are plans for the ESS to provide auxiliary power in the future.

The following general performance metrics were identified in the DOE-OE sponsored protocol development effort:

- RTE
- DC3 RTE
- Response time & ramp rate (this was considered to be an application-specific metric in the protocol but has been moved up to general metrics)
- Energy capacity stability (this can be performed at any time during ESS operation)
- Internal resistance during charge and discharge
- Stability of internal resistance over time

The following application duty cycle-related performance metrics were identified, with the application that these metrics are relevant to within brackets.

- Duty cycle RTE (PS and FR)
- Reference signal tracking (FR)
- SOC excursion (FR)

The following baseline performance tests will be conducted:

- Capacity test
- Response time and ramp rate test, completed at 50% SOC
- Internal resistance test, performed at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% SOC

This will be followed by applying PS and FR duty cycles as described in Bray et al. (2012). At the end of these duty cycles, the capacity test will be repeated. This will be followed by use case testing. At the end of the use case test, the baseline performance tests (capacity, response time/ramp rate, internal resistance) will be repeated. Table 2.2 lists the tests, the start and end SOCs and the anticipated test duration.

[3] Per UET's recommendation, this metric has been added.

Table 2.2. List of Tests and Duration

Test	Begin SOC	End SOC	Days
Stored Energy Capacity Test	Any (discharge to 15% SOC before starting test)	15% (recharge to 50% for response time and ramp test)	3
Response Time and Ramp Test	50%	50%	1
Internal Resistance Test	10% or 90% (Prefer 100% so end at 10% for PS)	90% or 10%	2
Peak Shaving Duty Cycle	Any (discharge to desired initial SOC before starting test)	Same as initial SOC	4
Frequency Regulation (FR)	60%	Recharge to initial SOC	2
Additional Capacity Tests (400 kW, 800 kW, 800 kW, 600 kVAR, 418 kW, 309 kVAR).	Any (discharge to 10%. 35%, 35%, 10% SOC respectively before starting test)	0 (recharge to 50% for response time and ramp test)	10
Capacity Stability Test	Any (discharge to 15% SOC before starting test)	15% (recharge to 50% for response time and ramp test)	3
Use Case 1			14
Use Case 2			21
Use Case 3			21
Use Case 5			28
Use Case 6			21
Use Case 7			28-56
Capacity Stability Test	Any (discharge to 0% SOC before starting test)		2
Response Time and Ramp Test	50%		1
Internal Resistance Test	10% or 90%	90 or 10%	2
Total Days (min)			163
Total Days (max)			191

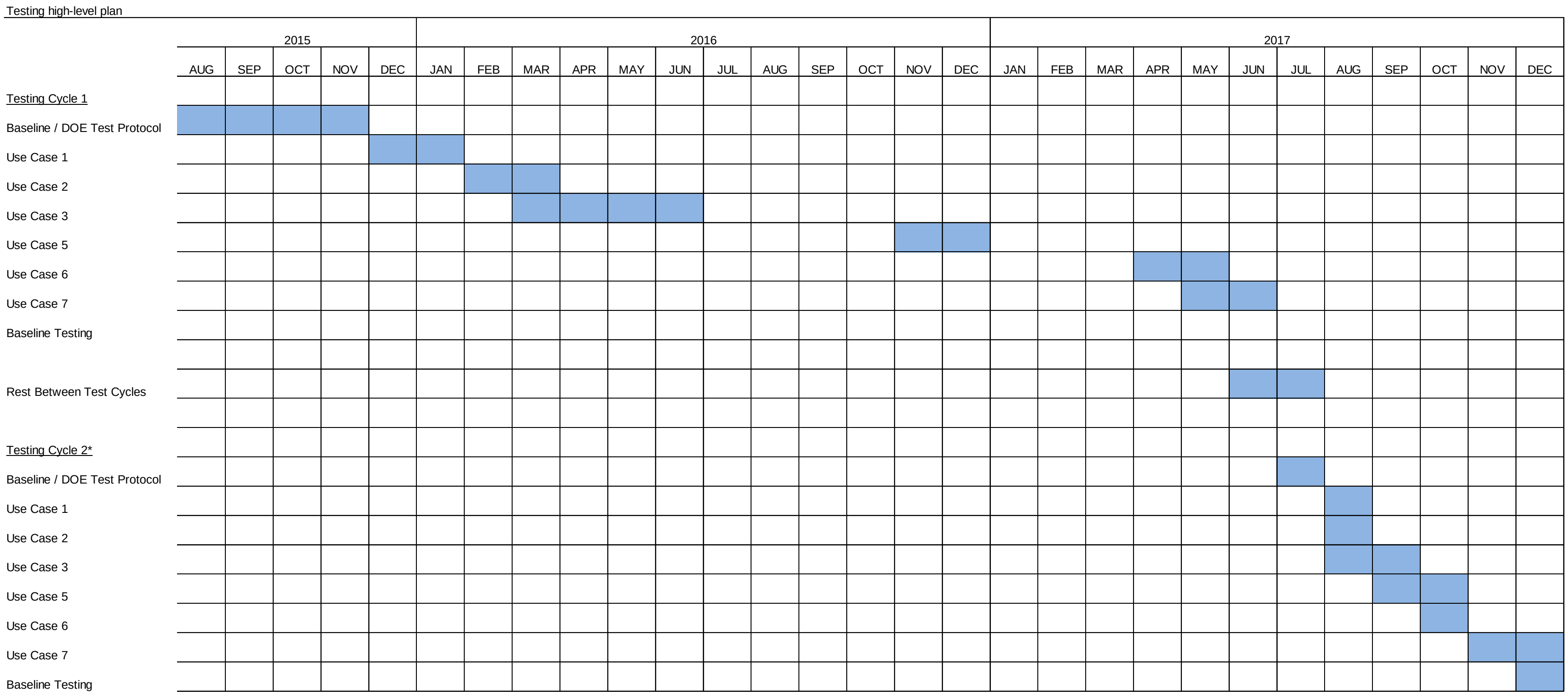
2.3 Comprehensive Data Recording

All measurements of charge rate, input current and voltage, output current and voltage, thermal output, system temperatures, ambient conditions, and other parameters that must be measured shall be collected simultaneously at a temporal resolution applicable to the function of the ESS application and ESS metrics to which they are being applied in accordance with recognized standards applicable to the measurements being taken. All parameters measured and recorded shall be reported in the ESS information model that must be used for further analysis and determination and reporting of ESS performance.

2.4 Expected Timeline

Table 2.3 presents the ESS testing plan. Field testing began in August 2015. Tests were originally expected to span five seasons (Summer 2015-Summer 2016). However, due to extended ESS outages, software updates, system repairs, and the need to replace the inverter, testing was significantly delayed as reflected in Table 2.3. Following inverter installation, new baseline tests will be performed to evaluate the impact of the new inverter on the metrics established through this test process. Testing is now expected to be complete by December 2017. A final report addressing the entire project will be submitted by September 2018.

Table 2.3. Updated Project Test Plan Timeline



*Testing cycle 1 was interrupted by extended outages, software updates and installation of new inverter. Prior to and following inverter installation, additional baseline tests will be performed.

3.0 Avista Test Protocols

This section outlines the tests that will be performed as part of the ESS technical performance testing for this research program. All UET data should be available through the AVISTA PI server, providing for only one data source. PNNL will summarize the performance evaluation for each of the control strategies defined in this section of the report. To acquire the needed data, the following tests will be conducted on the ESS:

1. Preliminary tests to determine rated power, energy content, RTE, and internal resistance.
2. Tests per PNNL/DOE protocol for PS and FR
3. Tests for each use case.

A reference performance test, also known as baseline performance test, shall be conducted in accordance with this section, and the results shall be used to determine baseline ESS performance that can be subsequently used as a baseline to assess any changes in the condition of the ESS and rate of performance over time and use. This test shall be repeated at regular intervals as specified in this document during cycle testing for same-system comparison purposes. Such intervals shall be selected to identify how the testing or operation affects the performance of the ESS and shall be in units of time, number of cycles, or energy throughput.

The Uni Energy battery system needs to be subjected to 2-3 charge-discharge cycles at 500 kW in order to bring the temperature to the 20 to 25 degrees C range, when the ambient and battery temperature is < 15 degrees C.

3.1 Stored Energy Capacity Test

A stored energy capacity test shall be performed in accordance with this section and is intended to be used to determine the stored energy capacity at the rated electrical power for the intended application as specified by the manufacturer.

3.1.1 Test Overview

The ESS shall be discharged at 520 kW to 20% SOC, which will be labeled SOC-min.

Energy storage system AC and DC power during charge and discharge shall be recorded every 10 seconds. The associated AC and DC energy input and output of the ESS shall be calculated from the recorded power.

3.1.1.1 Stored Energy Capacity Test Routine

The ESS shall be tested for its stored energy capacity at 520 kW in accordance with the procedure listed below. The measurements shall be collected in accordance with all test steps listed below. The auxiliary load is powered separately and its power consumption shall be monitored and recorded. Based on how Avista defines its ESS boundary, the power in and out of the transformer shall also be recorded to get the RTE inclusive of the transformer. If this data is not available, the total system efficiency will be calculated by multiplying the ESS RTE with the transformer RTE, where ESS ends at the PCS (and not transformer).

1. The ESS shall be discharged to SOC_min at 520 kW. The system shall be left at rest in an active mode for 10 minutes. The ESS is then brought to 100% SOC by charging at 600 kW. This is followed by resting in an active state for 10 minutes followed by a discharge at 520 kW for seven hours to SOC_min.
2. The ESS shall be charged for seven hours at 600 kW to 100% SOC. That upper SOC will be tracked by the BMS. Recorded as percentage SOC, the AC and DC energy input WhCi, into the ESS during ESS charging, including all auxiliary power consumption, shall be measured directly during charging and recorded as the charge energy capacity of the ESS. Here C corresponds to charge, and i corresponds to cycle number.
3. The system shall be left at rest in an active state in accordance with the ESS manufacturer's operating instructions for 10 minutes.
4. The ESS shall be discharged to SOC_min at 520 kW. The AC and DC energy output, WhDi, from the ESS during ESS discharging shall be calculated from the power measurements during discharge and recorded, where D corresponds to discharge.
5. The ESS shall be left at rest in an active standby state for the same period of time selected under Step 3 above (10 minutes).
6. Steps 2 through 5 above shall be repeated twice (total of three cycles). After three cycles, the ESS will be charged at 600 kW or discharged at 520 kW to bring the SOC to SOC_min. The reference performance test value shall be calculated as the mean of the values of WhCi and WDi as measured under Steps 2 and 4 above associated with each test and the standard deviation also shall be calculated and reported.
7. The ESS shall be recharged to 50% SOC by charging at 600 kW for two hours. That 50% SOC shall be measured and recorded as the manufacturer-specified V50 corresponding to the discharging conditions. The energy input for this step will not be used for calculation of RTE.

Note: For the capacity test performed after the duty cycle testing, the ESS shall be recharged to the SOC required for Use Case 1.

3.1.1.2 Roundtrip Energy Efficiency Calculation

An RTE calculation shall be conducted to determine the amount of energy that an ESS can deliver relative to the amount of energy injected into the ESS during the preceding charge for a cycle. A cumulative RTE is also calculated for a set of cycles by determining the total discharge and charge energy for those cycles. This calculation, with minor changes, shall also be used for the applicable duty cycle for the intended application of the system.

3.1.1.3 Roundtrip Energy Efficiency from Stored Energy Capacity Test Routine

The RTE of the ESS is the efficiency for each cycle, cumulative efficiency for 3 and 2 (3-1) cycles, and shall be determined in accordance with Equations 3-1 through 3-3 based on the data obtained from the tests conducted in accordance with the provisions in Section 3.1.1.1. Where constant power cannot be held during the test, the use of average power shall be considered acceptable and thus noted when reporting RTE in accordance with the provisions in Section 5.2.

$$Round\ trip\ efficiency\ for\ cycle\ i = \left(\frac{Wh_{D_i} - Auxiliary\ energy\ during\ discharge\ and\ rest}{Wh_{C_i} + Auxiliary\ Energy\ during\ charge}\right) \quad (3\text{-}1)$$

$$Cumulative\ Round\ trip\ efficiency\ for\ all\ 3\ cycles = \left(\frac{\sum_1^3 Wh_{D_i} - Auxiliary\ Energy\ during\ discharge\ and\ rest}{\sum_1^3 Wh_{C_i} + Auxiliary\ Energy\ during\ charge}\right) \quad (3\text{-}2)$$

$$Cumulative\ Round\ trip\ efficiency\ for\ cycles\ 2\ and\ 3 = \left(\frac{\sum_2^3 Wh_{D_i} - Auxiliary\ Energy\ during\ discharge\ and\ rest}{\sum_2^3 Wh_{C_i} + Auxiliary\ Energy\ during\ charge}\right) \quad (3\text{-}3)$$

Where: 3 is the total number of cycles; Wh_{Di} is the BESS electrical energy discharge output (AC) in watt-hours for cycle number i; and Wh_{Ci} is the Watt-hour charge input (AC) into the BESS, including all auxiliary power consumption for cycle number i. If the auxiliary power system is powered by the BESS, no adjustment to the above equations are needed. Note that equation 3 includes the charge or discharge energy to get the SOC to the initial value.

The DC round trip efficiencies are calculated using the same equations, by replacing AC energy input/output with DC energy input/output. The auxiliary energy consumption is ignored.

3.2 Response Time and Ramp Rate Test

The ESS shall have a response time and ramp rate test performed in accordance with this section to determine the amount of time required for the ESS output to transition from no discharge to full discharge rate and from no charge to full charge rate. The ramp rate of the ESS shall be determined by dividing the ESS rated power by the response time in accordance with the provisions in this section.

3.2.1 Test Overview

The method for measuring ramp rate shall be the same for all ESSs regardless of application. The manufacturer shall provide information about rated power as required by the provisions in Section 3.1.

The response time shall be measured in accordance with Figure 3.1 starting when the signal (command) is received at the ESS boundary as established in Section 3.1 and continuing until the ESS discharge power output (electrical or thermal) reaches 100 ± 2% of its rated power. The continuous rated power is 1000 kW during discharge and 800 kW during charge[1]

[1] Telephone conversation with Chauncey Sun of Uni Energy August 19, 2015

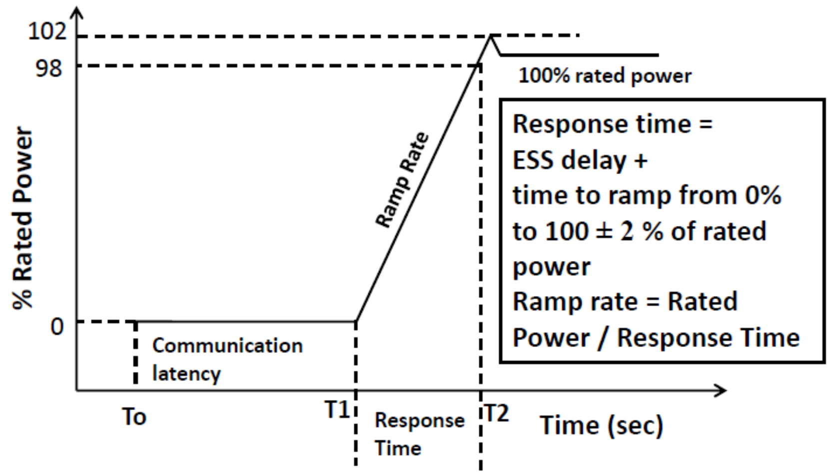


Figure 3.1. Response Time Test

3.2.2 Discharge Test Routine

The discharge response time test shall be conducted in accordance with the following procedure and the discharge response time calculated in accordance with Equation 3-4a.

1. The BESS shall be at the 50% SOC and in an active standby state.
2. The DAS shall be configured to record a time stamp T_0 when a change in set point from rest to a discharge output command is sent to the ESS.
3. The DAS shall be configured to record a time stamp T_1 when the ESS starts responding to the discharge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the output of the ESS reaches 100 ±2% of its rated power capacity (1000 +/- 20 kW). The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the discharge ramp rate of the ESS, as determined in accordance with Equation 3-4b, so that at least one intermediate data point shall be acquired as the ESS transitions from rest to full discharge.
5. The BESS shall be configured to respond to a step change in power output set point according to the BESS manufacturer's specifications.
6. The DAS shall be started and a command sent to the BESS to change the power output of the BESS to full rated discharge power output, and T_1 and T_2 shall be measured and recorded. Data will be recorded every second.
7. The DAS shall be reset to a state to begin recording data and the ESS placed in a state of active standby.

$$RTD = T2 - T1 \qquad (3\text{-}4a)$$

where RTD is the discharge response time in seconds; T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the ESS reaches 100 ±2 % of its rated power output.

The discharge ramp rate RR_D shall be calculated in accordance with Equation 3-4b and expressed in megawatts per minute.

$$RR_D = [P_{T2}]/[T_2 – T_1] \times 60 \tag{3-4b}$$

where P_{T2} is the power output of the ESS recorded at time T_2 (100 ±2% of rated power capacity); T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the ESS reaches 100 ±2% of its rated power output.

The discharge ramp rate shall also be expressed as percent rated power per minute ($R_{R\_pct,}$) in accordance with Equation 3-4c.

$$R_{Rpct} = RR_D / P_R \times 100 \tag{3-4c}$$

where P_R is the rated power of the ESS.

The response time and ramp rate will be reported in accordance with the provisions in Section 5.0.

3.2.3 Charge Test Routine

The charge response time test shall be conducted in accordance with the following procedure and the charge response time calculated in accordance with Equation 3-5.

1. The ESS shall be at the 50% SOC and in an active standby state.
2. The DAS shall be configured to record a time stamp T_0 when a change in set point from rest to a charge output command is sent to the ESS.
3. The DAS shall be configured to record a time stamp T_1 when the ESS starts responding to the charge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the input to the system reaches a 100 ±2% of its rated power capacity (800 kW +/- 16 kW). The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the ramp rate of the ESS, as determined in accordance with Equation 3-6a, so that at least one intermediate data point shall be acquired as the ESS transitions from rest to full charge.
5. The ESS shall be configured to respond to a step change in power input set point according to the ESS specifications provided by the manufacturer.
6. The DAS shall be started and a command sent to the BESS to change the power input to the ESS to full rated charge power input, and T_1 and T_2 shall be measured and recorded. For the UniEnergy ESS, the upper ramp rate limit is controlled by the BMS to avoid overcharge. Hence, this test is expected to verify that the ESS ramp rate reaches or approaches the upper limit as controlled by the BMS. Data will be recorded once a second.
7. The DAS shall be reset to a state to begin recording data and the ESS placed in a state of active standby.

$$RT_C = T_2 - T_1 \tag{3-5}$$

where RT_C is the charge response time in seconds; T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the charge signal; and T_2 is the end time stamp, in seconds, when the input to the ESS reaches 100 ±2 % of its rated power output.

The charge ramp rate RR shall be calculated in accordance with Equation 3-6a and expressed in megawatts per minute.

$$RR_C = [P_{T2}]/[T_2 - T_1] \times 60 \qquad (3\text{-}6a)$$

where P_{T2} is the power input to the ESS recorded at time T_2 (100 ±2% of rated power capacity).

The charge ramp rate shall also be expressed as percent rated power per minute (RRC_{pct}) in accordance with Equation 3-6b.

$$RRC_{pct} = RRC/\ PR \times 100 \qquad (3\text{-}6b)$$

where PR is the rated power of the ESS.

3.3 Internal Resistance Test

The internal resistance test shall be conducted in accordance with the following procedures. The test is illustrated in Figure 3.2.[2]

Figure 3.2 presents an example of a pulse discharge profile for an ESS. The open circuit voltage (OCV) before pulse is also shown.

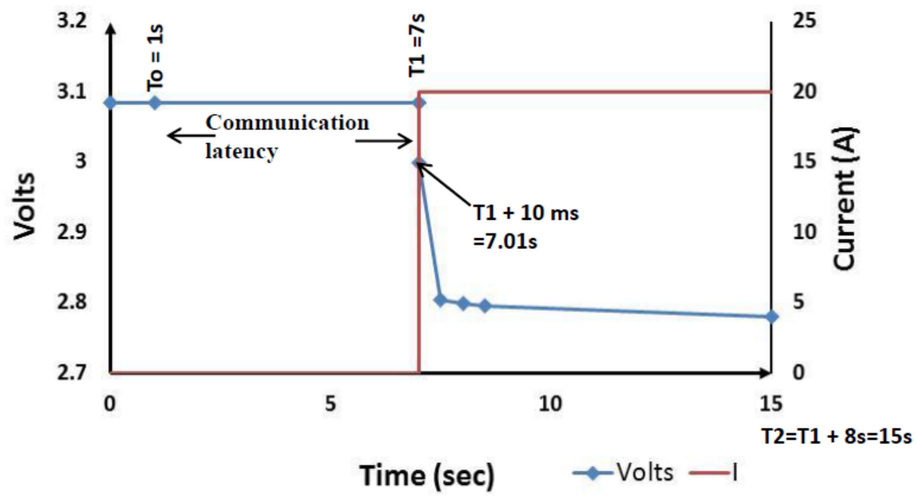


Figure 3.2. The Pulse Discharge Profile for ESS

1. The Avista system cannot accept commands less than 60 seconds apart, while the UET BESS maximum continuous charge power is 800 kW. Hence for charge, 800 kW is the pulse signal applied for 1 minute, while for discharge, a 1,000 kW pulse signal is applied for one minute. Take ESS to 90% SOC by charging at the rated power to 100%. Keep at rest for one hour. Measure open circuit voltage (OCV) at the end of the rest time. Go to step 2.

[2] The pulse is applied for 5 seconds in this figure. In this test, it will be changed to 8 seconds.

2. The DAS shall be configured to record a time stamp T0 when a change in set point from rest to a discharge output command is sent to the ESS, and time stamp T1 when the BESS starts responding to the discharge command signal. The ESS DC voltage is measured with a meter that records voltage every millisecond for 1st 10 ms, and every second thereafter during discharge. The discharge command is for discharging at 1,000 kW for 8 seconds (T2), after which the BESS is set on rest for 15 minutes. The AC and DC power during discharge are also recorded.
3. The DC voltages are measured every ms for the first 10 ms after discharge, and every second thereafter for 8 sec, and every minute thereafter for 15 minutes3.
4. The internal resistance of the ESS is calculated per Equations 3-12 through 3-16.

The AC power out of the ESS shall be recorded during the 8-sec charge.

The ohmic and total resistances are calculated by the following equation:

$$R_{total\text{-}discharge} = \{V(T0)\text{-}V(T1+8\ sec)\}/Idischarge \quad (3\text{-}12)$$

where T1+8s is T2

From the OCV data after charge, the ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}discharge} = \{\ V(T2+15\ minutes)\text{-}V(T2)\}/Idischarge \quad (3\text{-}13)$$

One way DC discharge efficiency, ηdc_dis_{chg}, is given by

$$\eta_{dc\_discharge} = V_{(T1+8\ sec)}\ /\ V_{To}\ DC \quad (3\text{-}14a)$$

$$\eta_{dc\_discharge} = V(T2)/V(T2+15\ minutes) \quad (3\text{-}14b)$$

Equation 3-14a gives the efficiency based on the voltage increase during charge, while equation 3-14b provides the efficiency based on voltage relaxation after charge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

One way PCS efficiency during discharge, $\eta_{PCS\_discharge}$ is given by

$$\eta_{PCS\_discharge} = AC\ power\ from\ PCS\ /\ DC\ power\ from\ battery\ to\ PCS \quad (3\text{-}15)$$

where DC power from battery to PCS = DC voltage X Idischarge at 8 sec

The one way ESS discharge efficiency, η_{ESS_dis} is given by:

$$\eta_{ESS\_discharge} = \eta_{dc\_dischg}\ x\ \eta_{PCS\_discharge} \quad (3\text{-}16)$$

The ESS RTE during the internal resistance measurement at each SOC is calculated as follows:[4]

[3] The OCV value at 30 minutes can be used to determine the total internal resistance, while OCV at 100 mS can be used to determine ohmic resistance.
[4] This can be cross-checked vs. the measured RTE from the reference performance test. Note that for the latter, the charge and discharge power are the same, resulting in different currents.

$$\eta_{ESS\_RTE} = \text{One way ESS charge efficiency x one way ESS discharge efficiency}$$

$$\text{DC RTE} = \text{one way DC charge efficiency x one way DC discharge efficiency}$$

$$\text{PCS RTE} = \text{one way PCS efficiency during charge x one way PCS efficiency during discharge.}$$

5. The DAS shall be configured to record a time stamp T0 when a change in set point from rest to a charge output command is sent to the ESS, and time stamp T1 when the BESS starts responding to the charge command signal. The ESS DC voltage is measured with a meter that records voltage every second. The command is for charging at 800 kW for 1 minute (T2), after which the BESS is set on rest for 15 minutes. The AC and DC power during charge are also recorded.
6. The DC voltages are measured every second for 8 seconds after charge, and every minute thereafter for 15 minutes.
7. The internal resistance of the ESS is calculated per Equations 3-7 through 3-10.

   The AC power in to ESS shall be recorded during the 8-sec charge.

   The ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}charge} = \{V(T1+8\text{ sec})-V(T0)\}/Icharge \quad (3\text{-}7)$$

   Where T1+8s is T2

   From the OCV data after charge, the ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}charge\,=} = \{V(T2+15\text{ minutes})-V(T2)\}/Icharge \quad (3\text{-}8)$$

   The DC efficiency and the PCS efficiency are calculated using Figure 3.3 as guide for power flow between the DC and AC side.

   One way DC charge efficiency, ηdc_{chg}, is given by the following equations:

$$\eta_{dc\_chg} = V_{(To)}/V_{(T1+8sec)}\text{ DC} \quad (3\text{-}9a)$$

$$\eta_{dc\_chg} = V(T2+15\text{ minutes})/V(T2) \quad (3\text{-}9b)$$

   Equation 3-9a gives the efficiency based on the voltage increase during charge, while equation 3-9b provides the efficiency based on voltage relaxation after charge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

   One way PCS efficiency during charge, η_{PCS_charge} is given by

$$\eta_{PCS\_charge} = \text{DC power in to battery/AC power in to PCS} \quad (3\text{-}10a)$$

   where

$$\text{DC power in to battery from PCS= DC voltage x Icharge at 8 sec} \quad (3\text{-}10b)$$

   The one way ESS charge efficiency, η_{ESS_dis} is given by:

$$\eta_{ESS\_charge} = \eta_{dc\_charge} \times \eta_{PCS\_charge} \quad (3\text{-}11)$$

8. Discharge at rated power to Reduce SOC by 10%, followed by 30 minutes of rest.
9. If SOC ≥ 10%, go to step 2.
10. If SOC < 10%, go to step 5, complete steps 5, 6 and 7 to end the test.

Figure 3.3 shows power flow in and out of the ESS (with PCS as the boundary).

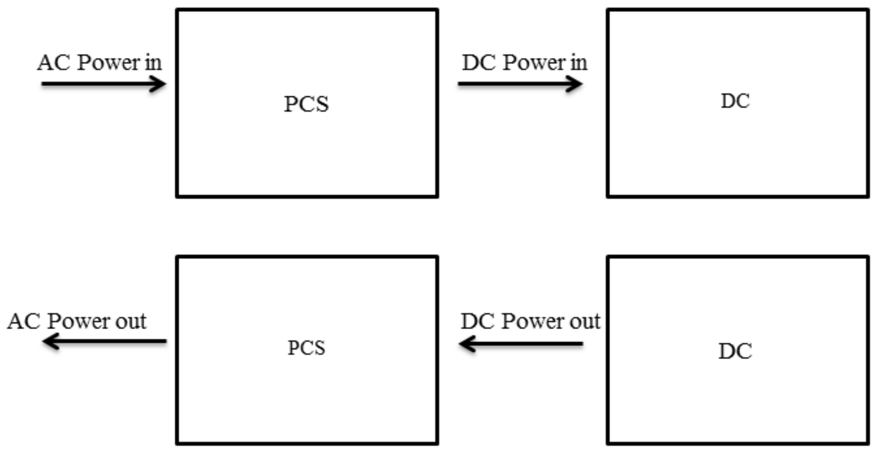


Figure 3.3. One-way DC System and PCS Efficiency during Charge and Discharge

At the end of the pulse test, charge or discharge the battery at rated power to the required SOC. If peak shaving (PS) is next, simply charge to 100% SOC at 600 kW and do the PS test. Else charge the ESS to 50% SOC at 600 kW.

4.0 Avista Peak Shaving and Frequency Regulation Test

4.1 System Ratings

Ratings for ESSs covering rated power and energy available at rated power and the performance of the ESS associated with response time, ramp rate, and RTE at the beginning of life shall be based on a set of ambient operating conditions specified by the manufacturer of the ESS. The manufacturer shall also provide an indication of how the performance of the ESS is expected to change based on the age and use of the system.

4.2 Peak Shaving (Management)

ESSs intended for use in peak-shaving (management) applications shall have their performance determined in accordance with this section.

4.2.1 Classification

ESSs intended for peak-shaving (management) applications shall be designated by their intended classification(s) as described in Sections 4.2.1.1 through 4.2.1.11.

4.2.1.1 Energy Time Shift (Arbitrage)

Energy time shift (arbitrage) shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is charged during low energy price periods and discharged during high energy price periods where either the ESS owner pays wholesale market energy rates plus a delivery charge or pays time-of-day retail rates.

4.2.1.2 Electric Supply Capacity

Electric supply capacity shall be considered a use classification of an ESS in a peak-shaving (management) application where the storage capacity of the system is used to defer the installation of new electric generation capacity, such as, but not limited to, a relatively small storage system or series of systems where growth has created a need for generation that cannot be satisfied in the short term and the storage system would be expected to supply load over the full period when the excess capacity is needed.

4.2.1.3 Load Following

Load following shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is used to reduce ramp rate magnitudes so that conventional load-following generating units can better moderate cycling and be brought on at, or near, full load.

4.2.1.4 Transmission Congestion Relief

Transmission congestion relief shall be considered a use classification of an ESS in a peak-shaving (management) application that is a special case of the energy time shift use classification in Section 4.2.1.1, where electric transmission congestion leads to price differences across a transmission system at the same point in time. In this use classification, the storage system shall be located on the load side of the congested network, charged in low price periods when the system is not congested and discharged during high price time periods when prices have increased due to congestion.

4.2.1.5 Distribution System Upgrades Deferral

Distribution system upgrade deferral shall be considered a use classification of an ESS in a peak-shaving (management) application where the system responds to a situation where a piece of equipment on the distribution system, including power line conductors, experiences loadings that approach the distribution system equipment’s rated capacity, thereby allowing the current distribution system equipment to remain online longer until other conditions necessitate that the distribution system equipment be upgraded.

4.2.1.6 Transmission System Upgrades Deferral

Transmission system upgrade deferral shall be considered a use classification of an ESS in a peak-shaving (management) application identical to the distribution upgrade deferral application covered in 4.2.1.5, except that it applies on higher voltages and higher power conditions found on the electric transmission system.

4.2.1.7 Retail Demand Charge Management

Retail demand charge management shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is applied and used to minimize the demand charge from a utility over the course of each month.

4.2.1.8 Wind Energy Time Shift

Wind energy time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where electric power generated from a wind technology during low price periods is stored and then delivered during high price periods.

4.2.1.9 Photovoltaic Energy Time Shift

Photovoltaic energy time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where electric power generated from photovoltaic technology is stored and then delivered to the system when needed.

4.2.1.10 Renewable Capacity Firming

Renewable capacity firming shall be considered a use classification of an ESS in a peak-shaving (management) application that involves the coupling of intermittent renewable generation with a specific capacity and type of energy storage that allows for an increase in the ability of the renewable generation to participate in the capacity market.

4.2.1.11 Baseload Generation Time Shift

Baseload generation time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where an ESS is configured to allow baseload units to operate at full capacity

during lighter nighttime loads, and deliver energy to the system in a way that minimizes or displaces higher-cost peaking generation.

4.2.2 System Ratings

The determination and reporting of ratings for ESSs applied in a peak-shaving (management) application shall be in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 1679 as expanded herein to provide more specific test procedures that apply to peak-shaving (management) applications. Such expansion shall include application of the duty cycle in Section 4.2.3 and taking measurements needed to determine the values for the metrics in Section 4.2.4 in determining and expressing the performance of ESSs for peak-shaving (management) applications.

4.2.3 Duty Cycle

The duty cycles presented in this section shall be used in the determination of the performance of systems intended for peak-shaving (management) applications and shall use charge and discharge time windows instead of normalized power levels or discharge rates to allow the duty-cycle profile to be applied the same to different technologies regardless of system size, type, age, and condition. The duty cycles applied in determining system performance shall be in accordance with Figure 4.1 and the provisions in Sections 4.2.3.1 through 4.2.3.4.

Each cycle must have a total charge time of 12 hours, a variable duration discharge window and two equal float windows that bring the total duration for each of the A, B, and C profiles to one 24-hour period. While Figure 4.1 displays these profiles for a 24-hour period with an evening peak, for the purposes of testing any start and end time shall be permitted to be selected as long as that time period is for 24 continuous hours. When conducting performance tests using these profiles, the baseline point selected from which to start the test and representing the beginning of each duty cycle shall be the same point the system is returned to after the 24-hour duration of the test profile. This baseline point shall be at any SOC of the ESS.

4.2.3.1 Charge Window

During the charge window, the ESS shall be charged at constant power up to 12 hours to bring the ESS to its upper SOC limit, after which the ESS shall be maintained at that SOC limit in accordance with the ESS manufacturer’s specifications and operating instructions.

4.2.3.2 Float Window

During the float window, the operation of any internal support loads for the ESS such as, but not limited to, heating, ventilation, and air-conditioning systems shall continue to operate as required in accordance with the ESS manufacturer’s specifications and operating instructions. During the float window the ESS shall not be maintained at the top of charge from an external source. Discharging of the ESS that does not serve a load external to the ESS shall be permitted during the float window.

4.2.3.3 Discharge Window

During the discharge window the ESS shall be discharged until the minimum SOC level, as specified by the ESS manufacturer, is reached. The discharge of the ESS shall be at constant power as specified by the manufacturer of the ESS to bring the ESS to its minimum SOC level as specified by the manufacturer for a peak-shaving application.

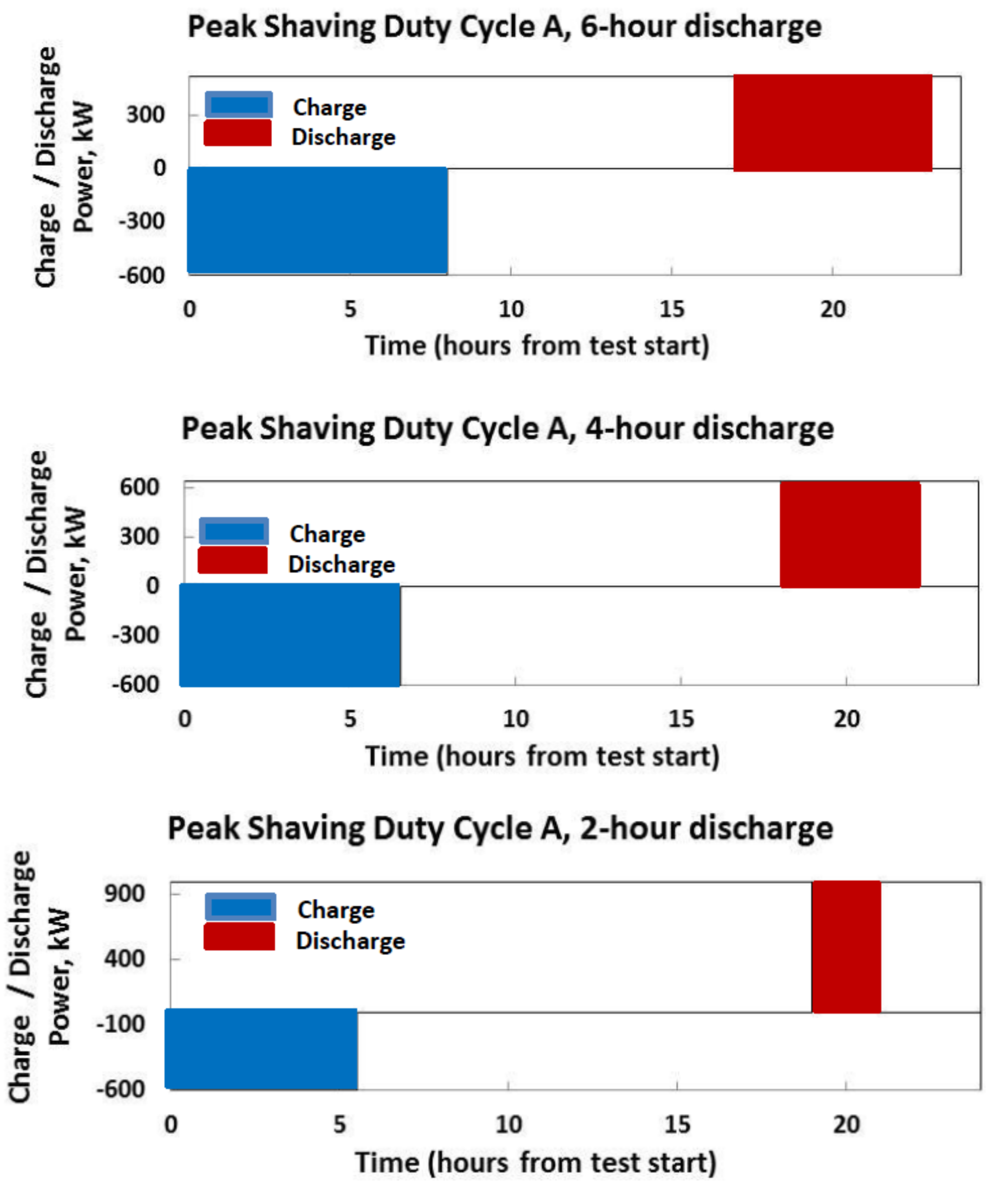


Figure 4.1. Peak-Shaving Duty Cycles

4.2.3.4 Application of the Duty Cycles

Performance testing shall consist of one application of duty-cycle A and bringing the ESS back to its initial state of charge, followed immediately by one application of duty-cycle B and then followed immediately by one application of duty-cycle C as shown in Figure 4.1, with the ESS brought back to its initial SOC after each duty cycle. These duty cycles, sequenced as required above, shall be used to calculate the metrics covered in Section 4.2.4 that are to be used as a basis for determining and reporting the operational effectiveness of an ESS in peak-shaving applications.

4.2.4 Performance Metrics

The performance of the ESS shall be expressed in accordance with the provisions of Sections 4.2.4.1 based on the application of the duty cycle provided in Section 4.2.3.

4.2.4.1 Duty-Cycle Roundtrip Efficiency for Peak-Shaving

The duty-cycle RTE of the ESS as a function of discharge power shall be determined in accordance with the provisions in this section.

The manufacturer shall select an intended application and apply the duty cycle as provided in Section 4.2.3. In conducting the tests required in Section 4.2, the charge and discharge of the ESS shall be in accordance with this section using the duty cycle in Section 4.2.3.

1. The system shall be brought to the desired initial SOC of 100% in accordance with duty-cycle A as provided in Section 4.2.3 by charging or discharging the BESS at the required level for the required duration. Charging is done at 600 kW.
2. The ESS shall then be subjected to the duty cycle as described in Section 4.2.3 and shown in Figure 4.1, starting with discharge. Based on discussions with UET, depending on the discharge rate, the SOC at which discharge power tapers varies. Tests have indicated that after discharge of a fully charged battery at 520 kW for 6 hours, the SOC is 34.5%. Discharging at 640 kW for 4 hours leads to an SOC of 50%, while discharge for 2 hours at 1,000 kW leads to an SOC of 60%. By setting the initial SOC at 100%, regardless of the end SOC during each discharge, the charging always takes place from that same SOC, thus making RTE calculations simple.
3. At the end of the duty cycle, the ESS shall be returned to the initial SOC_I by charging or discharging the ESS at rated power. Since the duty cycle ends with rest after the charge, it is anticipated that a brief charge would be required to get the SOC back to 100%.
4. Steps 1 through 3 shall be repeated for duty cycles B and then C as described in Section 4.2.3 using the same amount of time the ESS is held at initial SOC in applying duty-cycle A.
5. The duty-cycle RTE at each discharge power of each duty cycle shall be determined by dividing the energy removed (output) from the ESS at a given power by the energy required to recharge (input) the ESS. The discharge duration has been set such that the taper occurs before discharge ends. The discharge and charge energy in the 100% to taper SOC range, along with auxiliary power consumption, will be used to determine the RTE for each duty cycle. The duty cycle RTE as a function of discharge power shall be determined by dividing the energy removed from the ESS at a given power by the energy required to recharge the ESS as shown in Equation 3-1.

At the end of the test, the ESS shall be brought to the desired SOC using a procedure recommended by the manufacturer’s specifications and operating instructions. If frequency regulation is the next step, the ESS is brought to 60% SOC.

4.3 PNNL Frequency Regulation

4.3.1 Frequency Regulation Performance

Energy storage systems intended for use in frequency regulation shall have their performance determined in accordance with this section. Frequency regulation shall be permitted to represent area regulation as used by a balancing authority to meet North American Electric Reliability Corporation Balancing Authority Performance Control Standards.

4.3.2 System Ratings

The determination and reporting of ratings for an ESS to be applied for frequency regulation shall be in accordance with the provisions of this section using the duty cycle in Section 4.3.3 and metrics in Section 4.4.

4.3.3 Duty Cycle

The duty cycle to be applied in determining the performance of an ESS for a frequency regulation application is shown in Figure 4.2 as power normalized with respect to the rated power of the ESS over a 24-hour time period, where positive represents charge into the ESS and negative represents discharge from the ESS as a function of time in hours. The raw data upon which Figure 4.2 is based on the regulation duty cycle developed in Balducci et al (2013).

The ESS manufacturer shall be permitted to conduct additional testing using another duty cycle. Where this is done, the manufacturer shall provide a description of and rationale for the duty cycle chosen, shall conduct all tests required herein while subjecting the ESS to the additional duty cycle chosen, and shall report all performance measures as required in Section 5.0.

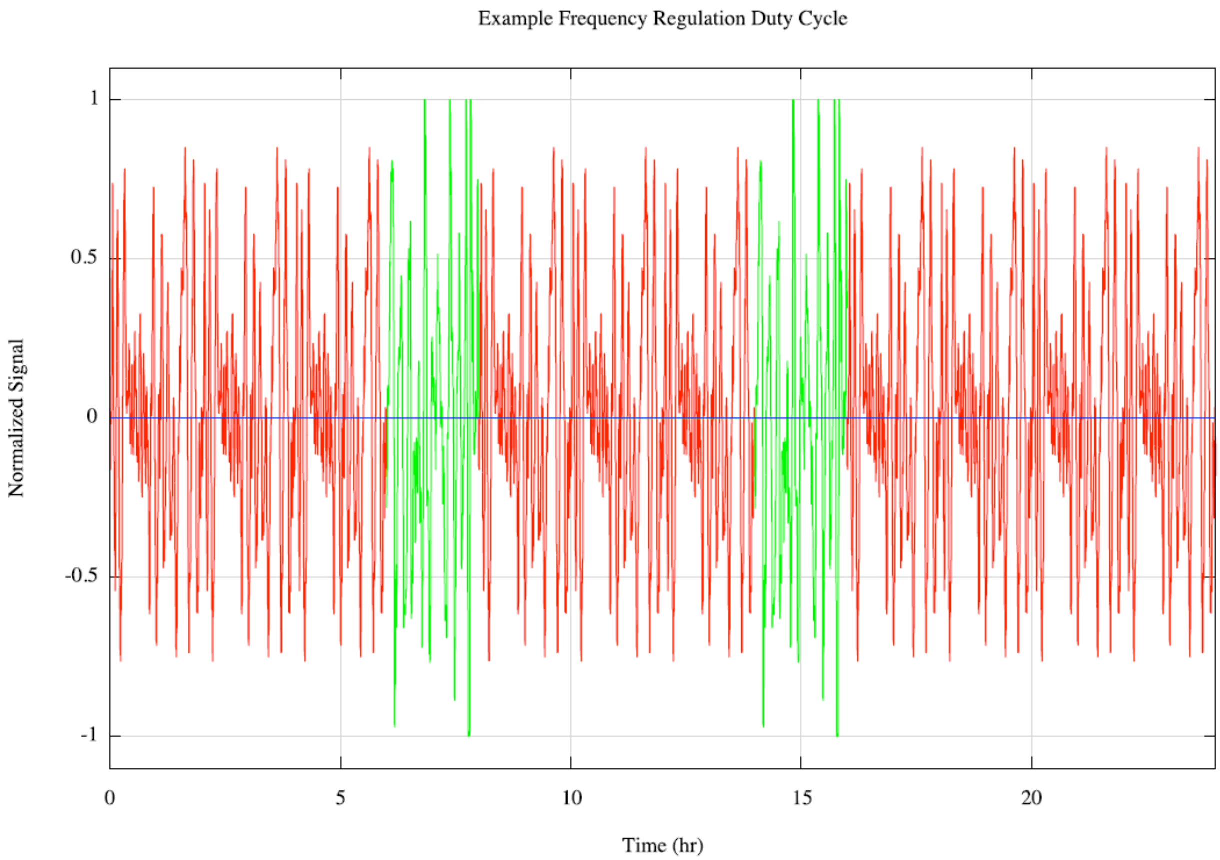


Figure 4.2. Frequency-Regulation Duty Cycle

In conducting the tests required in Section 4.3, the charge and discharge of the ESS shall be in accordance with the duty cycle described in this section.

1. The system shall be brought to the initial desired SOC of 65% as dictated by a given $V_{initial}$ by removing the necessary amount of charge at the rated power of the ESS as provided by the manufacturer's specifications. The ESS shall be held at that voltage (V) corresponding to the initial SOC for at least 10, but no more than 30, minutes. Alternatively, the system shall be permitted to be brought directly to the desired initial SOC by charging or discharging the ESS to the desired $V_{initial}$ at rated power and held at that V or T for at least 10 but no more than 30 minutes.

2. The ESS shall then be subjected to the duty cycle as described in this section and shown in Figure 4.2.

3. At the end of the duty cycle, the ESS shall be returned to the initial SOC as dictated by a given $V_{initial}$ by charging or discharging at rated power and holding at that voltage (V) for at least 10 but no more than 30 minutes.

4. At the end of this test, the ESS shall be brought to the required SOC to prepare for the next test using a procedure as recommended by the manufacturer's specifications and operating instructions. If capacity stability is the next test, the ESS shall be brought to the minimum SOC level at the rated power of the ESS as provided by the manufacturer's specifications.

4.4 Performance Metrics

The performance of the ESS shall be expressed in accordance with the provisions of Sections 4.4.1 through 4.4.4 based on the application of the duty-cycle regimen provided in Section 4.3.3.

4.4.1 Roundtrip Energy Efficiency

The RTE of the ESS shall be determined in accordance with the provisions in Section 3.1.1.3.

4.4.2 Duty-Cycle Roundtrip Efficiency

The duty-cycle RTE of the ESS shall be determined by dividing the energy removed (output) from the ESS by the energy required to recharge (input) the ESS.

4.4.3 Reference Signal Tracking

The ability of the ESS to respond to the signal for the 24-hour duty cycle described in Section 4.3.3 shall be defined and determined by the manufacturer of the ESS in accordance with the provisions in this section. The balancing signal shall be changed every 4 seconds during the duty cycle.

In addition, the manufacturer of the ESS shall also determine and report separately the total percentage tracking and the times when the ESS stops tracking and restarts tracking as an indication of whether the ESS is capable of tracking high peaks and/or high energy half cycles. The manufacturer shall also determine if the ESS can go through a 24-hour period without reaching the lower or upper SOC limits. Any time during that period when the ESS indicates an ability or inability to follow the signal, it shall be reported. An inability to follow the signal shall be considered a situation where the ESS cannot deliver or absorb required signal power during the 4-second duration and cannot deliver or absorb the required signal energy during the duration when the signal remains above or below the x-axis. The total time the ESS cannot follow the signal and percentage tracked shall be determined in accordance with the provisions in this section.

The ability of the ESS to respond to a reference signal shall be recorded during the RTE test. The root mean of the sum of the square of errors (RMSE) between the balancing signal (Psignal) and the power delivered or absorbed by the ESS (Pess) shall be calculated in accordance with Equation 4-1a and used to estimate the inability of the ESS to track the signal.

$$\text{RMSE} = \text{Sqrt}(\Sigma\ (\text{Psignal} - \text{Pess})2)/n \qquad (4\text{-}1a)$$

where Psignal is the balancing signal and Pess is ESS power (watts) and n is the number of data points

$$\text{Normalized RMSE} = \text{RMSE/average of absolute value of signals} \qquad (4\text{-}1b)$$

where average of absolute value of signals = $\Sigma\ |Xi|/n$

The measurements shall be taken at every point in time that the ESS receives a change in the balancing signal. The mean of the absolute magnitude of the difference between the balancing signal and ESS power shall be calculated in accordance with Equation 4-2.

$$(\Sigma|Psignal - Pess|)/n \quad (4\text{-}2)$$

where Psignal is the balancing signal and Pess is ESS power (watts).

The mean of the absolute magnitude of the difference between the balancing signal energy and ESS energy shall be calculated in accordance with Equation 4-3 and reported by the manufacturer of the ESS to account for the inability for the ESS to follow the signal due to the ESS reaching the SOC limits provided in the manufacturer's specifications and operating instructions.

$$(\Sigma|Esignal - Eess|)/n \quad (4\text{-}3)$$

where Esignal is the signal energy for a half-cycle, with half-cycle being the signal of the same sign (above or below the x-axis), and Eess is the energy supplied to or absorbed by the ESS for each half-cycle.

When |(Psignal-Pess)/Psignal| is less than 0.01or 0.1, the ESS shall be considered to track the signal. The percentage signal tracking shall be determined in accordance with Equation 4-4.

$$\text{\% of time signal is tracked} = [\text{Number of points that track the signal/Total number of points}] \times 100 \quad (4\text{-}4)$$

The above is repeated by ignoring signals that are < 10% of rated power.

As an additional metric, Psignal is replaced by rated power, and the criterion for signal following is set to be < 0.04.

All of these signal tracking metrics are reported with and without auxiliary power.

4.4.4 State-of-Charge Excursions

The SOC of the ESS during testing required under the protocol shall be monitored and continuously updated by integrating the current with respect to time for each half-cycle. For the purpose of this requirement, a half-cycle shall be considered the amount of time when the current or power is of the same sign. The integrated area shall be added to the SOC as the charge half-cycle is started or subtracted from the prior SOC as the discharge cycle is started. The SOC excursion shall be reported in accordance with the provisions in Section 5.6.

4.4.5 Additional Capacity Tests Recommended by Avista

The BESS will be brought to SOC_min using the specified discharge rate listed below and capacity tests as described in Section 3.1.1.1 will be conducted at the following discharge rates:

- 400 kW (SOC_min ~ 10% SOC, 9.75h discharge from 100% SOC, 11h charge)
- 800 kW (SOC_min ~ 35% SOC, 3.5h discharge, 9h charge)
- 800 kW, 600 kVAR (SOC_min ~ 35% SOC, 3.5h discharge, 9h charge)
- 418 kW, 309 kVAR (SOC_min ~ 10% SOC, 9.75h discharge,11h charge)

For tests involving reactive power, the real power will be used to bring the BESS to SOC_min at the start of the test. After 3 cycles, the BESS will be charged or discharged to the SOC_min for the next test.

4.4.6 Energy Capacity Stability

After the peak shaving and frequency regulation duty cycles, the stored energy capacity shall be repeated. After the use case testing, the stored energy capacity, response & ramp rate test, and internal resistance test shall be repeated.

The energy capacity stability of the ESS shall be determined by dividing the stored energy capacity by the initial stored energy capacity of the ESS. Stored energy capacity shall be determined in accordance with Section 3.1. The capacity stability of the ESS is reported in accordance with the provisions in Section 5.2.

4.5 Avista Use Case Tests

4.5.1 Use Case 1: Energy Shifting

4.5.1.1 Energy Arbitrage

The arbitrage duty cycle for Avista is developed using the forecast hourly energy prices obtained by Avista from Pattern Recognition Technologies, Inc. (PRT). Hourly prices are forecast for the next week and are updated hourly throughout the week. Forecast energy price data for the next day will be provided to PNNL by Avista through a secure site. This data will be used as an input into BSET. The optimization engine within BSET will then be used to define an hourly charge/discharge schedule for the battery over the next day maximizing "buy low sell high" transactions. BSET will be used to define the optimal charging and discharging schedule in order to either maximize value to the system or minimize losses. That is, even if the transaction results in financial losses, the test should be carried out for testing/learning reasons. The arbitrage duty cycle is shown in Figure 4.3. Actual duty cycle data is provided in Table A.1 in Appendix A.

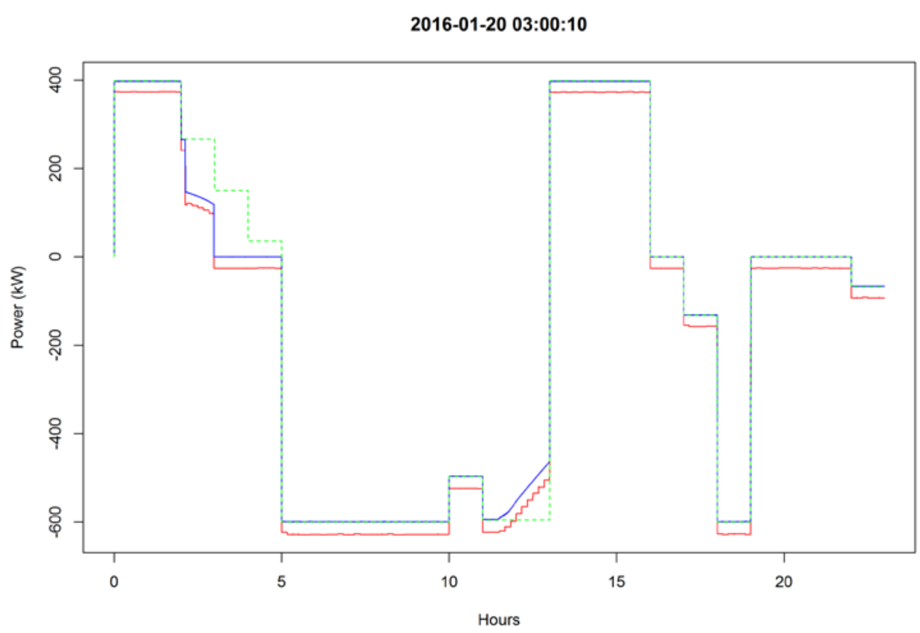


Figure 4.3. Energy Arbitrage Duty Cycle

4.5.1.2 System Capacity to Meet Adequacy Requirements

To determine the hours when the energy storage would be needed to provide capacity services, hourly system-wide load data will be obtained for 2011 through 2015. The capacity trigger will be set at the peak load point for each year. Capacity is required over a three-day period that includes the day prior to, and the day following, the annual peak load day. The capacity must be available during the 18 peak hours over the course of the three-day peak: three hours in the morning peak and three hours in the evening peak each day.

Based on the data provided by Avista, PNNL defines an hourly duty cycle that provided six hours of capacity each day, discharging during the peak loads for the day. A unique schedule was formed for three consecutive days according to Avista's capacity requirements. The capacity duty cycle is shown in Figure 4.4 and actual data of the three-day duty cycle is provided in Table A.2 of Appendix A.

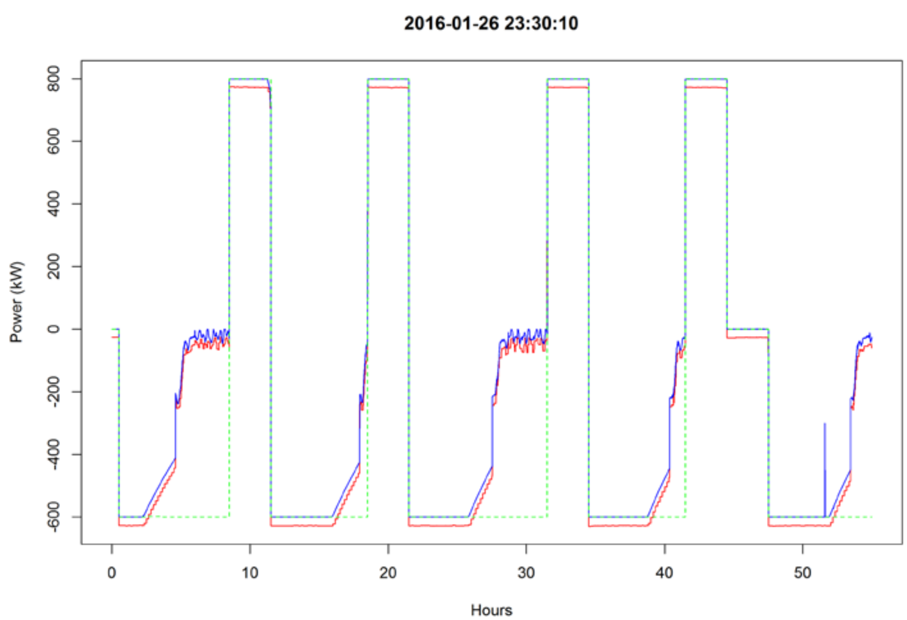


Figure 4.4. System Capacity Duty Cycle

4.5.2 Use Case 2: Provide Grid Flexibility

4.5.2.1 Regulation

The duty cycle for regulation testing is developed using an ACE signal internally calculated by Avista. This signal closely matches an industry standard frequency regulation signal. The formal frequency regulation signal calculated by Avista has limited variation as Avista uses contracted hydro and allowed frequency variation to minimize frequency regulation costs.

To use the ACE signal for frequency regulation, a scaling factor (defined as a Response Factor with a unit of kW/MW) must be defined to bring the multi-MW ACE signal down into the ESS's sub-MW operating range; this value is called the response factor and will be a negative value, indicating the output of the ESS will work against ACE to regulate it. The response factor must be defined in consideration of how long the ACE signal will stay at a given power level; the ESS can operate at power levels greater than steady-state for brief periods of time. The ESS output power is defined by the power limits and response factor and must be chosen carefully to maximize the amount of regulation the ESS is providing while minimizing the amount of time it is saturated at the chosen power limits. To define the response factor and accompanying power limits a year of historical ACE data is analyzed to determine the most appropriate combination of values.

The test will be conducted in two ways. First the ESS will be controlled using the duty cycle developed based on the approach described above. Only AC Battery1 (ACB1) is used with a response factor of -10 kW/MW. The duty cycle is shown in Figure 4.5. Three runs of this duty cycle will be performed using three different response factors. After that, a three-day test will be conducted by engaging an appropriate automatic mode for providing regulation service in the ESS control system. Only five minutes' data of the duty cycle is provided in Table A.3 in Appendix A.

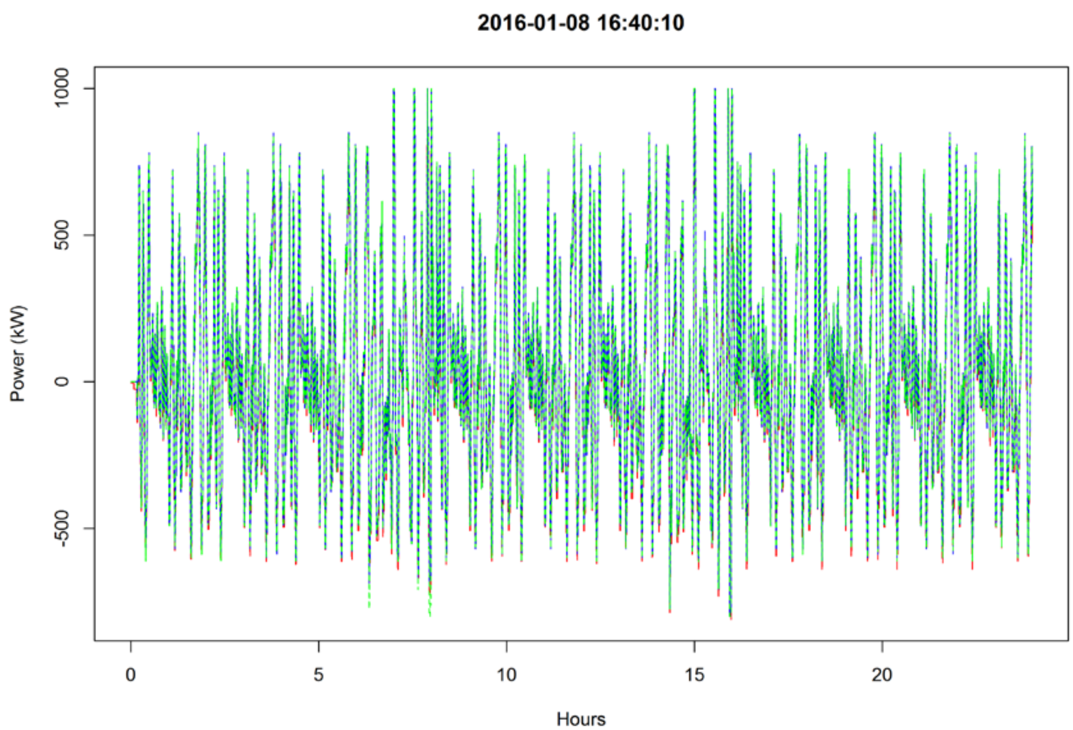


Figure 4.5. Regulation Duty Cycle

4.5.2.2 Load Following

Since load following is not a distinct service to Avista, the same testing protocol that was used for FR will be used here with one significant difference. As in the case of frequency regulation, the ACE signal will be used as the raw input signal and response factor will be defined that allows for the ESS to provide the greatest amount of balancing without operating in a saturated state (at the lower or upper power limit) for extended periods of time. The signal sent to the ESS, though, will be the average of the past five minutes of this scaled signal. This operation will smooth out the rapid changes in the ACE signal and show the trends in system imbalance on the multi-minute scale. The duty cycle is shown in Figure 4.6.

Similar to the regulation test, the load following test will be conducted using the duty cycle provided by PNNL and also engaging the corresponding automatic mode. Only AC Battery1 (ACB1) is used with a response factor of -10 kW/MW. Table A.4a in Appendix A provides the duty cycle data for the load following test for five minutes and Table A.4b provides the settings used Load Following test using auto mode.

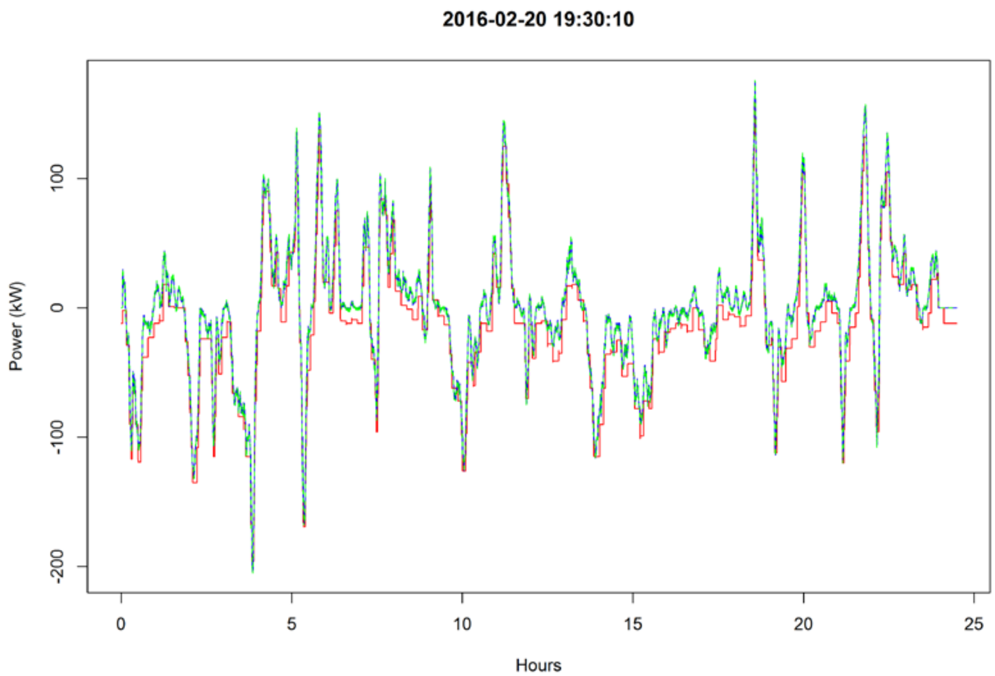


Figure 4.6. Load Following Duty Cycle

4.5.2.3 Real-World Flexibility

Avista has been contracted by a number of wind farms in the region for providing “firming capacity” to said farms during periods when wind energy production falls short of the forecasted value. During such times, Avista exports energy to the wind farm to supplement its production, allowing them to deliver on any energy obligations it may have. One of these farms in particular has also contracted with Avista to serve as a sink for the excess energy it produces. This need to both source and sink energy is an ideal scenario in which energy storage can provide benefit.

The signal received by Avista from the wind farm is presented as a unit-less value from -10 to +10 with negative values indicating Avista is being requested to import energy from the wind farm. To determine the duty cycle for the test, a scaling factor is used to match the ESS rated charge and discharge power. Because of the asymmetric power limits of the UET ESS, scaling factors for charge and discharge will be unequal. Analysis of 72 hours of data reveal multi-hour periods during which the ESS will be required to charge and discharge, indicating the steady-state power limits of -600 kW charge and 1,000 kW discharge should be used. The real world flexibility duty cycle is shown in Figure 4.6. Data is provided in Table A.5 in Appendix A. Only AC Battery1 (ACB1) was used.

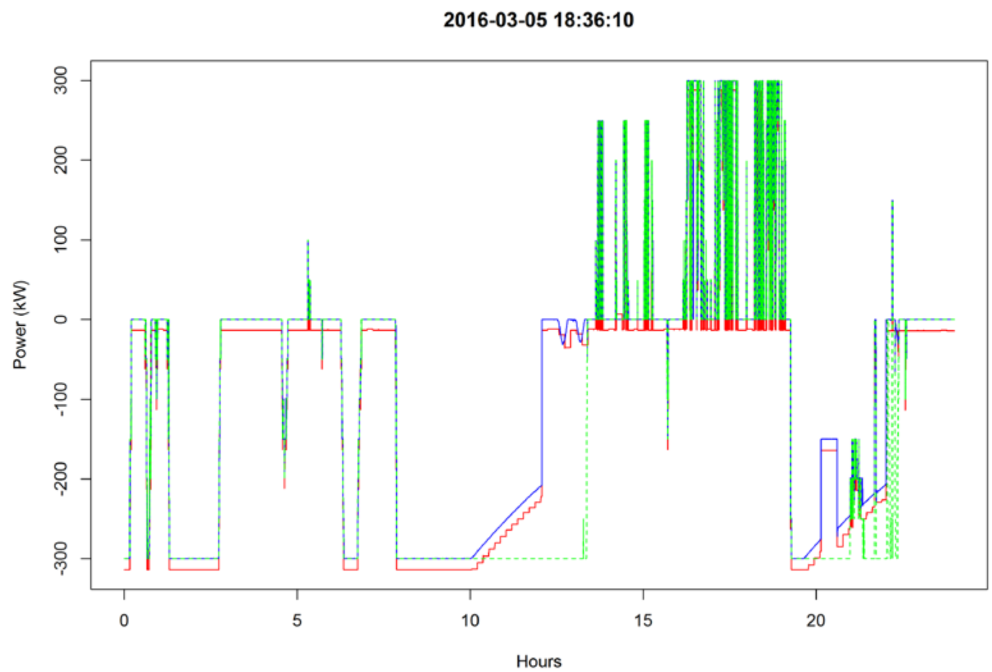


Figure 4.7. Real World Flexibility Duty Cycle

4.5.3 Use Case 3: Improving Distribution System Efficiency

4.5.3.1 Volt/VAR

This use case is tested by verifying the ability of the ESS inverters to provide VARs to achieve a certain objective. Achieving unity power factor at a certain location in the feeder is set as an objective in this case. Avista has instrumentation at their substation that measures the distribution feeder's total reactive power load in a real-time basis (every five seconds). To determine the reactive power output of the ESS to meet the target, the difference between the current reactive demand of the feeder and the current ESS reactive power output is calculated every ten seconds. This difference is added to the existing ESS output to define the total ESS reactive power output. A profile of VAR commands issued to ESS for achieving this objective is shown in Figure 4.7. Table A.6 in Appendix A provides the duty cycle information.. Only AC Battery1 (ACB1) was used for the test.

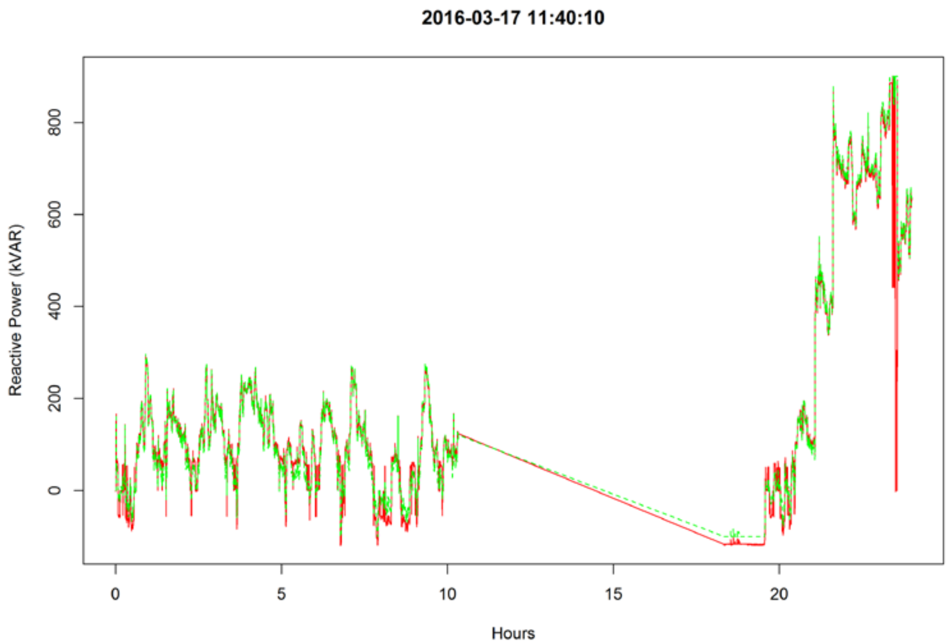


Figure 4.8. Volt/VAR Control Duty Cycle

4.5.3.2 Load Shaping

This use case could be tested in a number of ways (e.g., limiting load within a certain threshold or limiting rate of change of load with time). For Avista, this test is conducted by limiting fast variations of feeder load. Using historical 10 s or faster feeder load data from 2011-2015, a low-pass filter is designed by PNNL and implemented by Avista (with the algorithm provided by PNNL). This filter is able to remove the signal components that vary faster than those on a ten-minute time scale (that is, the cut-off frequency of the filter will be ten minutes). The current feeder load will be fed through this filter and the difference in the filtered feeder load will be used to define the current ramp rate of the feeder. The output of the ESS will be this ramp rate multiplied by a response factor to more thoroughly exercise the ESS. This use case assumes there are no solar PV ramp rates to mitigate and the load ramp rate on the feeder is minimal. A profile showing power commands issued to ESS for this test is shown in Figure 4.8 and duty cycle information is provided in Table A.7 in Appendix A. Only AC Battery1 (ACB1) used for the test.

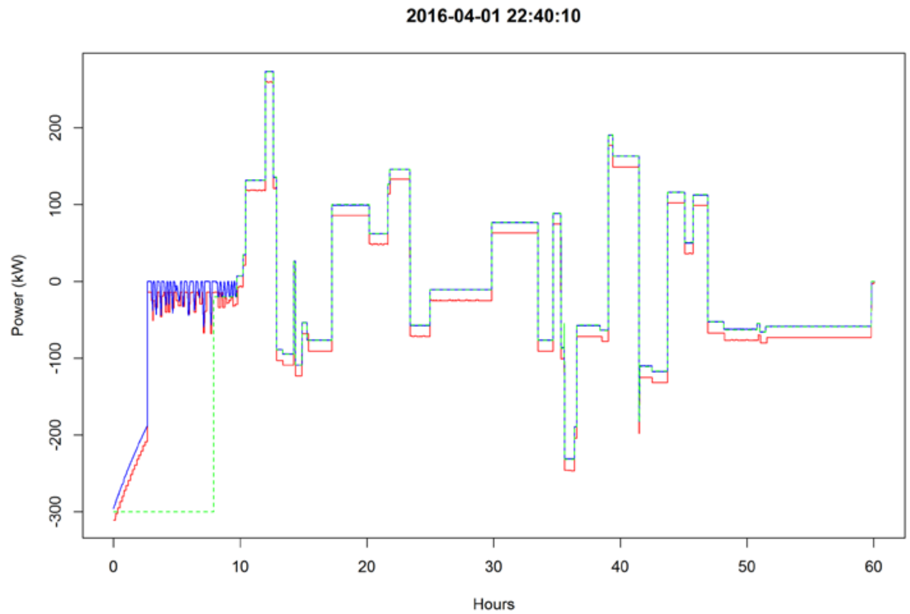


Figure 4.9. Load Shaping Duty Cycle

4.5.3.3 Deferment of Distribution Upgrade

The feeder in which the ESS is installed is currently not experiencing loads that are nearing the capacity of any equipment. To induce the ESS to behave as if this was the situation, an artificial demand limit will be defined, which the ESS will seek to enforce by reducing the total feeder load by discharging. Statistical analysis of recent feeder load data was used to estimate the expected peak load on the feeder during the testing period. Based on this value, the artificial load limit will be defined as a specified fraction (85%-95%). This will define when the ESS will discharge; charging will take place when the feeder load is beneath a certain fraction of the load (70%-80%) so as to ensure that the act of charging does not drive the feeder load back above the artificial load limit. Adjustment of these values may be necessary based on early test results. Because the periods of peak load on a feeder are relatively brief, it is not anticipated that the ESS will need dedicated recharging periods outside of those provisioned by the above algorithm. This test was conducted with and without VAR. A profile showing power commands issued to ESS for this test is shown in Figure 4.10 and duty cycle information is provided in Table A.8 in Appendix A.

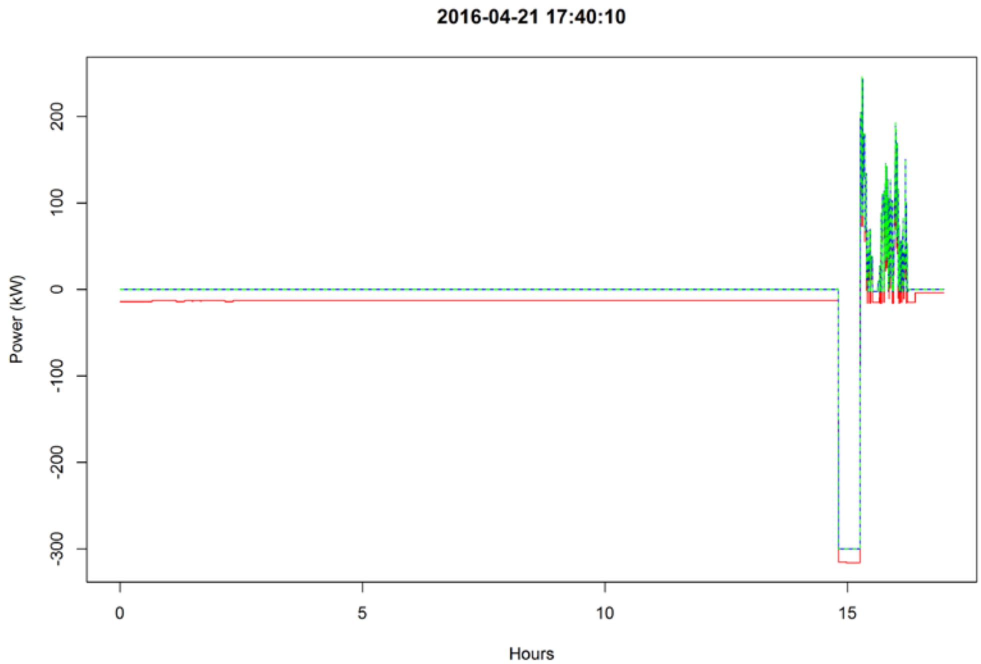


Figure 4.10. Feeder Load Limiting Duty Cycle for Deferment of Distribution Upgrade

4.5.4 Use Case 5: Enhanced Voltage Control

The Integrated Volt/VAR Controller (IVVC) in the feeder will be used to conduct this use case test by utilizing the ESS inverter VAR capability to source/sink VAR for implementing Conservation Voltage Reduction (CVR) as a form of enhanced voltage control. Optionally, the switching capacitors on the feeder will be disabled and only the ESS and voltage regulators will be used to regulate voltage on the feeder.

There are potentially multiple means by which the ESS inverter can provide value when used for CVR. Given the installation location of the ESS at the end of the distribution feeder, using the VAR output to improve the end-of-line voltage will help flatten the voltage profile and potentially allow the IVVC system to operate at a lower voltage, thereby increasing CVR benefits. Alternatively, it may be possible for the ESS to adequately flatten the voltage profile of the existing feeder(s) without the assistance of other IVVC assets (voltage regulators and switched capacitors). If this is the case, the value of the ESS is avoided capital costs for replacement of the existing devices when they reach end-of-life in addition to any value provided by the general CVR benefits described above. As a secondary test, the ESS will be placed in power-factor regulation mode (regulating the head of the feeder to unity power factor) and the IVVC system will be engaged with only voltage regulators online (physical switched capacitors still disconnected). This test will determine if IVVC is able to appropriately regulate the voltage of the feeder with the ESS acting in an independent manner. In both scenarios, smart meter data from the feeder will be used to determine if the IVVC is able to achieve lower target voltages on the feeder without triggering low-voltage alarms from the smart meters.

To most fully estimate the benefits of all of these use cases, testing will need to be conducted over a variety of system conditions, most especially different circuit loads. The ESS could be included and excluded from the IVVC on a periodic basis, with an interval defined by how long it takes the IVVC to re-equilibrate after such changes.

4.5.5 Use Case 6: Micro-grid Operations

Avista has developed its own test plan to verify the capabilities of the ESS to perform the operations needed during islanded microgrid operation. That test will, however, not fulfill all of the project needs associated with evaluating the battery's performance during islanding operations. Therefore, PNNL has produced a separate test plan and duty cycles for this use case following the approach of the DOE protocol, with relevant modifications to incorporate Avista ESS parameters (Conover et al 2014). The approach used for developing the duty cycles is briefly described below, followed by graphical representation of the actual duty cycles.

The key to developing the duty cycles was to determine the ESS output that would be able to serve microgrid load in conjunction with intermittent generation resources (e.g., solar PV and wind) while ensuring ESS operational limits (e.g., charging/discharging power, minimum and maximum SOC) are not violated. Three use cases were considered: (a) microgrid with a mix of renewables (solar and wind generation), (b) microgrid with renewables but no frequency regulation, and (c) microgrid with no renewables and no frequency regulation. All of the use cases include VAR support, power quality, frequency response, and black start.

To develop a generic duty cycle, the DOE microgrid test working group chose load, solar PV, and wind generation data from literature. The frequency regulation signal was obtained from the PJM market. The balancing signal is obtained as generation minus load. Frequency response consists of primary, secondary, and tertiary response. Primary frequency response involves charging or discharging the ESS for 30 seconds. Secondary response simply is a response to the frequency regulation signal. Tertiary frequency response corresponds to tertiary frequency control provided by generators that are on standby mode, and is therefore not relevant to the ESS.

For the purpose of determining the duty cycle for an ESS in an islanded mode, parameters are set in such a manner that peak charge and discharge power does not exceed ESS rated power, and the energy used does not exceed ESS rated energy. During the duty cycle, the ESS charges or discharges based on the difference between load and generation. Table 4.1 shows the energy content and maximum power used for the various cases.

Black start refers to the process of restoring electric power from a complete blackout, without relying on an external power source. In terms of the microgrid, a black start means the failure of all generating sources within the microgrid. If any renewable energy sources are part of the power system, those will not be able to come back on line until grid voltage and frequency are restored and stable. If black start is a desired capability, the following criteria need to be met: (a) capacity to operate expected maximum microgrid demand by itself for up to 60 seconds or automated load management to disconnect any noncritical loads and capacity to operate all critical loads by itself for up to 60 seconds; (b) capacity to provide electrical power to start offline generators; (c) capability to operate in isochronous speed control while other generation sources are offline; (d) capability to hand off isochronous speed control to any one generator that comes back on line and go to droop speed control; and (e) possible capability to keep operating in isochronous speed control with other generating sources in droop speed control. For this to work, the black start duty cycle must be set to discharge at rated power for 60 seconds once in 24 hours. Note that during black start, the ESS is not used for any other application, such as regulation, voltage/VAR support, or frequency response.

The duty cycles are shown in Figure 4.11 and the values are shown in Table A.9 in Appendix A. The top end plot in Figure 4.11 corresponds to a duty cycle in the presence of solar PV and wind generation whereas the middle plot contains duty cycle in the presence of PV, wind and frequency regulation services. The bottom plot represents a scenario where neither solar PV and wind nor frequency regulation is present.

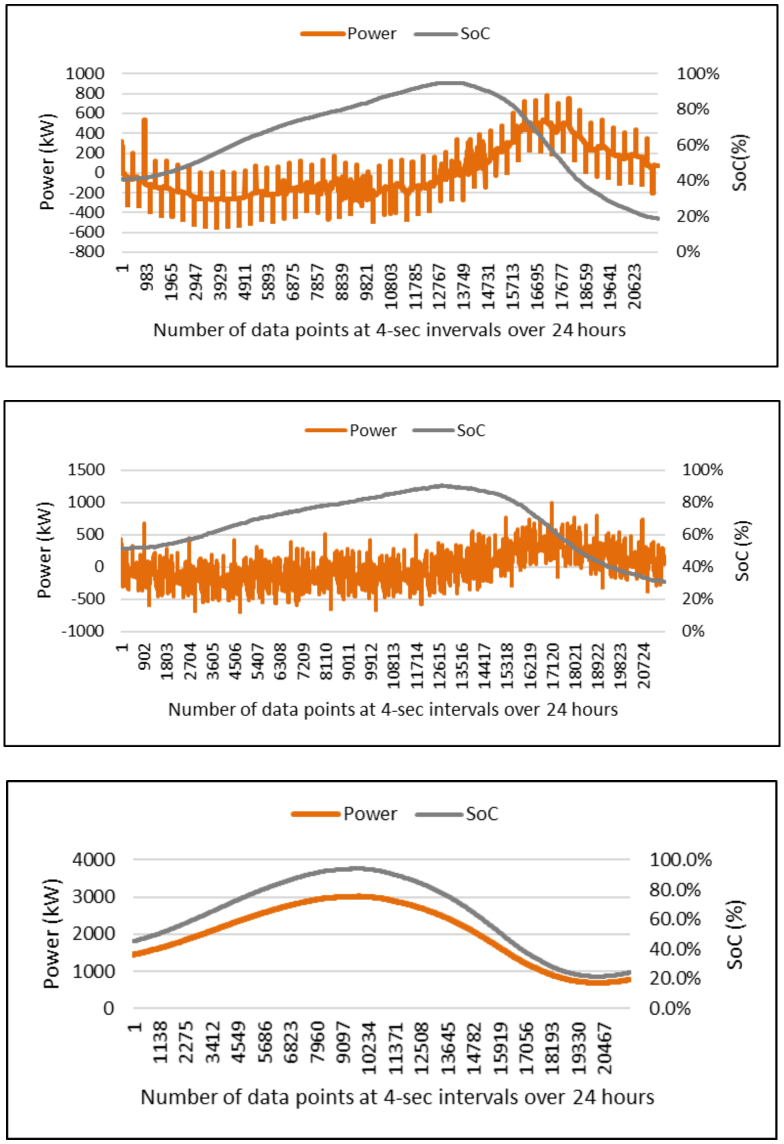


Figure 4.11. Duty Cycles for Islanded Microgrid Operation Test at Avista

Table 4.1. Power and Energy Requirements for Different Cases of Islanded Microgrid Operation

Service	Energy (kWh)	DOD (%)	Max Charge Power (kW)	Max Discharge Power (kW)
Renewables, no Frequency Regulation	3,200	76	-535	778
Renewables, and Frequency Regulation	3,200	60	-680	1000
No Renewables, and no Frequency Regulation	3,200	72.5	-480	554

4.5.6 Use Case 7: Optimal Utilization of Battery Storage

At the end of the use cases 1-6, the BESS will be deployed to optimize benefits by responding to all use cases addressed. The BSET model considers the battery system SOC, energy available at various power levels, and the benefits of each use case. It simulates battery operation for one year and the charging and discharging patterns reflect the demands placed on the battery system by the highest-value applications at any given point in time. BSET sets 24-hour operating schedules that are updated on an hourly basis. These optimized charging and discharging schedules will serve as the bases of the duty cycles used in Use Case 7.

5.0 Reporting Avista Performance Results

The performance of an ESS shall be reported in accordance with the provisions in Section 4.0 as determined in accordance with the applicable provisions of Section 3.0.

5.1 System Stored Energy Capacity and Roundtrip Efficiency

The stored energy capacity of the ESS determined in accordance with the provisions in Section 3.2 and the RTE determined in accordance with the provisions in Section 3.1.1.3 shall be reported as provided in Table 5.1. Where additional testing is performed beyond the minimum required two cycles, an additional row shall be added for each cycle and the total charge and discharge energy shall be the sum of all values reported and the RTE based on those totals.

5.2 Energy Capacity and Stability

The energy capacity stability of the ESS shall be reported as a percent of initial performance as determined in accordance with Section 4.4.5 and as shown in Table 5.1, along with the date of the test upon which the reported value is based and the ambient temperature and barometric pressure during the test. For the other power values, similar tables are generated.

Table 5.1. Stored Energy Capacity and Roundtrip Efficiency at Rated Power – Baseline PS and FR Duty Cycles

Date					
Ambient Temperature °C					
Barometric Pressure, psia					
	Charge Energy (Wh)	Discharge Energy (Wh)	Cycle Roundtrip Efficiency	Cumulative RTE	Capacity stability (% of initial energy capacity)
Cycle 1	______	______	______		______
Cycle 2	______	______	______		______
Cycle 3	______	______	______		______
Sum cycle 1-3				______	
Sum cycle 2-3				______	

5.3 Response Time and Ramp Rate

The response times in seconds and ramp rates in megawatts per minute of the ESS shall be reported as determined in accordance with the provisions in Section 3.2 as shown in Table 5.2. This test is performed as part of baseline or reference performance test, and after use case tests.

Table 5.2. Response Time and Ramp Rate

Date			
Ambient Temperature °C			
Barometric pressure, psia			
		Ramp rate	
Mode	Response time (T_2-T_1) (s)	MW/min	% rated power/min
Discharge			
Change with respect to baseline (Present – baseline)			
Charge			
Change with respect to baseline (Present – baseline)			

5.4 Internal Resistance Test

The internal resistance shall be reported in accordance with the provisions in Section 3.3 and as shown in Table 5.3. This test is done as part of baseline testing, and after use case tests.

Table 5.3. Internal Resistance of the ESS

Date:				
Ambient Temperature °C				
Barometric pressure, psia				
	Internal Resistance Charge		Internal Resistance Discharge	
SOC, %				
100	NA[1]	NA		
90				
80				
70				
60				
50				
40				
30				
20				
10				
0			NA	NA

[1] Not applicable.

5.5 Peak Shaving Duty-Cycle Results

The duty-cycle RTE shall be reported together with respect to discharge power and to the discharge duration based on the data collected in accordance with the provisions in Section 4.2.3. Table 5.4 shall be used to report the measured charge and discharge power and charge and discharge energy of the ESS, the percent of rated power during discharge and the ESS duty-cycle RTE. The information in Table 5.4 shall also be provided in a graphical form, with the x-axis being the percentage rated power during discharge and the y-axis being the duty cycle RTE.

Table 5.4. Peak Shaving Duty-Cycle Roundtrip Efficiency

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

5.6 Frequency-Regulation Applications

The performance of an ESS intended for a frequency regulation application shall be reported by the manufacturer in accordance with the provisions in Sections 5.6.1 and 5.6.2 as determined in accordance with the applicable provisions of Section 4.3.

5.6.1 Duty-Cycle Roundtrip Efficiency

The duty-cycle RTE shall be reported together with respect to peak discharge power divided by the energy of the ESS and to the discharge duration based on the data collected in accordance with the provisions in Section 4.4.2 (Table 5.5).

5.6.2 Reference Signal Tracking and SOC Excursion

The reference signal tracking of the ESS shall be reported in accordance with the provisions in Section 4.4.3. The SOC excursion shall be reported as determined in accordance with the provisions in Section 4.4.4. These results will be reported in Table 5.5.

Table 5.5. Frequency Regulation Metrics

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

5.7 Use Case Performance

Duty cycles for use case tests subject the ESS to a series of charge/discharge operations. Reporting of use case performance includes a summary of ESS operation during the period of a given test. For all of the use cases in general, information on test duration, minimum and maximum SoC, average charge/ discharge power, RTE, operating temperature, and charge/ discharge energy are reported. For tests that expose ESS to fast variations of real power (e.g. Regulation) or reactive power (Volt/VAR) in response to the duty cycle signal, performance reporting also includes metrics to understand how closely ESS followed the duty cycle (e.g. Root Mean Square Error, Absolute Error). To avoid the impact of auxiliary consumption on these metrics, performance will be reported with and without considering auxiliary power consumption.

Performance reporting tables for each of the use case tests conducted for this utility are provided in the following subsections.

5.7.1 Use Case 1: Energy Shifting

5.7.1.1 Energy Arbitrage

The results for Energy Arbitrage duty cycle as described in Section 4.5.1.1 and performance metrics as described in Section 4.4 are shown in Table 5.6.

Table 5.6. Energy Arbitrage Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

5.7.1.2 System Capacity to Meet Adequacy Requirements

The results for System Capacity duty cycle as described in Section 4.5.1.2 and performance metrics as described in Section 4.4 are shown in Table 5.7.

Table 5.7. System Capacity Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

5.7.2 Use Case 2: Provide Grid Flexibility

5.7.2.1 Regulation

The results for Regulation duty cycle as described in Section 4.5.2.1 and performance metrics as described in Section 4.4 are shown in Table 5.8.

Table 5.8. Regulation Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1%
Max Power, No Aux

5.7.2.2 Load Following

The results for Load Following duty cycle as described in Section 4.5.2.2 and performance metrics as described in Section 4.4 are shown in Table 5.9.

Table 5.9. Load Following Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1%
Max Power, No Aux

5.7.2.3 Real World Flexibility

The results for Real World Flexibility duty cycle as described in Section 4.5.2.3 and performance metrics as described in Section 4.4 are shown in Table 5.10.

Table 5.10. Real World Flexibility Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)

Date
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

5.7.3 Use Case 3: Improving Distribution System Efficiency

5.7.3.1 Volt/VAR

The results for Volt/VAR duty cycle as described in Section 4.5.3.1 and performance metrics as described in Section 4.4 are shown in Table 5.11.

Table 5.11. Volt/VAR Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Strings Active
Temp. °C
SOCMax
SOCMin
Maximum Reactive Power, kVAR
Reactive Power RMSE, kVAR.
Normalized Reactive Power RMSE, kVAR
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed, Reactive
% Time Signal Followed for > 10% Rated Power, Reactive
% Time Signal Followed with deviation < 1% Max Power, Reactive
Notes

5.7.3.2 Load Shaping

The results for Load Shaping duty cycle as described in Section 4.5.3.2 and performance metrics as described in Section 4.4 are shown in Table 5.12.

Table 5.12. Load Shaping Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1%
Max Power, No Aux

5.7.3.3 Deferment of Distribution Upgrade

The results for Deferment of Distribution Upgrade duty cycle as described in Section 4.5.3.3 and performance metrics as described in Section 4.4 are shown in Table 5.13.

Table 5.13. Load Shaping Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

5.7.4 Use Case 5: Enhanced Voltage Control

The results for Enhanced Voltage Control duty cycle as described in Section 4.5.3.3 and performance metrics as described in Section 4.4 are shown in Table 5.14.

Table 5.14. Enhanced Voltage Control Performance

Date	
Type of test (e.g. Improving End-of-Line Voltage with IVVC/ Flattening Voltage Profile without IVVC/ Power Factor Correction)	
Duration (h)	
RTE	
RTE, No Rest	
RTE, No Aux	
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Maximum Reactive Power, kVAR	
Reactive Power RMSE, kVAR.	
Normalized Reactive Power RMSE, kVAR	
% Time Signal Followed for > 10% Rated Power	
% Time Signal Followed for > 10% Rated Power, No Aux	
% Time Signal Followed, Reactive	
% Time Signal Followed for > 10% Rated Power, Reactive	
% Time Signal Followed with deviation < 1% Max Power, Reactive	
Notes	

5.7.5 Use Case 6: Micro-grid Operations

5.7.5.1 Black Start

Table 5.15. Black Start Performance

Date	
Outage Duration (h)	
RTE (based on bring BESS to initial SOC)	
RTE, No Aux	
Charge Power (kW)	
Discrete Discharge Power Levels / duration (kW / h)	kW1 / T1, kW2 / T2….
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Average Discharge Power (kW)	
Average Charge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

5.7.5.2 Grid-connected Micro-grid Operation

Table 5.16. Grid-connected Micro-grid Performance

Question	Answer
Was transition from Preferred to Alternate source successful?	
Transition time from Preferred to Alternate Source (sec)	
Was transition from Alternate to Preferred source successful?	
Transition time from Alternate to Preferred Source (sec)	

5.7.5.3 Islanded Micro-grid Operation

Table 5.17. Islanded Micro-grid Performance

Date
Duration (h)
RTE (based on bringing BESS to initial SOC)
RTE, No Aux
Charge Power (kW)
Discrete Discharge Power Levels / duration (kW / h)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Discharge Power (kW)
Average Charge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)
% time load is mer

6.0 SnoPUD Test Data Requirements and Expected Timeline

6.1 Data Requirements

The following data are requested from SnoPUD during testing.

Alternating Current (AC) Side:

- The control signal to the ESS, which would simply be a power signal – charge or discharge at certain power
- Actual power and energy delivered or absorbed by the ESS – both in and out of transformer and in and out of the PCS
- ESS SOC – this may be communicated to the PCS by the direct current battery management system (BMS) or be available from the DC BMS

DC Side:

- Power and energy – we could use efficiency information from the inverter manufacturer at various power levels as an alternative
- Voltage
- Current
- SOC

Optional Data, DC Side:

When the ESS powers the auxiliary loads, it is not necessary to have the auxiliary load data.

When the ESS does not power auxiliary loads, the electricity required to power auxiliary loads should be measured separately. Auxiliary power is a catch-all for multiple items: heating, ventilation and air conditioning (HVAC) for the battery container, lighting, communications, battery heating with heater blankets, or active cooling with circulating coolant. In either case, it would be useful to have auxiliary power data. For SnoPUD, the difference between meters 8WVH1 – 8WVH2 is discharge net output, and 8WVH1 + 8W/VH2 is charge net input to BESS. Hence, we will need auxiliary load data from 8W/VH2. Based on this, it appears during charge, grid powers auxiliary loads. Alternatively, during discharge, ESS powers auxiliary loads.

It would be useful to have data at the point of common coupling (PCC) in terms of power in and out of the transformer connecting the ESS to the grid. This allows calculation of system efficiency at the PCC. If this is not available, the transformer efficiency could be provided as a function of power in and out to allow determination of system efficiency inclusive of the transformer. Requested data are summarized in Table 6.1.

Table 6.1. Data Requested from SnoPUD

Test	Data Frequency	Critical Data	Optional
Stored Energy Capacity Test	Every 10 sec	Watt (W), watt-hour (Wh), current, volts (AC and DC), SOC, and DC battery temperature, auxiliary power consumption (if powered by a separate line), transformer power in and out	Auxiliary power (if ESS supplies it)
Response time and ramp test	Every second	Same as above	Same as above
Internal resistance test	Every second	Same as above	Same as above
Peak Shaving (PS) duty cycle	Every 10 sec	Same as above	Same as above
Frequency regulation (FR)	Every second	Same as above	Same as above
Capacity stability test	Every 10 sec	Same as above	Same as above

6.2 Baseline Testing

The ESS will be subjected to baseline tests to determine beginning-of-life reference performance. These tests will allow the research team to determine ESS degradation during operation by repeating these baseline performance tests. Tests developed by the DOE OE-sponsored working groups will be used with modifications as appropriate. The DOE-OE published document will be referred to as the protocol in this work.

Baseline testing consists of baseline performance or reference performance tests to determine the initial performance of the ESS. This reference performance test can be repeated at any time to assess the state of health of the ESS. Duty cycle testing will involve subjecting the ESS to PS and FR duty cycles to determine the performance of the ESS for these two extreme use cases. PS is an energy-intensive application, while FR involves exercising the ESS around a narrow SOC range using an energy neutral signal of 1-4s frequency, with the ability of the ESS to follow the signal being of great importance. It should be noted that while the FR duty cycle is energy neutral, the round trip efficiency of the ESS will result in a deviation of the ending SOC from the starting SOC.

The following general performance metrics were identified in the DOE-OE sponsored Protocol development effort:

- RTE
- Response time & ramp rate (this was considered to be an application-specific metric in the Protocol but has been moved up to general metrics)
- Energy capacity stability (this can be performed at any time during ESS operation)
- Internal resistance during charge and discharge
- Stability of internal resistance over time

The following application duty cycle-related performance metrics were identified, with the application that these metrics are relevant to within brackets:

- Duty cycle round trip efficiency (PS and FR)
- Reference signal tracking (FR)
- SOC excursion (FR)

The following baseline performance tests will be conducted:

- Capacity test
- Response time and ramp rate test, completed at 50% SOC
- Internal resistance test, performed at 20%, 30%, 40%, 50%, 60%, 70%, and 80% SOC

This will be followed by applying PS and FR duty cycles as described in the Protocol. At the end of these duty cycles, the capacity test will be repeated. This will be followed by use case testing (details to be determined). At the end of the use case test, the baseline performance tests (capacity, response time/ramp rate, internal resistance) will be repeated. Table 6.2 lists the tests, the start and end SOCs and the anticipated test duration.

The BESS specifications in terms of rated power, rated energy and the SOC range corresponding to rated energy shall be provided by the manufacturer.

Table 6.2. List of Tests and Duration

Test	Begin SOC	End SOC	Duration (Days)
Stored Energy Capacity Test	80%	20%	3
Response time & ramp test; internal resistance test	80%		2
PS duty cycle	80%	20%	3
FR	65%	35%	2
Capacity stability test	80%	20%	3
			13 days total for baseline
Use case 1			14
Use case 2*			21
Use case 3			14
Use case 7**			28
Capacity stability test	80%	20%	2
Response time and ramp test	80%	20%	2
Internal resistance test	80%	20%	2
Total days			75 (MESA 1) – 96 (MESA 2)

*MESA1 will not be subjected to use case 2 testing.
**Use case 7 will not be implemented until the end of the testing process for MESA 1 and will include both MESA 1a and 1b. Both MESA1 and MESA2 will take part in the combined use case test at the conclusion of the 2nd MESA 2 test cycle.

6.3 Comprehensive Data Recording

The ESS creates, captures and stores operational and non-operational data. These systems and the associated data characteristics are detailed in the Concept of Operations document.

All measurements of charge rate, input current and voltage, output current and voltage, thermal output, system temperatures, ambient conditions, and other parameters that must be measured shall be collected simultaneously at a temporal resolution applicable to the function of the ESS application and ESS metrics to which they are being applied, in accordance with recognized standards applicable to the measurements being taken. All parameters measured and recorded shall be used for determination and reporting of ESS performance.

6.4 Expected Timeline

Table 6.3 presents the ESS testing plan as originally designed. Field testing was originally expected to begin in February 2016. Tests were designed to span seven seasons (Summer 2016 – Winter 2017). Testing was expected to be completed by December 2017. The delay in the 2nd test cycles of MESA 1 reflects the dedication of the battery to a demand response program, thus taking it out of use for testing purposes.

Table 6.3. Project Test Plan Timeline

	2016							2017											
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	Nov	Dec
MESA 1																			
Testing Cycle 1																			
Testing Cycle 2																			
MESA 2																			
Testing Cycle 1																			
Testing Cycle 2																			

7.0 SnoPUD Test Protocols

This section outlines the tests that will be performed as part of the technical performance testing of this research program. PNNL will coordinate with SnoPUD in the implementation of the data acquisition for the evaluation. PNNL will summarize the performance evaluation for each of the control strategies defined in this section of the report. To acquire the needed data, the following tests will be conducted on the ESS:

1. Preliminary tests to determine rated power, energy content, RTE, and internal resistance.
2. Tests per PNNL/DOE protocol for PS and FR.
3. Tests for each use case.

A reference performance test, also known as baseline performance test, shall be conducted in accordance with this section, and the results shall be used to determine baseline ESS performance that can be subsequently used as a baseline to assess any changes in the condition of the ESS and rate of performance over time and use. This test shall be repeated at regular intervals as specified in this document during cycle testing for same-system comparison purposes. Such intervals shall be selected to identify how the testing or operation affects the performance of the ESS and shall be in units of time, number of cycles, or energy throughput.

7.1 Stored Energy Capacity Test

A stored energy capacity test shall be performed in accordance with this section and is intended to be used to determine the stored energy capacity at the rated electrical power for the intended application as specified by the manufacturer.

7.1.1 Test Overview

The ESS shall be discharged at the rated power of 1 MW to the lower SOC limit specified by the manufacturer, which will be labeled 20% SOC.

Energy storage system AC and DC power during charge and discharge shall be recorded every minute. The associated energy input and output of the ESS shall be calculated from the recorded power.

7.1.1.1 Stored Energy Capacity Test Routine

The ESS shall be tested for its stored energy capacity at selected power in accordance with the procedure listed below. The measurements shall be collected in accordance with all test steps identified later in this section. Any auxiliary power consumed that is not powered by the ESS shall also be monitored and recorded. Based on how SnoPUD defines its ESS boundary, the power in and out of the transformer shall also be recorded to get the RTE inclusive of the transformer. If this data is not available, the total system efficiency will be calculated by multiplying the ESS RTE with the transformer RTE, where ESS ends at the PCS (and not the transformer).

1. The ESS shall be discharged to its lower SOC limit (or minimum SOC) at the AC rated power of 1 MW (or in accordance with the system manufacturer’s specifications and operating instructions) and held at that SOC for 15 minutes. That lower SOC shall be measured and recorded as the manufacturer-specified Vmin corresponding to the discharging conditions.

2. The ESS shall be charged to its upper SOC limit (or maximum SOC) at the AC rated power of 1 MW (or in accordance with the system manufacturer's specifications and operating instructions) and held at that SOC for 15 minutes. That upper SOC shall be measured and recorded as Vmax (electrical storage) corresponding to charging conditions. The AC energy input WhCi, into the ESS during ESS charging, including all auxiliary power consumption, shall be measured directly during charging and recorded as the charge energy capacity of the ESS. Here C corresponds to charge, and i corresponds to cycle number.
3. The system shall be left at rest in an active state in accordance with the ESS manufacturer's operating instructions for 30 minutes.
4. The system shall be discharged at the rated power of 1 MW to the lower SOC limit specified by the manufacturer, at the discharge time prescribed by the duty cycle. That lower SOC shall be measured and recorded as Vmin (voltage). The AC energy output, WhDi, from the ESS during ESS discharging shall be calculated from the power measurements during discharge and recorded, where D corresponds to discharge.
5. The ESS shall be left at rest in an active standby state for the same period of time selected under Step 3 above (30 minutes).
6. Steps 2 through 5 above shall be repeated at least twice (total of three cycles). The reference performance test value shall be calculated as the mean of the values of WhCi and WDi as measured under Steps 2 and 4 above associated with each test and the standard deviation also shall be calculated and reported.
7. The ESS shall be recharged to 50% SOC and held at that SOC for 15 minutes. That 50% SOC shall be measured and recorded as the manufacturer-specified V50 corresponding to the discharging conditions. The energy input for this step will not be used for calculation of RTE.

Note: For the capacity test performed after the duty cycle testing, the ESS shall be recharged to the SOC required for use case 1.

7.1.1.2 Roundtrip Energy Efficiency Calculation

An RTE calculation shall be conducted to determine the amount of energy that an ESS can deliver relative to the amount of energy injected into the ESS during the preceding charge for a cycle. A cumulative RTE is also calculated for a set of cycles by determining the total discharge and charge energy for those cycles. This calculation, with minor changes, shall also be used for the applicable duty cycle for the intended application of the system.

7.1.1.3 Roundtrip Energy Efficiency from Stored Energy Capacity Test Routine

The RTE of the ESS is the efficiency for each cycle, cumulative efficiency for two and three cycles, and shall be determined in accordance with Equations 7-1 through 7-3 based on the data obtained from the tests conducted in accordance with the provisions in Section 7.1.1.1. Where constant power cannot be held during the test, the use of average power shall be considered acceptable and thus noted when reporting RTE in accordance with the provisions in Section 9.2.

$$Round\ trip\ efficiency\ for\ cycle\ i = \left(\frac{Wh_{D_i}}{Wh_{C_i}}\right) \tag{7-1}$$

$$Cumulative\ Round\ trip\ efficiency\ for\ all\ 3\ cycles = \left(\frac{\sum_1^3 Wh_{D_i}}{\sum_1^3 Wh_{C_i}}\right) \quad (7\text{-}2)$$

$$Cumulative\ Round\ trip\ efficiency\ for\ cycles\ 2\ and\ 3 = \left(\frac{\sum_2^3 Wh_{D_i}}{\sum_2^3 Wh_{C_i}}\right) \quad (7\text{-}3)$$

where 3 is the total number of cycles; Wh_{Di} is the BESS electrical energy discharge output (AC) in watt-hours for cycle number i; and Wh_{Ci} is the watt-hour charge input (AC) into the BESS, including all auxiliary power consumption for cycle number i. If the auxiliary power system is powered by the BESS, no adjustment to the above equations are needed. If the auxiliary load is powered by another line, the RTE will be calculated by subtracting the auxiliary load during discharge from the numerator and adding it to the denominator during charge.

7.2 Response Time and Ramp Rate Test

The ESS shall have a response time and ramp rate test performed in accordance with this section to determine the amount of time required for the ESS output to transition from no discharge to full discharge rate and from no charge to full charge rate. The ramp rate of the ESS shall be determined by dividing the ESS rated power by the response time in accordance with the provisions in this section. This test is done in conjunction with the internal resistance test. The starting SOC is the maximum allowable SOC – which is 80%. The end SOC is the minimum allowable SOC – which is 20%.

7.2.1 Test Overview

The method for measuring ramp rate shall be the same for all ESSs regardless of application. The manufacturer shall provide information about rated power as required by the provisions in Section 6.2.

The response time shall be measured in accordance with Figure 7.1 starting, when the signal (command) is received at the ESS boundary as established in Section 4.2 of the DOE protocol (Viswanathan et al 2014) and continuing until the ESS discharge power output (electrical or thermal) reaches 100 ± 2% of its rated power.

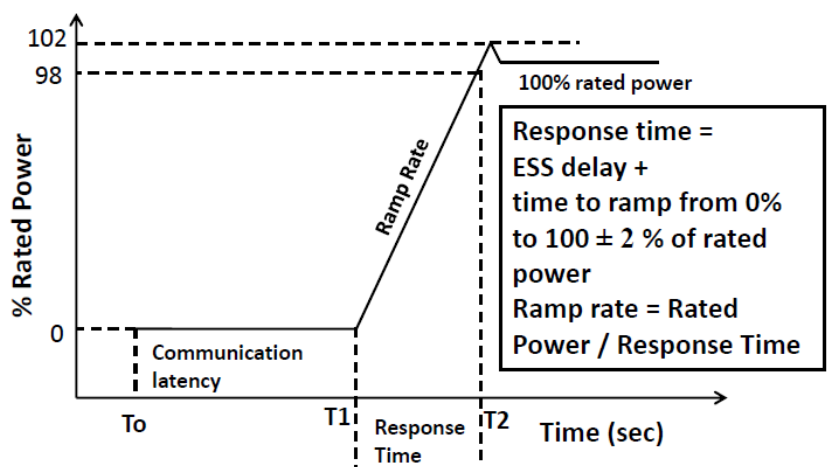


Figure 7.1. Response Time Test

7.2.2 Discharge Test Routine

The discharge response time test shall be conducted in accordance with the following procedure and the discharge response time calculated in accordance with Equation 7-4.

1. Take ESS to 80% SOC by charging at the rated power. Keep at rest for 30 minutes. Measure OCV at the end of the rest time. Go to step 6.
2. The DAS shall be configured to record a time stamp T_0 when a change in set point from rest to a discharge output command is sent to the ESS. Data is collected every second.
3. The DAS shall be configured to record a time stamp T_1 when the ESS starts responding to the discharge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the output of the ESS reaches 100 ±2% of its rated power capacity. The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the discharge ramp rate of the ESS, as determined in accordance with Equation 7-4a, and at least one intermediate data point shall be acquired as the ESS transitions from rest to full discharge.
5. The ESS shall be configured to respond to a step change in power output set point according to the ESS manufacturer's specifications.
6. The DAS shall be started and shall command to change the power output of the ESS to full rated discharge power output, and T_1 and T2 shall be measured and recorded. The ESS is maintained at rated power for 30 seconds. This is followed by 15 minutes rest.
7. The DAS shall be reset to a state to begin recording data and the ESS placed in a state of active standby.

$$RTD = T_2 - T_1 \qquad (7\text{-}4)$$

where RTD is the discharge response time in seconds; T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the ESS reaches 100 ±2 % of its rated power output.

The discharge ramp rate RR_D shall be calculated in accordance with Equation 7-4a and expressed in megawatts per minute.

$$RR_D = [P_{T2}]/[T_2 - T_1] \times 60 \qquad (7\text{-}4a)$$

where P_{T2} is the power output of the ESS recorded at time T_2(100 ±2% of rated power capacity); T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the ESS reaches 100 ±2% of its rated power output.

The discharge ramp rate shall also be expressed as percent rated power per minute (R_{R_pct},) in accordance with Equation 7-4b.

$$R_{Rpct} = RR_D / P_R \times 100 \qquad (7\text{-}4b)$$

where P_R is the rated power of the ESS.

The response time and ramp rate will be reported in accordance with the provisions in Section 5.0. After discharge ramp rate measured, the BESS is kept at rest for 15 minutes and a similar measurement is done for charge ramp rate as described in 7.2.3.

The internal resistance is measured as described below.

Procedure to determine current corresponding to rated power:

Figure 7.2 presents the pulse discharge profile for the ESS. Chart (a) shows the OCV before pulse and the full pulse. Chart (b) shows the first 50 ms of the discharge pulse.

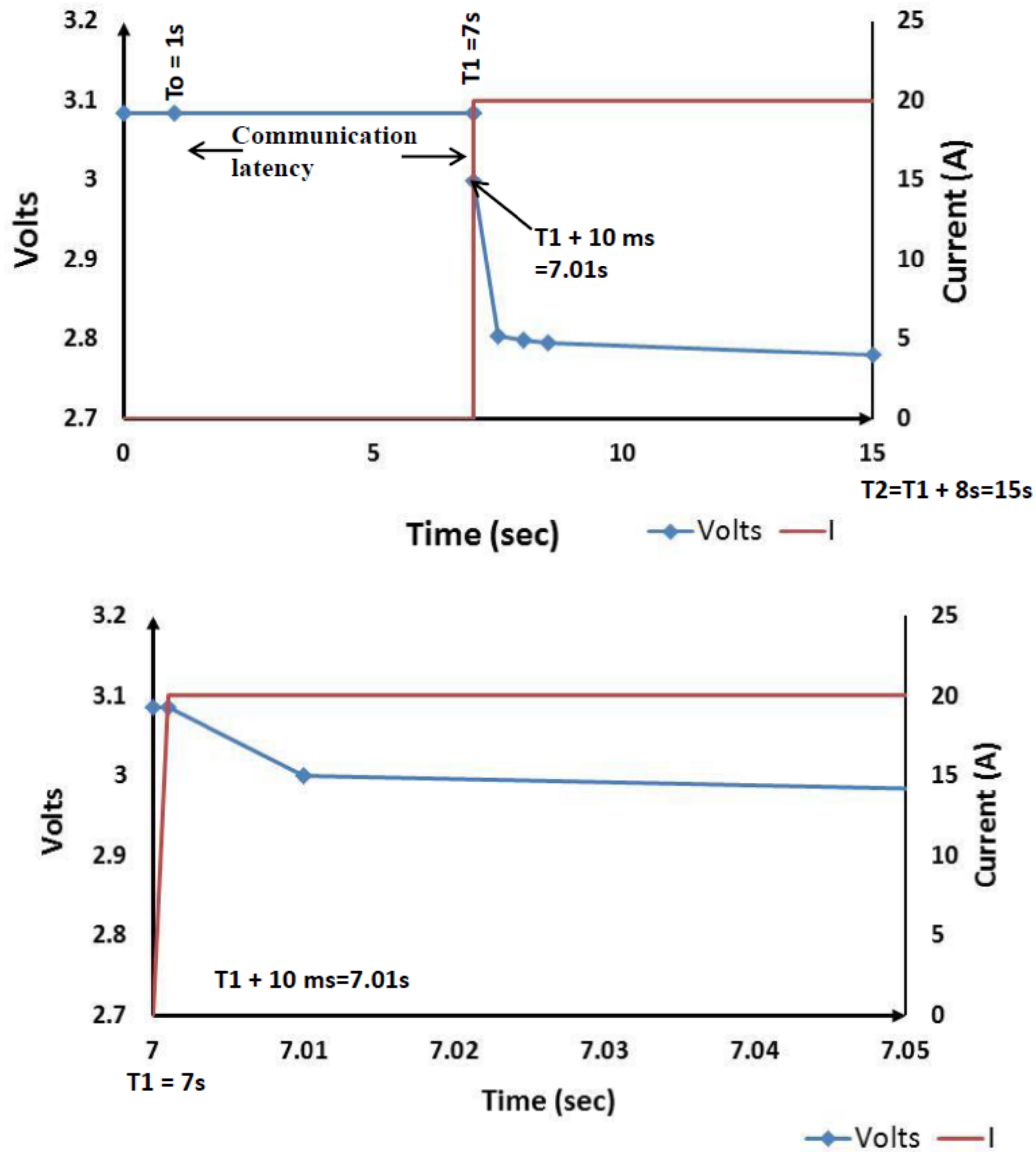


Figure 7.2. The Pulse Discharge Profile for ESS

The ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}charge} = \{V(T1+8\ sec)-V(T0)\}/Icharge \quad (7\text{-}5)$$

where T1+8s is T2

From the open circuit voltage data after charge, the ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}charge\ =} = \{V(T2+15\ minutes)-V(T2)\}/Icharge \qquad (7\text{-}6)$$

The DC efficiency and the PCS efficiency are calculated using Figure 7.3 as guide for power flow between the DC and AC side.

One-way DC charge efficiency, ηdc_{chg}, is given by the following equations:

$$\eta_{dc\_chg} = V_{(To)}/V_{(T1+8sec)}\ DC \qquad (7\text{-}7a)$$

$$\eta_{dc\_chg} = V(T2+15\ minutes)/V(T2) \qquad (7\text{-}7b)$$

Equation 7-8a gives the efficiency based on the voltage increase during charge, while equation 7-8b provides the efficiency based on voltage relaxation after charge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

One-way PCS efficiency during charge, η_{PCS_charge} is given by

$$\eta_{PCS\_charge} = DC\ power\ into\ battery/AC\ power\ in\ to\ PCS \qquad (7\text{-}8a)$$

where

$$DC\ power\ into\ battery\ from\ PCS = DC\ voltage\ x\ Icharge\ at\ 8\ sec \qquad (7\text{-}8b)$$

The one way ESS charge efficiency, η_{ESS_dis} is given by:

$$\eta_{ESS\_charge} = \eta_{dc\_charge}\ x\ \eta_{PCS\_charge} \qquad (7\text{-}9)$$

7.2.3 Charge Test Routine

The charge response time test shall be conducted in accordance with the following procedure and the charge response time calculated in accordance with Equation 3-10.

1. The ESS shall be at the 80% SOC and in an active standby state.
2. The DAS shall be configured to record a time stamp T_0 when a change in set point from rest to a charge output command is sent to the ESS. Data is collected every second.
3. The DAS shall be configured to record a time stamp T_1 when the ESS starts responding to the charge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the input to the system reaches 100 ±2% of its rated power capacity. The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the ramp rate of the ESS, as determined in accordance with Equation 3-11a, and at least one intermediate data point shall be acquired as the ESS transitions from rest to full charge.

5. The ESS shall be configured to respond to a step change in power input set point according to the ESS specifications provided by the manufacturer.
6. The DAS shall be started and shall command to change the power input to the ESS to full rated charge power input, and T_1 and T_2 shall be measured and recorded. The BESS is maintained at rated power for 30 seconds. This is followed by 15 minutes of rest.
7. The DAS shall be reset to a state to begin recording data and the ESS placed in a state of active standby.

$$RT_C = T_2 - T_1 \quad (7\text{-}10)$$

where RT_C is the charge response time in seconds; T_1 is the beginning time stamp, in seconds, when the ESS starts responding to the charge signal; and T_2 is the end time stamp, in seconds, when the input to the ESS reaches 100 ±2 % of its rated power output.

The charge ramp rate RR shall be calculated in accordance with Equation 7-6a and expressed in megawatts per minute.

$$RR_C = [P_{T2}]/[T_2 - T_1] \times 60 \quad (7\text{-}11a)$$

where P_{T2} is the power input to the ESS recorded at time T_2 (100 ±2% of rated power capacity).

The charge ramp rate shall also be expressed as percent rated power per minute (RRC_{pct}) in accordance with Equation 7-6b.

$$RRC_{pct} = RRC/ PR \times 100 \quad (7\text{-}11b)$$

where PR is the rated power of the ESS.

The ohmic and total resistances are calculated by the following equation:

$$R_{total\text{-}discharge} = \{ V(T0)\text{-}V(T1+8\ sec)\}/Idischarge \quad (7\text{-}12)$$

where T1+8s is T2

From the open circuit voltage data after charge, the ohmic and total resistance are calculated by the following equations:

$$R_{total\text{-}discharge} = \{ V(T2+15\ minutes)\text{-}V(T2)\}/Idischarge \quad (7\text{-}13)$$

One-way DC discharge efficiency, ηdc_dis_{chg}, is given by

$$\eta_{dc\_discharge} = V_{(T1+8\ sec)} / V_{To}\ DC \quad (7\text{-}14a)$$

$$\eta_{dc\_discharge} = V(T2)/V(T2+15\ minutes) \quad (7\text{-}14b)$$

Equation 7-15a gives the efficiency based on the voltage increase during charge, while equation 7-15b provides the efficiency based on voltage relaxation after charge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

One-way PCS efficiency during discharge, $\eta_{PCS\_discharge}$ is given by

$$\eta_{PCS\_discharge} = \text{AC power from PCS / DC power from battery to PCS} \quad (7\text{-}15a)$$

where

$$\text{DC power from battery to PCS} = \text{DC voltage X Idischarge at 8 sec.} \quad (7\text{-}15b)$$

The one way ESS discharge efficiency, η_{ESS_dis} is given by:

$$\eta_{ESS\_discharge} = \eta_{dc\_dischg} \text{ x } \eta_{PCS\_discharge} \quad (7\text{-}16)$$

The ESS RTE during the internal resistance measurement at each SOC is calculated as follows:[1]

η_{ESS_RTE} = one way ESS charge efficiency x one way ESS discharge efficiency

DC RTE = one way DC charge efficiency x one way DC discharge efficiency

PCS RTE = one way PCS efficiency during charge x one way PCS efficiency during discharge.

Figure 7.3 shows power flow in and out of the ESS (with PCS as the boundary).

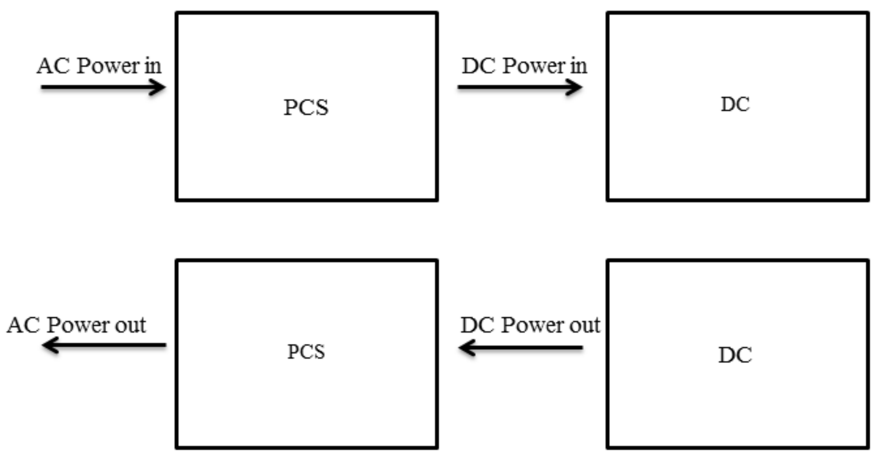


Figure 7.3. One-way DC System and PCS Efficiency during Charge and Discharge

If the BESS SOC is > or = to 30%, discharge the BESS at rated power to decrease its SOC by 10%. Then go to step 2 in Section 7.2.2. If the BESS SOC = 20%, go to step 2 in Section 7.2.2., go through the discharge and charge ramp rate/internal resistance steps, and then stop.

[1] This can be cross-checked vs. the measured RTE from the reference performance test. Note that for the latter, the charge and discharge power are the same, resulting in different currents.

8.0 SnoPUD Peak Shaving and Frequency Regulation Test

8.1 System Ratings

Ratings for ESSs covering rated power and energy available at rated power and the performance of the ESS associated with response time, ramp rate, and RTE at the beginning of life shall be based on a set of ambient operating conditions specified by the manufacturer of the ESS. The manufacturer shall also provide an indication of how the performance of the ESS is expected to change based on age and use of the system.

8.2 Peak Shaving (Management)

Energy storage systems intended for use in peak-shaving (management) applications shall have their performance determined in accordance with this section.

8.2.1 Classification

Energy storage systems intended for peak-shaving (management) applications shall be designated by their intended classification(s) as described in Sections 8.2.1.1 through 8.2.1.11.

8.2.1.1 Energy Time Shift (Arbitrage)

Energy time shift (arbitrage) shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is charged during low energy price periods and discharged during high energy price periods, where the ESS owner either pays wholesale market energy rates plus a delivery charge or pays time-of-day retail rates.

8.2.1.2 Electric Supply Capacity

Electric supply capacity shall be considered a use classification of an ESS in a peak-shaving (management) application where the storage capacity of the system is used to defer the installation of new electric generation capacity, such as, but not limited to, a relatively small storage system or series of systems where growth has created a need for generation that cannot be satisfied in the short term and the storage system would be expected to supply load over the full period when the additional, incremental capacity is needed.

8.2.1.3 Load Following

Load following shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is used to reduce ramp rate magnitudes so that conventional load-following generating units can better moderate cycling and be brought on at, or near, full load.

8.2.1.4 Transmission Congestion Relief

Transmission congestion relief shall be considered a use classification of an ESS in a peak-shaving (management) application that is a special case of the energy time shift use classification in Section 4.2.1.1, where electric transmission congestion leads to price differences across a transmission system at the same point in time. In this use classification, the storage system shall be located on the load side of the congested network, charged in low-price periods when the system is not congested and discharged during high-price time periods when prices have increased due to congestion.

8.2.1.5 Distribution System Upgrades Deferral

Distribution system upgrade deferral shall be considered a use classification of an ESS in a peak-shaving (management) application where the system responds to a situation where a piece of equipment on the distribution system, including power line conductors, experiences loadings that approach the distribution system equipment's rated capacity, thereby allowing the current distribution system equipment to remain online longer until other conditions necessitate that the distribution system equipment be upgraded.

8.2.1.6 Transmission System Upgrades Deferral

Transmission system upgrade deferral shall be considered a use classification of an ESS in a peak-shaving (management) application identical to the distribution upgrade deferral application covered in Section 4.2.1.5, except that it applies on higher voltages and higher power conditions found on the electric transmission system.

8.2.1.7 Retail Demand Charge Management

Retail demand charge management shall be considered a use classification of an ESS in a peak-shaving (management) application where the system is applied and used to minimize the demand charge from a utility over the course of each month.

8.2.1.8 Wind Energy Time Shift (Arbitrage)

Wind energy time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where electric power generated from a wind technology during low-price periods is stored and then delivered during high-price periods.

8.2.1.9 Photovoltaic Energy Time Shift (Arbitrage)

Photovoltaic energy time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where electric power generated from photovoltaic technology is stored and then delivered to the system when needed.

8.2.1.10 Renewable Capacity Firming

Renewable capacity firming shall be considered a use classification of an ESS in a peak-shaving (management) application that involves the coupling of intermittent renewable generation with a specific capacity and type of energy storage that allows for an increase in the ability of the renewable generation to participate in the capacity market.

8.2.1.11 Baseload Generation Time Shift

Baseload generation time shift shall be considered a use classification of an ESS in a peak-shaving (management) application where an ESS is configured to allow baseload units to operate at full capacity

during lighter nighttime loads, and deliver energy to the system in a way that minimizes or displaces higher-cost peaking generation.

8.2.2 System Ratings

The determination and reporting of ratings for ESSs applied in a peak-shaving (management) application shall be in accordance with IEEE Standard 1679 as expanded herein to provide more specific test procedures that apply to peak-shaving (management) applications. Such expansion shall include application of the duty cycle in Section 8.2.3 and taking measurements needed to determine the values for the metrics in Section 8.2.4 in determining and expressing the performance of ESSs for peak-shaving (management) applications.

8.2.3 Duty Cycle

The duty cycles presented in this section shall be used in the determination of the performance of systems intended for peak-shaving (management) applications and shall use charge and discharge time windows instead of normalized power levels or discharge rates to allow the duty-cycle profile to be applied the same to different technologies regardless of system size, type, age, and condition. The duty cycles applied in determining system performance shall be in accordance with Figure 8.1 and the provisions in Sections 8.2.3.1 through 8.2.3.4.

Each cycle must have a total charge time of 12 hours, a variable duration discharge window and two equal float windows that bring the total duration for each of the A, B, and C profiles to one 24-hour period. While Figure 8.1 displays these profiles for a 24-hour period with an evening peak, for the purposes of testing, any start and end time shall be permitted to be selected as long as that time period is for 24 continuous hours. When conducting performance tests using these profiles, the baseline point selected from which to start the test and representing the beginning of each duty cycle shall be the same point the system is returned to after the 24-hour duration of the test profile. This baseline point shall be at any SOC of the ESS.

8.2.3.1 Charge Window

During the charge window, the ESS shall be charged at constant power up to a 12-hour time period to bring the ESS to its upper SOC limit, after which the ESS shall be maintained at that SOC limit in accordance with the ESS manufacturer’s specifications and operating instructions.

8.2.3.2 Float Window

During the float window, the operation of any internal support loads for the ESS such as, but not limited to, heating, ventilation, and air-conditioning systems shall continue to operate as required in accordance with the ESS manufacturer’s specifications and operating instructions. During the float window the ESS shall not be maintained at the top of charge from an external source. Discharging of the ESS that does not serve a load external to the ESS shall be permitted during the float window.

8.2.3.3 Discharge Window

During the discharge window, the ESS shall be discharged until the minimum SOC level, as specified by the ESS manufacturer, is reached. The discharge of the ESS shall be at constant power as specified by the manufacturer of the ESS to bring the ESS to its minimum SOC level as specified by the manufacturer for a peak-shaving application.

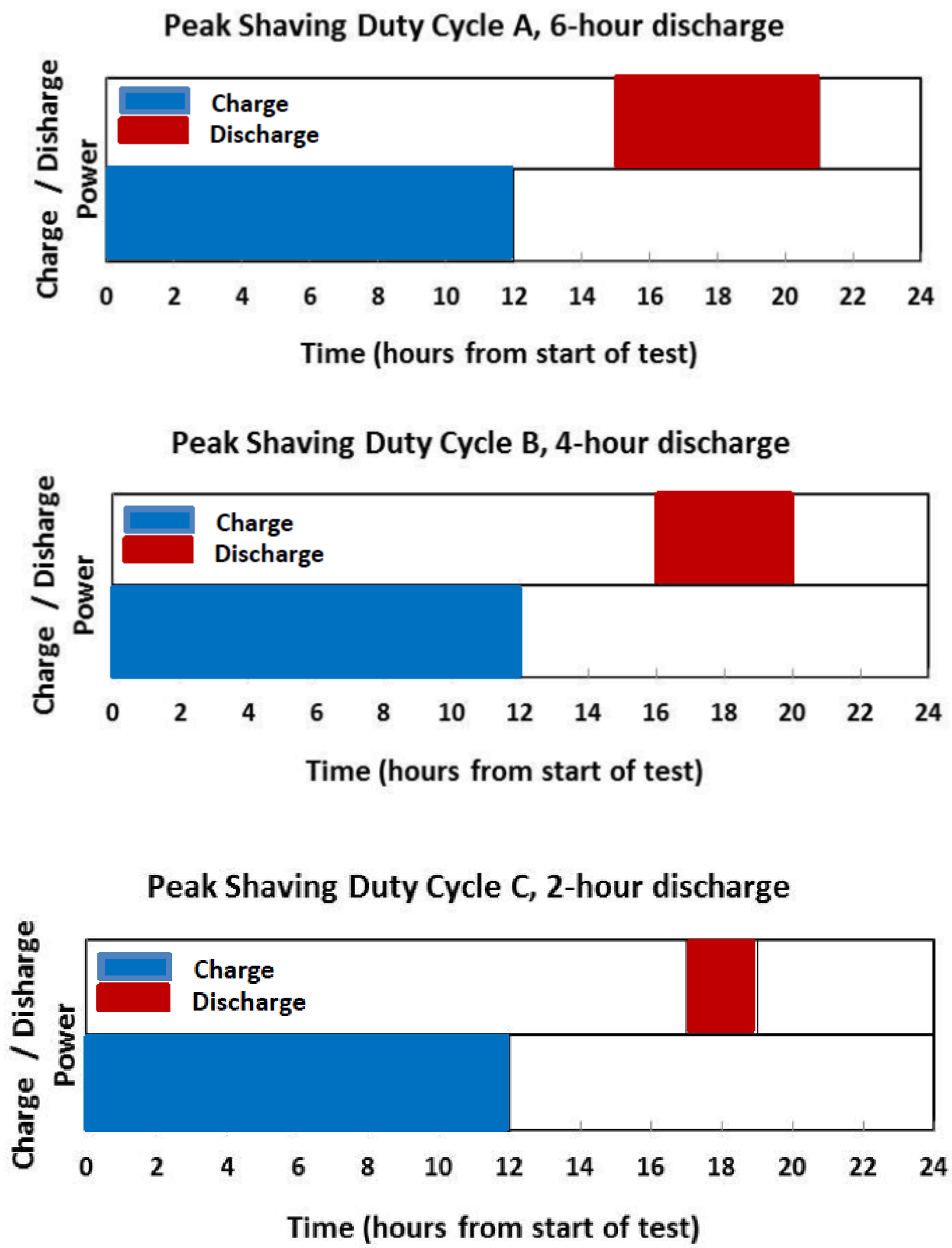


Figure 8.1. Peak-Shaving Duty Cycles

8.2.3.4 Application of the Duty Cycles

Performance testing shall consist of one application of duty-cycle A and bringing the ESS back to its initial SOC, followed immediately by one application of duty-cycle B and then followed immediately by one application of duty-cycle C as shown in Figure 8.1, with the ESS brought back to its initial SOC after each duty cycle. These duty cycles, sequenced as required above, shall be used to calculate the metrics covered in Section 8.2.4 that are to be used as a basis for determining and reporting the operational effectiveness of an ESS in peak-shaving applications.

8.2.4 Performance Metrics

The performance of the ESS shall be expressed in accordance with the provisions of Sections 8.2.4.1 based on the application of the duty cycle provided in Section 8.2.3.3.

8.2.4.1 Duty-Cycle Roundtrip Efficiency for Peak-Shaving

The duty-cycle RTE of the ESS as a function of discharge power shall be determined in accordance with the provisions in this section.

SnoPUD shall select an intended application and apply the duty cycle as provided in Section 8.2.3.3. In conducting the tests required in Section 8.2.3.3, the charge and discharge of the ESS shall be in accordance with this section using the duty cycle in Section 8.2.3.3.

1. The system shall be brought to the minimum SOC as dictated by a given $Vmin_l$, in accordance with duty-cycle A as provided in Section 8.2.3, by removing the necessary amount of charge at the rated power of the ESS as provided by the manufacturer’s specifications. The ESS shall be held at that voltage (V) corresponding to the initial SOC, for at least 10, but not more than 30, minutes. Alternatively, the system shall be permitted to be brought directly to the desired initial SOC by charging or discharging the ESS to the desired $V_{initial}$, $T_{initial}$, or $P_{initial}$ at rated power and held at that V, T, or P for at least 10 but not more than 30 minutes.
2. The ESS shall then be subjected to the duty cycle as described in Section 8.2.3. If the upper or lower voltage limit is reached during charge or discharge, the ESS is maintained at that voltage for the remaining duration.
3. At the end of the duty cycle, the ESS shall be returned to the initial SOC as dictated by a given $V_{initial}$, $T_{initial}$, or $P_{initial}$ by charging or discharging the ESS at rated power and holding at that voltage (V), temperature (T), or mass percentage of the relevant phase (P) for at least 10 but not more than 30 minutes.
4. Steps 1 through 3 shall be repeated for duty cycles B and then C as described in Section 8.2.3 using the same amount of time the ESS is held at initial SOC in applying duty-cycle A.
5. The duty-cycle roundtrip efficiency at each discharge power of each duty cycle shall be determined by dividing the energy removed (output) from the ESS at a given power by the energy required to recharge (input) the ESS.

The duty-cycle RTE as a function of discharge power shall be determined by dividing the energy removed from the ESS at a given power by the energy required to recharge the ESS as shown in Equation 7-1.

At the end of the test, the ESS shall be brought to the desired SOC using a procedure recommended by the manufacturer’s specifications and operating instructions. If frequency regulation is the next step, the ESS is brought to 60% SOC.

8.3 PNNL Frequency Regulation (Not required for MESA 1)

8.3.1 Frequency Regulation Performance

Energy storage systems intended for use in frequency regulation shall have their performance determined in accordance with this section. Frequency regulation shall be permitted to represent area regulation as used by a balancing authority to meet North American Electric Reliability Corporation Balancing Authority Performance Control Standards.

8.3.2 System Ratings

The determination and reporting of ratings for an ESS to be applied for frequency regulation shall be in accordance with the provisions of this section using the duty cycle in Section 8.3.3 and metrics in Section 8.4.

8.3.3 Duty Cycle

The duty cycle to be applied in determining the performance of an ESS for an FR application is shown in Figure 8.2 as power normalized with respect to the rated power of the ESS over a 24-hour time period, where positive represents charge into the ESS and negative represents discharge from the ESS as a function of time in hours. The raw data upon which Figure 8.2 is based on the regulation duty cycle developed in Balducci et al. (2013).

The ESS manufacturer shall be permitted to conduct additional testing using another duty cycle. Where this is done, the manufacturer shall provide a description of and rationale for the duty cycle chosen, shall conduct all tests required herein while subjecting the ESS to the additional duty cycle chosen and shall report all performance measures as required in Section 5.0 under the designation “alternative duty-cycle.”

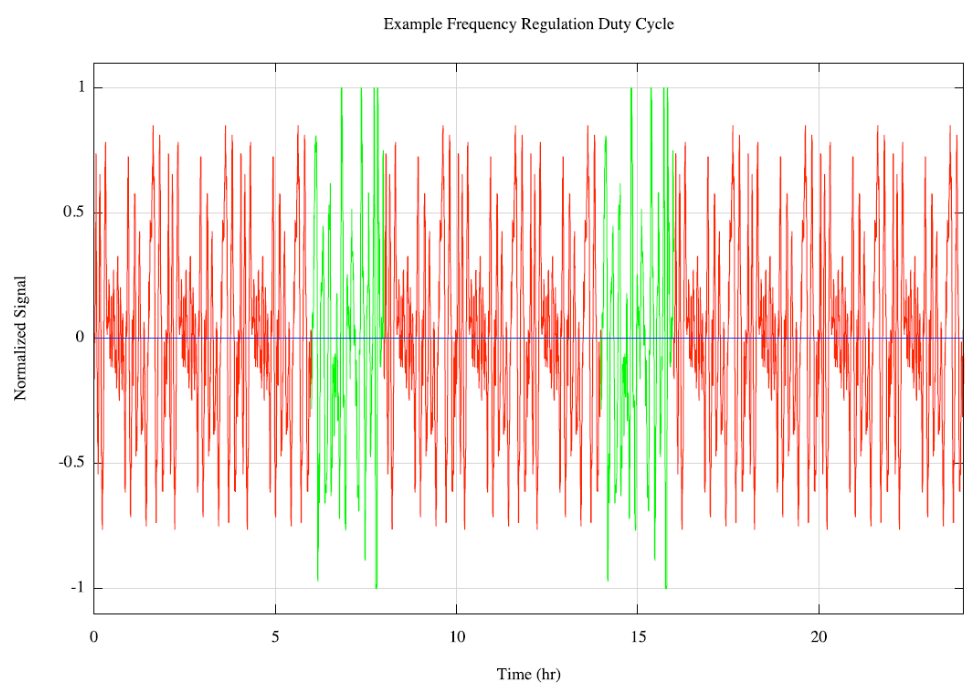


Figure 8.2. Frequency-Regulation Duty Cycle

In conducting the tests required in Section 8.3, the charge and discharge of the ESS shall be in accordance with the duty cycle described in this section.

1. The system shall be brought to the initial desired SOC of 60% as dictated by a given $V_{initial}$ by adding or removing the necessary amount of charge at the rated power of the ESS as provided by the manufacturer's specifications. The ESS shall be held at that voltage (V) corresponding to the initial SOC for at least 10 but no more than 30 minutes. Alternatively, the system shall be permitted to be brought directly to the desired initial SOC by charging or discharging the ESS to the desired $V_{initial}$ at rated power and held at that V or T for at least 10 but no more than 30 minutes.
2. The ESS shall then be subjected to the duty cycle as described in this section and shown in Figure 8.2.
3. At the end of the duty cycle, the ESS shall be returned to the initial SOC as dictated by a given $V_{initial}$ by charging or discharging at rated power and holding at that voltage (V) for at least 10 but no more than 30 minutes.
4. At the end of this test, the ESS shall be brought to the required SOC to prepare for the next test using a procedure as recommended by the manufacturer's specifications and operating instructions. If capacity stability is the next test, the ESS shall be brought to the minimum SOC level at the rated power of the ESS as provided by the manufacturer's specifications.

8.4 Performance Metrics

The performance of the ESS shall be expressed in accordance with the provisions of Sections 8.4.1 through 8.4.4 based on the application of the duty-cycle regimen provided in Section 8.3.3.

8.4.1 Roundtrip Energy Efficiency

The RTE of the ESS shall be determined in accordance with the provisions in Section 7.1.1.3.

8.4.2 Duty-Cycle Roundtrip Efficiency

The duty-cycle RTE of the ESS shall be determined by dividing the energy removed (output) from the ESS by the energy required to recharge (input) the ESS.

8.4.3 Reference Signal Tracking

The ability of the ESS to respond to a signal for the 24-hour duty-cycle described in Section 8.3.3 shall be defined and determined by the manufacturer of the ESS in accordance with the provisions in this section. The balancing signal shall be changed every four seconds during the duty cycle.

In addition, the manufacturer of the ESS shall also determine and report separately the total percentage tracking and the times when the ESS stops tracking and restarts tracking as an indication of whether the ESS is capable of tracking high peaks and/or high energy half cycles. The manufacturer shall also determine if the ESS can go through a 24-hour period without reaching the lower or upper SOC limits. Any time during that period when the ESS indicates an ability or inability to follow the signal, it shall be reported. An inability to follow the signal shall be considered a situation where the ESS cannot deliver or absorb required signal power during the four-second duration and cannot deliver or absorb the required signal energy during the duration when the signal remains above or below the x-axis. The total time the

ESS cannot follow the signal and percentage tracked shall be determined in accordance with the provisions in this section.

The ability of the ESS to respond to a reference signal shall be recorded during the RTE test. The sum of the square of errors between the balancing signal (Psignal) and the power delivered or absorbed by the ESS (Pess) shall be calculated in accordance with Equation 8-1 and used to estimate the inability of the ESS to track the signal.

$$\Sigma\,(\text{Psignal} - \text{Pess})^2 \tag{8-1}$$

where Psignal is the balancing signal and Pess is ESS power (watts).

The measurements shall be taken at every point in time that the ESS receives a change in the balancing signal. The sum of the absolute magnitude of the difference between the balancing signal and ESS power shall be calculated in accordance with Equation 8-2.

$$\Sigma|\text{Psignal} - \text{Pess}| \tag{8-2}$$

where Psignal is the balancing signal and Pess is ESS power (watts).

The sum of the absolute magnitude of the difference between the balancing signal energy and ESS energy shall be calculated in accordance with Equation 8-3 and reported by the manufacturer of the ESS to account for the inability for the ESS to follow the signal due to the ESS reaching the SOC limits provided in the manufacturer's specifications and operating instructions.

$$\Sigma|\text{Esignal} - \text{Eess}| \tag{8-3}$$

where Esignal is the signal energy for a half-cycle, with half-cycle being the signal of the same sign (above or below the x-axis), and Eess is the energy supplied to or absorbed by the ESS for each half-cycle.

When |(Psignal-Pess)/Psignal| is less than 0.02, the ESS shall be considered to track the signal. The total time the ESS cannot follow the signal and percentage tracked where (Psignal – Pess)/Psignal is less than 0.02 shall be determined in accordance with Equation 8-4.

$$\%\text{ of time signal is tracked} = [\text{Time signal is tracked (h)}/24\text{ h}] \times 100 \tag{8-4}$$

8.4.4 State-of-Charge Excursions

The SOC of the ESS during testing required under the protocol shall be monitored and continuously updated by integrating the current with respect to time for each half-cycle. For the purpose of this requirement, a half-cycle shall be considered the amount of time when the current or power is of the same sign. The integrated area shall be added to the SOC as the charge half-cycle is started or subtracted from the prior SOC as the discharge cycle is started. The state-of-charge excursion shall be reported in accordance with the provisions in Section 9.6.

8.4.5 Energy Capacity Stability

After the peak shaving and frequency regulation duty cycles, the stored energy capacity test shall be repeated. After the use case testing, the stored energy capacity, response & ramp rate test and internal resistance test shall be repeated.

The energy capacity stability of the ESS shall be determined by dividing the stored energy capacity by the initial stored energy capacity of the ESS. Stored energy capacity shall be determined in accordance with Section 7.1. The capacity stability of the ESS is reported in accordance with the provisions in Section 9.2.

8.5 SnoPUD Use Case Tests

In the previous sections, test protocols for various baseline test cases were described using duty cycles developed in Bray et al. (2012). This section outlines a number of duty cycles that are more relevant to the MESA1 and MESA2 energy storage systems located in Everett, Washington. These duty cycles are derived from utility-specific data collected from SnoPUD and represent the optimal input and output of power for each use case as modeled in BSET.

8.5.1 Use Case 1: Energy Shifting

This use case will test the ESS' ability to provide effective energy arbitrage to capture economic opportunities present due to peak and off-peak wholesale energy prices. Further, it will test the ESS' ability to provide system-wide peak shaving as needed in order to meet capacity or resource adequacy needs. The remainder of this section defines the duty cycles modeled for each use case.

8.5.1.1 Energy Arbitrage

Energy arbitrage was modeled in BSET for a one-week period using historic mid-Columbia (Mid-C) wholesale energy price data purchased from Powerdex for the 2011-2016 time period. In running the duty cycle, the following procedures should be performed:

1. ESS shall first be brought to an SOC of 10%
2. The ESS is then subjected to the duty cycle outlined in Appendix A. The day of the week in which the test begins should correspond to the same day of the week identified in the duty cycle.

One week of the duty cycled generated by BSET for MESA1 is presented in Figure 8.3. The arbitrage duty cycle for MESA2 will be provided separately. The dashed line represents the modeled SOC of the battery system over the use case test. The modeled case assumes an average RTE of 84.6%.

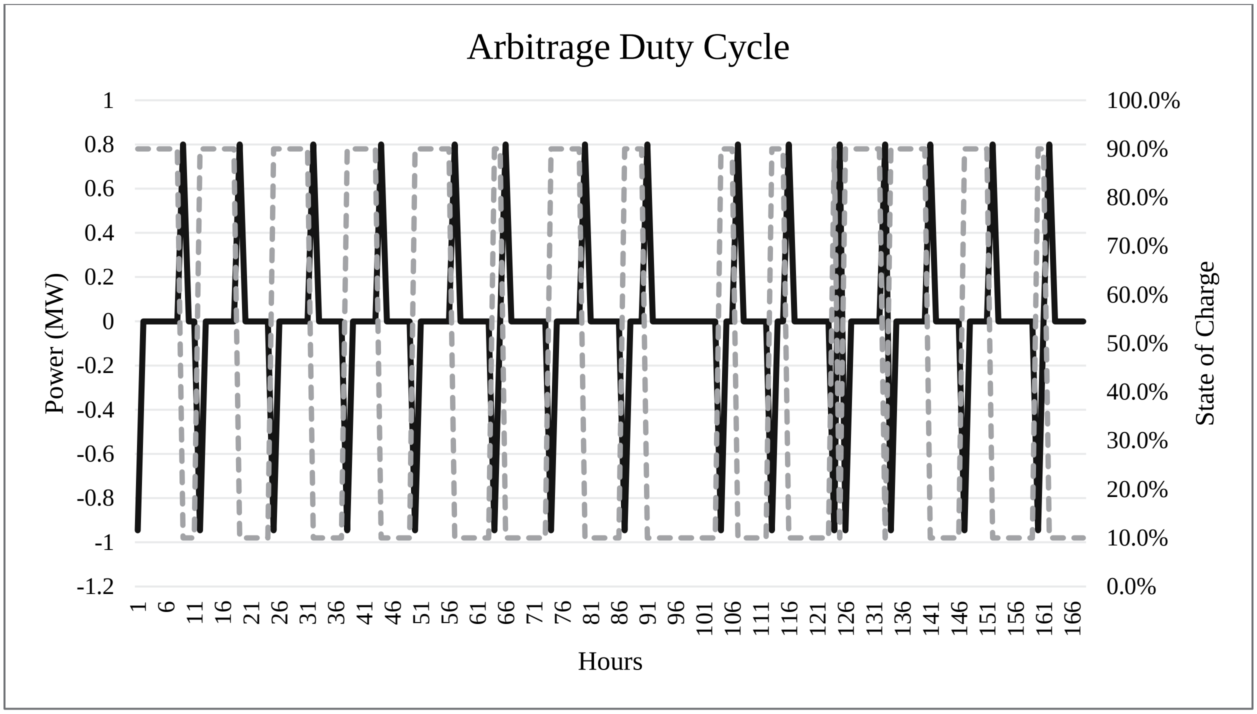


Figure 8.3. Arbitrage Duty Cycle over One-Week Period

8.5.1.2 System Capacity to Meet Adequacy Requirements

System capacity or resource adequacy results from peak shaving services tied to system-wide peak load conditions. To determine the hours when energy storage would be needed to provide capacity services, hourly system-wide load data was obtained for 2015. Capacity triggers are defined differently for each utility. For SnoPUD, the capacity duty cycle assumed a 4-hour peak shaving requirement, which is a standard industry requirement and was confirmed as reasonable by SnoPUD staff. The capacity duty cycle is developed as a seven-day schedule of charging/discharging cycles with discharge periods from 1-4 hours.

In running the duty cycle, the following procedures should be performed:

1. ESS shall first be brought to an SOC of 90%.
2. The ESS is then subjected to the duty cycle outlined in Appendix A. The day of the week in which the test begins should correspond to the same day of the week identified in the duty cycle. SnoPUD is required to provide demand response during the weekdays and therefore only available for testing during weekends. Therefore, only the weekend days of the developed duty cycles are used for testing.

The duty cycle is presented in Figure 8.4. The dashed line represents the modeled SOC of the battery system over the use case test.

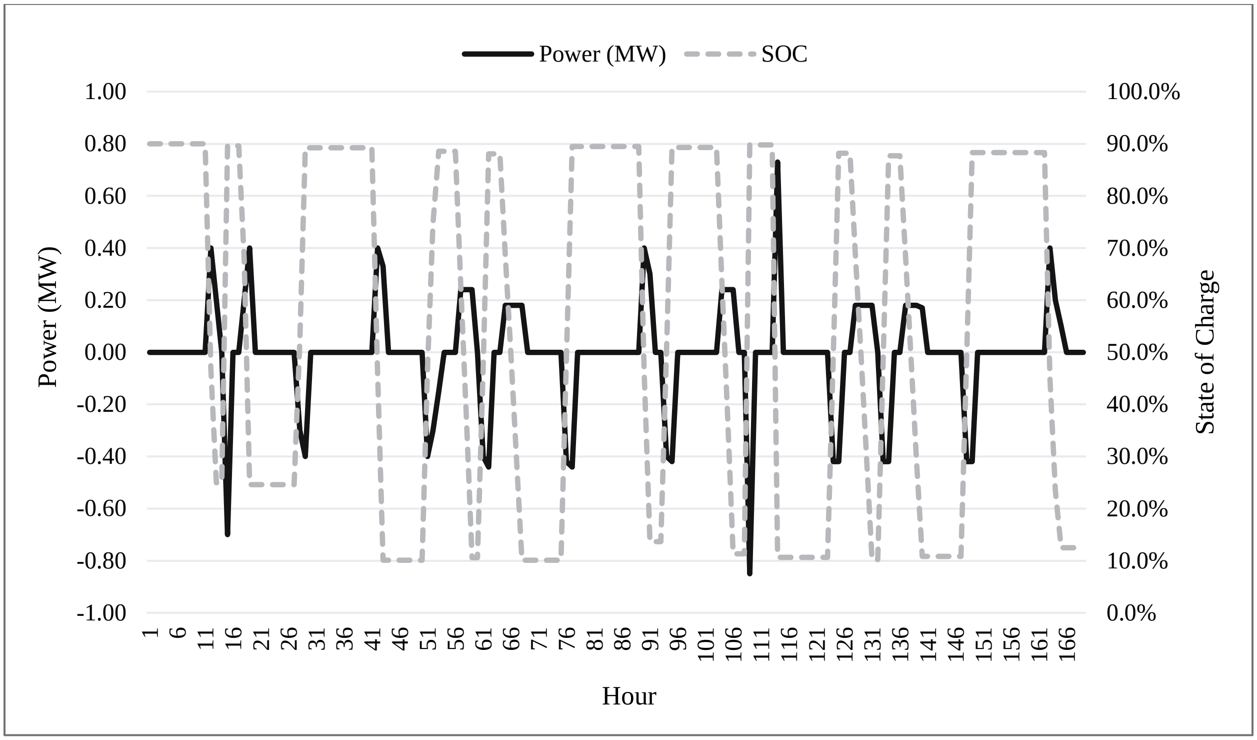


Figure 8.4. Capacity Duty Cycle over One-Week Period

8.5.2 Use Case 3: Improving Distribution System Efficiency

8.5.2.1 Volt/VAR

To perform in any Volt/VAR-related application, the BESS inverters will have to dispatch a certain amount of VAR to achieve a VAR-dependent target. Therefore, as a simplistic approach, this use case test is conducted by deploying the BESS inverters to correct the power factor at a specific location in the feeder to unity.

8.5.2.2 Load Shaping

The load-shaping duty cycle for SnoPUD is developed in BSET by minimizing the balancing payment to BPA, which is composed of varying levels of charges depending on the gap between scheduled and actual load demand and energy price. Minimizing the balancing payment while maintaining the SOC between 10% and 90% produces an optimum charge/discharge schedule. A one-month balancing duty cycle using December 2015 data was developed. However, the actual test was conducted for slightly over a week. The duty cycle is shown in Figure 8.5. The dashed line represents the modeled SOC of the battery system over the use case test.

In running the duty cycle, the following procedures should be performed:

1. ESS shall first be brought to an SOC of 10%.
2. The ESS is then subjected to the duty cycle outlined in Appendix A. The day of the week in which the test begins should correspond to the same day of the week identified in the duty cycle. The duty cycle should then be run continuously until the completion of the seventh day of testing.

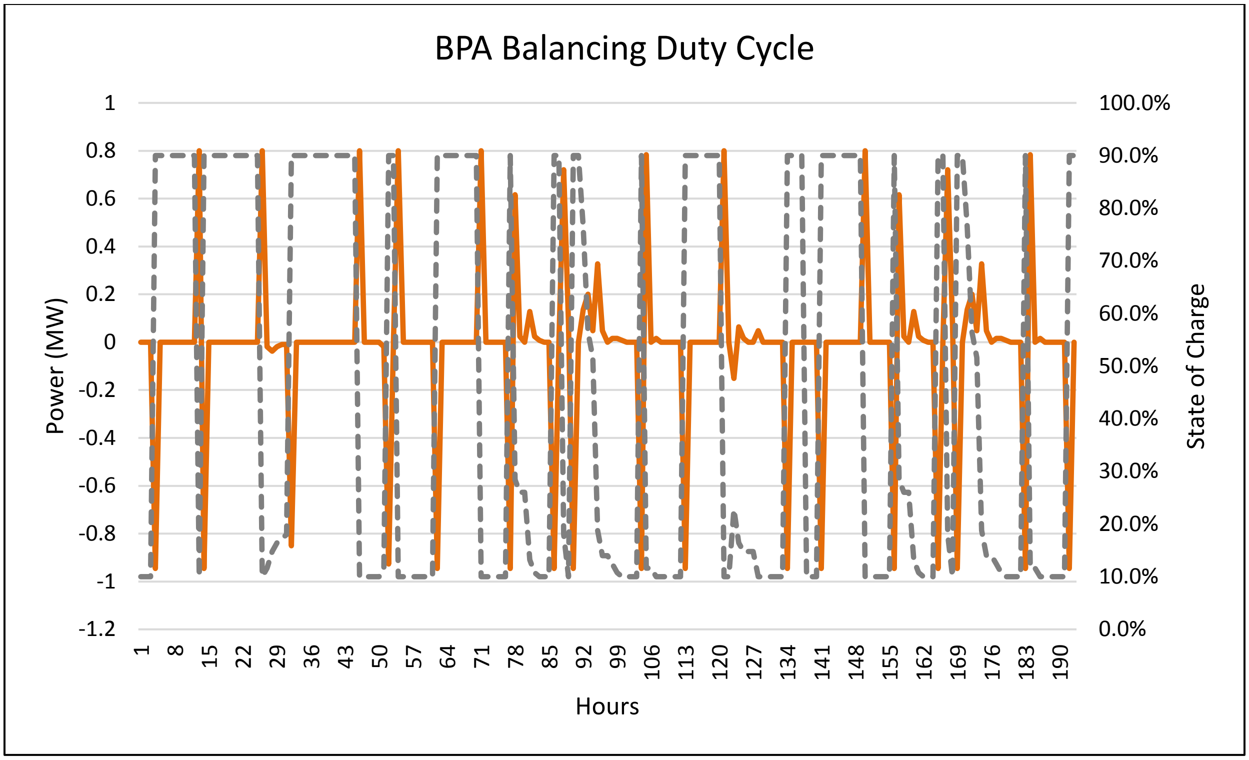


Figure 8.5. Load Shaping Duty Cycle over One-Week Period

8.5.3 Use Case 7: Optimal Utilization of Energy Storage

The objective of this test is to evaluate ESS performance when a set of services from all other use cases is co-optimized. MESA 1 will not complete use case 7. At the end of the first test phase for MESA 2, this use case will be implemented by using the optimization results produced by BSET. At the conclusion of the second phase of MESA 2 testing, PNNL will complete the SNO-controls integration work highlighted in Figure 8.6 by evaluating the performance of Doosan GridTech's Distributed Energy Resources Optimizer (DERO).

8.5.3.1 Control Requirements for Use Case 7 Demonstrations

Use case 7 is a multi-service deployment of an ESS that intends to maximize the value of storage by co-optimizing at least two or more services from use case 1 (energy shifting), use case 2 (regulation/load following), and use case 3 (Volt/VAR control, load shaping, and distribution system upgrade deferral). Controlling an ESS therefore essentially needs an optimization routine to be executed at certain intervals of time with updated data and information. The appropriateness of the input data and optimization technique would significantly impact the performance of the storage controller in maximizing energy storage value. DERO, developed by Doosan GridTech, is used for controlling SnoPUD ESSs. A methodology to test and evaluate the performance of DERO in co-optimizing multiple services and maximizing energy storage benefits is outlined below. Adequate understanding of DERO would be essential for evaluating its performance and therefore available information on DERO is reviewed and summarized in this document.

8.5.3.2 Review of DERO Controller

Doosan GridTech DERO (Doosan GridTech 2016) is a management system for distributed energy resources that optimally aggregates economic values from fleets of distributed ESSs and other distributed resources. Control and monitoring of distributed storage systems and other assets are performed using Doosan GridTech Intelligent Controller (DG-IC) (Doosan 2016), which is integrated with the DERO platform. Built-in operating modes of DG-IC include Market-based Charge/Discharge, Frequency Correction, Spinning Reserve, Forecast Assurance, Power Following, Peak Power Limiting, Power Factor Correction, Volt/VAr, Volt/Watt, Power Smoothing, Islanding, and SOC Maintenance. These control functions are developed based on the active and reactive power control modes described in the MESA ESS specification document (MESA 2015). Creating user-defined, new control modes is also supported via an Application Programming Interface (API). Based on the SnoPUD-supported, non-proprietary MESA standard, DG-IC provides interoperability to integrate multi-vendor solutions for managing ESSs.

The suite of bulk power applications that DERO considers in optimizing storage benefits includes energy arbitrage, and avoiding certain market situations such as energy congestion, unfavorable purchase, and forecast error penalties (DoosanGridtech: DERO 2016). Based on historical load and price data, local resource constraints, maintenance events and expected SOC at the start of the day, DERO provides day-ahead schedules for optimal charging and discharging operations, typically looking ahead 24 to 48 hours. Recommendations for schedule adjustments at different time horizons are made by DERO in response to changed conditions. For example, response to a significant deviation forecasted in the following day's predicted load is provided by the Energy Arbitrage application through a day-ahead recommendation to adjust charge/discharge timing and power over that period. Hour-ahead recommendations on charge or discharge adjustments are made by Wind Variance application if weather forecasters predict a large variance from expected wind energy generation. The SOC Correction application is used to make further adjustments to SOC between different operations, so that energy is available when needed without causing undue stress on energy assets or the local circuit.

The degree of success of the DERO platform in optimizing ESS benefit based on a bundle of services will largely depend on the type and extent of the data/information, and the methods used in decision making. PNNL will analyze the data received from Doosan to assess the controller performance, and will provide recommendations if any modification is necessary, as indicated in the performance methodology section below.

8.5.3.3 Performance Evaluation Methodology

The Use Case 7 test will run for 30 days. At a minimum, the co-optimization of two services from use cases 1 to 3 must be demonstrated. A conceptual diagram of the proposed performance evaluation methodology is shown in Figure 8.6 and the steps are briefly described below.

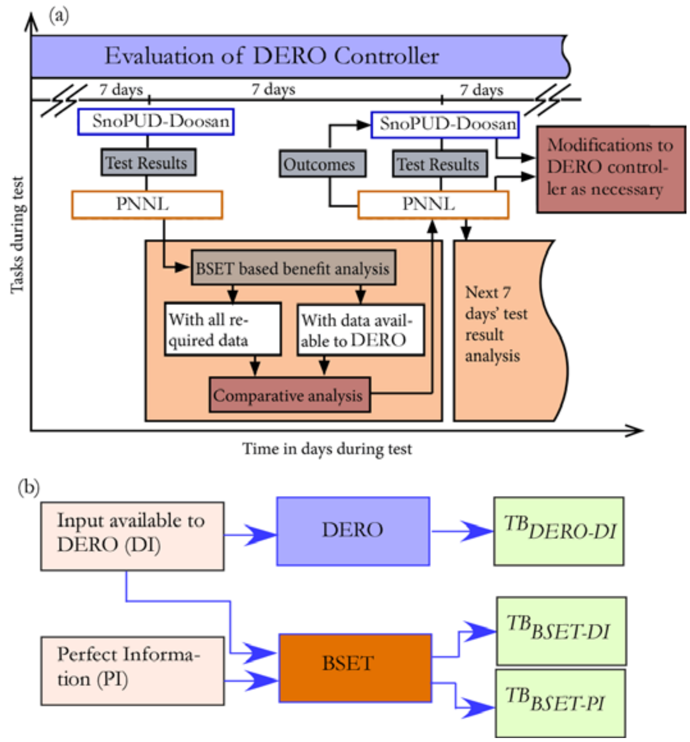


Figure 8.6. DERO Performance Evaluation Methodology. (a) Test arrangement and task outline. (b) DERO and BSET input and output.

Tests will be conducted with DERO in seven-day increments as shown in Figure 8.6(a). After each test run is completed, PNNL will obtain the test results from the client and will re-evaluate the optimal control strategies using the BSET model, based on two scenarios of input data as shown in Figure 8.6(b). In one scenario, all required information (e.g., schedule and actual load, price and other potential inputs into the optimization calculations from the previous week) would be considered as perfectly available and would be used in BSET analysis. In the other scenario, only the information that was available to DERO would be used as inputs in the BSET analysis.

1. PNNL will obtain the input information provided to DERO and the output results produced by DERO during the test and utilize that to understand DERO controller performance. Comparing the economic benefit produced by BSET using imperfect information (that was provided to DERO during the test) with the economic benefit produced by BSET using perfect information provides an idea on how the accuracy or perfectness of input information affects economic benefits. Comparing economic benefits produced by BSET using information provided to DERO with the DERO output results suggests how DERO as an optimizer differs from BSET. PNNL will define suitable metrics that will use these comparative analyses for evaluating DERO performance.

2. PNNL will communicate results of the comparative analysis with the client on a weekly basis during Use Case 7 testing as outlined in the test plan, thus allowing for review of PNNL calculations and potential modifications to the DERO optimization routines.

3. As the performance assessment is communicated with the client, results of the next seven-day test will be collected by PNNL for analysis and this process will continue until the required test length is accomplished. PNNL will issue a report at the conclusion of the test process summarizing all the results, assessment of the controller performance during the whole test period, and will define any recommendations for modifying the DERO optimization routine.

8.5.3.4 Performance Evaluation Metrics

Identifying suitable metrics to evaluate DERO performance is a critical part of this task, given the complexity of interactions between diverse input data and optimal outputs. For example, a controller having access to perfect information on energy prices and load data will generate a revenue different than a controller not having access to this information. Similarly, a non-linear battery storage model considering SOC variations, temperature, and charge-discharge power may produce a different transaction decision, and hence a different benefit estimate than that with a simple model that does not consider these aspects. The optimization approach used in the DERO controller could also be a contributing factor in the controller success. The impacts of input information and optimization approach considered in defining metrics to evaluate DERO controller performance in generating optimum revenue in UC7 operation as outlined below. BSET is used to generate the reference benefit estimate for evaluation purposes.

The impact of input information on economic benefits is evaluated using a Performance Metric (PM) calculated based on the difference between the benefit estimated by BSET using perfect information and the benefit estimated by BSET using information available to DERO per kW of storage rated power. Similarly, the impact of the optimization approach is determined based on the difference between the benefit estimated by BSET using information available to DERO and the actual benefit generated by DERO controller. Expressions of both metrics are given bellow with reference to Figure 8.6(b).

$$PM_{input} = \frac{TB_{BSET-PI} - TB_{BSET-DI}}{P_{ESS}} \quad (8\text{-}5)$$

$$PM_{approach} = \frac{TB_{BSET-DI} - TB_{DERO-DI}}{P_{ESS}} \quad (8\text{-}6)$$

where:

PM_{input} = Performance Metric considering input information
$PM_{approach}$ = Performance Metric considering optimization approach
$TB_{BSET-PI}$ = Total Benefit calculated by BSET using perfect information
$TB_{BSET-DI}$ = Total Benefit calculated by BSET using information available to DERO
$TB_{DERO-DI}$ = Total Benefit generated by DERO controller during the test
P_{ESS} = Rated power of the Energy Storage System (ESS).

Positive values of PM_{input} would indicate that economic benefit could be enhanced with more perfect input information and positive values of $PM_{approach}$ would indicate that the optimization approach currently used in the DERO controller produce less benefit as compared to BSET and might have some room for improvement.

8.5.3.5 Data and Information Required from SnoPUD/Doosan GridTech

PNNL will require the following technical information to assess the performance of the DERO controller:

1. Time series of revenue or avoided costs from the optimally bundled services.
2. Starting and ending times of optimization of services.
3. Time series of charging and discharging commands from the DERO controller.

4. Time series of charging and discharging measured at the AC side of the ESS (in kW) at time intervals either at SCADA sampling rates or at one-minute rates, whichever is faster. Where available, the measurements will also be performed on the DC side of the PCS.
5. Time series of SOC.
6. Any error messages from the ESS that could be generated by the BMS for the DC battery and could be related to cells, modules or strings, and from the PCS for the overall power flow in and out of the ESS.

9.0 Reporting SnoPUD Performance Results

The performance of an ESS shall be reported by the manufacturer of the system in accordance with the provisions in Section 8.0 as determined in accordance with the applicable provisions of Section 7.0. PNNL will oversee all ESS testing operation and will be responsible for capturing and filling out all report documentation with support from SnoPUD.

9.1 System Stored Energy Capacity and Roundtrip Efficiency.

The stored energy capacity of the ESS determined in accordance with the provisions in Section 7.1 and the RTE determined in accordance with the provisions in Section 7.1.1.3 shall be reported as provided in Table 9.1. Where additional testing is performed beyond the minimum required two cycles, an additional row shall be added for each cycle and the total charge and discharge energy shall be the sum of all values reported and the RTE based on those totals.

9.2 Energy Capacity and Stability.

The energy capacity stability of the ESS shall be reported as a percent of initial performance as determined in accordance with Section 8.4.5 and as shown in Table 9.1, along with the date of the test upon which the reported value is based and the ambient temperature and barometric pressure during the test.

Table 9.1. Stored Energy Capacity and Roundtrip Efficiency at Rated Power – Baseline PS and FR Duty Cycles

Date					
Ambient Temperature °C					
Barometric pressure, psia					
	Charge Energy (Wh)	Discharge Energy (Wh)	Cycle Roundtrip Efficiency	Cumulative RTE	Capacity stability (% of initial energy capacity)
Cycle 1	______	______	______		______
Cycle 2	______	______	______		______
Cycle 3	______	______	______		______
Sum cycle 1-3				______	
Sum cycle 2-3				______	

9.3 Response Time and Ramp Rate

The response times in seconds and ramp rates in megawatts per minute of the ESS shall be reported as determined in accordance with the provisions in Section 7.2 as shown in Table 9.2. This test is performed as part of baseline or reference performance test, and after use case tests.

Table 9.2. Response Time and Ramp Rate

Date			
Ambient Temperature °C			
Barometric pressure, psia			
		Ramp rate	
Mode	Response time (T_2-T_1) (s)	MW/min	% rated power/min
Discharge			
Change with respect to baseline (Present – baseline)			
Charge			
Change with respect to baseline (Present – baseline)			

9.4 Internal Resistance Test

The internal resistance shall be reported in accordance with the provisions in Section 7.2 and as shown in Table 9.3. This test is done as part of baseline testing, and after use case tests.

Table 9.3. Internal Resistance of the ESS

Date:			
Ambient Temperature °C			
Barometric pressure, psia			
	Internal Resistance Charge	Internal Resistance Discharge	
SOC, %			
80			
70			
60			
50			
40			
30			
20			
		NA	NA

9.5 Peak Shaving Duty-Cycle Results

The duty-cycle RTE shall be reported together with respect to discharge power and to the discharge duration based on the data collected in accordance with the provisions in Section 8.2.3. Table 9.4 shall be used to report the measured charge and discharge power and charge and discharge energy of the ESS, the percent of rated power during discharge and the ESS duty-cycle roundtrip efficiency. The information in

Table 9.4 shall also be created by PNNL in a graphical form, with the x-axis being the percentage rated power during discharge and the y-axis being the duty cycle roundtrip efficiency.

Table 9.4. Peak Shaving Duty-Cycle Roundtrip Efficiency

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

9.6 Frequency-Regulation Applications

The performance of an ESS intended for a frequency regulation application shall be reported by the manufacturer in accordance with the provisions in Sections 9.6.1 and 9.6.2 as determined in accordance with the applicable provisions of Section 8.3.

9.6.1 Duty-Cycle Roundtrip Efficiency

The duty-cycle RTE shall be reported together with respect to peak discharge power divided by the energy of the ESS and to the discharge duration based on the data collected in accordance with the provisions in Section 8.4.2 (Table 9.5).

9.6.2 Reference Signal Tracking and SOC excursion

The reference signal tracking of the ESS shall be reported in accordance with the provisions in Section 8.4.3. The state-of-charge excursion shall be reported as determined in accordance with the provisions in Section 8.4.4. These results will be reported in Table 9.5.

Table 9.5. Frequency Regulation Metrics

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

9.7 Use Case Performance

Duty cycles for use case tests subject the ESS to a series of charge/discharge operations. Reporting of use case performance includes a summary of ESS operation during the period of a given test. For all of the use cases in general, information on test duration, minimum and maximum SoC, average charge/ discharge power, RTE, operating temperature, and charge/discharge energy are reported. For tests that expose ESS to fast variations of real power (e.g. Regulation) or reactive power (Volt/VAR) in response to the duty cycle signal, performance reporting also includes metrics to understand how closely ESS followed the duty cycle (e.g. Root Mean Square Error, Absolute Error). To avoid the impact of auxiliary consumption on these metrics, performance will be reported with and without considering auxiliary power consumption.

Performance reporting tables for each of the use case tests conducted for this utility are provided in the following subsections.

9.7.1 Use Case 1: Energy Shifting

9.7.1.1 Energy Arbitrage

The results for Energy Arbitrage duty cycle as described in Section 8.5.1.1 and performance metrics as described in Section 8.4 are shown in Table 9.6.

Table 9.6. Energy Arbitrage Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

9.7.1.2 System Capacity to Meet Adequacy Requirements

The results for Energy Arbitrage duty cycle as described in Section 8.5.1.2 are shown in Table 9.7.

Table 9.7. System Capacity Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)
Average Discharge Power (kW)
Discharge Energy (kWh)
Charge Energy (kWh)
Discharge Duration (h)
Charge Duration (h)

9.7.2 Use Case 3: Improving Distribution System Efficiency

9.7.2.1 Volt/VAR

The results for Energy Arbitrage duty cycle as described in Section 8.5.2.1 and performance metrics as described in Section 8.4 are shown in Table 9.8.

Table 9.8. Volt/VAR Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Strings Active
Temp. °C
SOCMax
SOCMin
Maximum Reactive Power, kVAR
Reactive Power RMSE, kVAR.
Normalized Reactive Power RMSE, kVAR
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed, Reactive
% Time Signal Followed for > 10% Rated Power, Reactive
% Time Signal Followed with deviation < 1% Max Power, Reactive
Notes

9.7.2.2 Load Shaping

The results for Energy Arbitrage duty cycle as described in Section 8.5.2.2 and performance metrics as described in Section 8.4 are shown in Table 9.9.

Table 9.9. Load Shaping Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

10.0 PSE Test Data Requirements and Expected Timeline

10.1 Data Requirements

The following data are requested from PSE during testing.

Alternating Current (AC) Side:

- The control signal to the BESS, which would simply be a power signal – charge or discharge at certain power
- Actual power and energy delivered or absorbed by the ESS – both in and out of the transformer and in and out of the PCS
- ESS state of charge – this may be communicated to the PCS by the direct current battery management system (BMS) or be available from the DC BMS

DC Side:

- Power and energy – we could use efficiency information from the inverter manufacturer at various power levels as an alternative
- Voltage
- Current
- SOC

Optional Data, DC Side:

When the BESS powers the auxiliary loads, it is not necessary to have the auxiliary load data. However, access to this data would be useful to estimate RTE with and without including auxiliary power consumption.

When the BESS does not power auxiliary loads, the electricity required to power auxiliary loads should be measured separately. Auxiliary power is a catch-all for multiple items: heating, HVAC for the battery container, lighting, communications, battery heating with heater blankets or active cooling with circulating coolant. In either case, it would be useful to have auxiliary power data.

It would be useful to have data at the point of common coupling (PCC) in terms of power in and out of the transformer connecting the BESS to the grid. This allows calculation of system efficiency at the PCC. If this is not available, the transformer efficiency could be provided as a function of power in and out to allow determination of system efficiency inclusive of the transformer. Requested data are summarized in Table 10.1.

Table 10.1. Data Requested from PSE

Test	Data Frequency	Critical Data	Optional
Stored Energy Capacity Test	Every 10 sec	Watt (W), watt-hour (Wh), current, volts (AC and DC), SOC, and DC battery temperature, auxiliary power consumption (if powered by a separate line), transformer power in and out	Auxiliary power (if BESS supplies it)
Response Time and Ramp Test	Every second	Same as above	Same as above
Internal Resistance Test	Every second	Same as above	Same as above
Peak Shaving (PS) Duty Cycle	Every 10 sec	Same as above	Same as above
Frequency Regulation (FR)	Every second	Same as above	Same as above
Capacity Stability Test	Every 10 sec	Same as above	Same as above

10.2 Baseline Testing

The BESS will be subjected to baseline tests to determine the beginning-of-life reference performance. These test will allow the research team to determine BESS degradation during operation by repeating these baseline performance tests. Tests developed by DOE OE-sponsored working groups will be used with modifications as appropriate. The DOE-OE published document will be referred to as the Protocol in this work.

Baseline testing consists of baseline performance or reference performance tests to determine the initial performance of the BESS. This reference performance test can be repeated at any time to assess the state of health of the BESS. Duty cycle testing will involve subjecting the BESS to PS and FR duty cycles to determine the performance of the BESS for these two extreme use cases. PS is an energy intensive application, while FR involves exercising the BESS around a narrow SOC range using an energy neutral signal of 1-4s frequency, with the ability of the BESS to follow the signal being of great importance. It should be noted that while the FR duty cycle is energy neutral, the round trip efficiency (RTE) of the BESS will result in a deviation of the ending SOC from the starting SOC.

The following general performance metrics were identified in the DOE-OE sponsored Protocol development effort:

- RTE
- Response time & ramp rate (this was considered to be an application-specific metric in the Protocol but has been moved up to general metrics)
- Energy capacity stability (this can be performed at any time during BESS operation)
- Internal resistance during charge and discharge
- Stability of internal resistance over time

The following application duty cycle-related performance metrics were identified, with the application that these metrics are relevant to within brackets.

- Duty cycle round trip efficiency (PS and FR)
- Reference signal tracking (FR)
- SOC excursion (FR)

The following baseline performance tests will be conducted:

- Capacity test
- Response time and ramp rate test, completed at 50% SOC
- Internal resistance test, performed at 20%, 30%, 40%, 50%, 60%, 70%, and 80% SOC

This will be followed by applying PS and FR duty cycles as described in the Protocol. At the end of these duty cycles, the capacity test will be repeated. This will be followed by use case testing (details to be determined). At the end of the use case test, the baseline performance tests (capacity, response time/ramp rate, internal resistance) will be repeated. Table 10.2 lists the tests, the start and end states of charge (SOCs) and the anticipated test duration. This is the first of two test cycles. The second test cycle will begin after a 1-month rest period and will repeat the same tests in identical order.

Table 10.2. List of Tests and Duration

Test	Begin SOC	End SOC	Duration (Days)
Stored Energy Capacity Test at C/2.2, C/4 and C/6	95%	10%	9
Response Time and Ramp Test; Internal Resistance Test	90%	20%	2
PS Duty Cycle	95%	10%	3
FR Duty Cycle	65%	35%	2
Capacity Stability Test at C/2.2, C/4 and C/6	95%	10%	9
			25 days total for baseline
Use Case 1			14
Use Case 2			21
Use Case 3			21
Use Case 4			14
Use Case 7			28
Capacity Stability Test at C/2.2, C/4 and C/6	95%	10%	9
Response Time and Ramp Test	95%	10%	2
Internal Resistance Test	90%	20%	2
Total Days			136

10.3 Comprehensive Data Recording

The BESS creates, captures and stores operational and non-operational data. These systems and the associated data characteristics are detailed in the Concept of Operations document (Craig 2015).

All measurements of charge rate, input current and voltage, output current and voltage, thermal output, system temperatures, ambient conditions, and other parameters that must be measured shall be collected simultaneously at a temporal resolution applicable to the function of the BESS application and BESS metrics to which they are being applied, in accordance with recognized standards applicable to the measurements being taken. All parameters measured and recorded shall be used for determination and reporting of BESS performance.

10.4 Expected Timeline

Table 10.3 presents the preliminary BESS testing plan. Field testing began in February 2017. Tests will span five seasons (Winter 2016/2017-Winter 2017/2018). The testing process was expected to be completed by December 2017.

Table 10.3. Project Test Plan Timeline

	2017											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
<u>Testing Cycle 1</u>												
Baseline / DOE Test Protocol		■	■									
Use Case 1			■									
Use Case 2			■	■								
Use Case 3				■	■							
Use Case 4					■							
Use Case 7					■	■						
Baseline Testing												
Rest Between Test Cycles							■					
<u>Testing Cycle 2</u>												
Baseline / DOE Test Protocol							■	■				
Use Case 1								■	■			
Use Case 2									■	■		
Use Case 3										■		
Use Case 4										■	■	
Use Case 7											■	■
Baseline Testing												■

11.0 PSE Test Protocols

This section outlines the tests that will be performed as part of the technical performance testing of this research program. PNNL will coordinate with PSE in the implementation of the data acquisition for the evaluation. PNNL will summarize the performance evaluation for each of the control strategies defined in this section of the report. To acquire the needed data, the following tests will be conducted on the BESS:

1. Preliminary tests to determine rated power, energy content, RTE, and internal resistance.
2. Tests per PNNL/DOE protocol for PS and FR.
3. Tests for each use case.

The remainder of this section is organized around these tests, though the use case tests will be defined later in this project.

A reference performance test, also known as baseline performance test, shall be conducted in accordance with this section, and the results shall be used to determine baseline BESS performance that can be subsequently used as a baseline to assess any changes in the condition of the BESS and rate of performance over time and use. This test shall be repeated at regular intervals as specified in this document during cycle testing for same-system comparison purposes. Such intervals shall be selected to identify how the testing or operation affects the performance of the BESS and shall be in units of time, number of cycles, or energy throughput.

11.1 Stored Energy Capacity Test

A stored energy capacity test shall be performed in accordance with this section and is intended to be used to determine the stored energy capacity at the rated electrical for the intended application as specified by the manufacturer.

11.1.1 Test Overview

The BESS shall be discharged at the rated power of 2 MW to the lower SOC limit specified by the manufacturer, which will be labeled 10% SOC.

Energy storage system AC and DC power during charge and discharge shall be recorded every minute. The associated energy input and output of the BESS shall be calculated from the recorded power.

11.1.1.1 Stored Energy Capacity Test Routine

The BESS shall be tested for its stored energy capacity at selected power in accordance with the procedure listed below. The measurements shall be collected in accordance with all test steps, listed below. Any auxiliary power consumed that is not powered by the BESS shall also be monitored and recorded. Based on how PSE defines its BESS boundary, the power in and out of the transformer shall also be recorded to get the RTE inclusive of the transformer. If this data is not available, the total system efficiency will be calculated by multiplying the BESS RTE with the transformer RTE, where BESS ends at the PCS (and not transformer).

1. The BESS shall be discharged to its lower SOC limit (or minimum SOC) at the AC rated power of 2 MW (or in accordance with the system manufacturer’s specifications and operating instructions). That

lower SOC shall be measured and recorded as the manufacturer-specified Vmin corresponding to the discharging conditions.

2. The BESS shall be charged to its upper SOC limit (or maximum SOC) at the AC rated power of 2 MW (or in accordance with the system manufacturer's specifications and operating instructions) and held at that SOC for 15 minutes. That upper SOC shall be measured and recorded as Vmax (electrical storage) corresponding to charging conditions. The AC energy input WhCi, into the BESS during BESS charging, including all auxiliary power consumption, shall be measured directly during charging and recorded as the charge energy capacity of the BESS. Here C corresponds to charge, and i corresponds to cycle number.
3. The system shall be left at rest in an active state in accordance with the BESS manufacturer's operating instructions for 30 minutes.
4. The system shall be discharged at the rated power of 2 MW to the lower SOC limit specified by the manufacturer, at the discharge time prescribed by the duty cycle. That lower SOC shall be measured and recorded as Vmin (voltage). The AC energy output, WhDi, from the BESS during BESS discharging shall be calculated from the power measurements during discharge and recorded, where D corresponds to discharge.
5. The BESS shall be left at rest in an active standby state for the same period of time selected under Step 3 above (30 minutes).
6. Steps 2 through 5 above shall be repeated at least twice (total of 3 cycles). The reference performance test value shall be calculated as the mean of the values of WhCi and WDi as measured under Steps 2 and 4 above associated with each test. The standard deviation also shall be calculated and reported.
7. The BESS shall be recharged to 50% SOC. That 50% SOC shall be measured and recorded as the manufacturer-specified V50 corresponding to the discharging conditions. The energy input for this step will not be used for calculation of RTE.

Note: for the capacity test performed after the duty cycle testing, the BESS shall be recharged to the SOC required for Use Case 1 (TBD).

11.1.1.2 Roundtrip Energy Efficiency Calculation

An RTE calculation shall be conducted to determine the amount of energy that a BESS can deliver relative to the amount of energy injected into the BESS during the preceding charge for a cycle. A cumulative RTE is also calculated for a set of cycles by determining the total discharge and charge energy for those cycles. This calculation, with minor changes, shall also be used for the applicable duty cycle for the intended application of the system.

11.1.1.3 Roundtrip Energy Efficiency from Stored Energy Capacity Test Routine

The RTE of the BESS is the efficiency for each cycle, cumulative efficiency for two and three cycles, and shall be determined in accordance with Equations 11-1 through 11-3 based on the data obtained from the tests conducted in accordance with the provisions in Section 11.1.1.1. Where constant power cannot be held during the test, the use of average power shall be considered acceptable and thus noted when reporting RTE in accordance with the provisions in Section 13.2.

$$Round\ trip\ efficiency\ for\ cycle\ i = \left(\frac{Wh_{D_i}}{Wh_{C_i}}\right) \quad (11\text{-}1)$$

$$Cumulative\ Round\ trip\ efficiency\ for\ all\ 3\ cycles = \left(\frac{\sum_1^3 Wh_{D_i}}{\sum_1^3 Wh_{C_i}}\right) \quad (11\text{-}2)$$

$$Cumulative\ Round\ trip\ efficiency\ for\ cycles\ 2\ and\ 3 = \left(\frac{\sum_2^3 Wh_{D_i}}{\sum_2^3 Wh_{C_i}}\right) \quad (11\text{-}3)$$

where 3 is the total number of cycles; Wh_{Di} is the BESS electrical energy discharge output (AC) in watt-hours for cycle number i; and Wh_{Ci} is the watt-hour charge input (AC) into the BESS, including all auxiliary power consumption for cycle number i. If the auxiliary power system is powered by the BESS, no adjustment to the above equations are needed. If the auxiliary load is powered by another line, the RTE will be calculated by subtracting the auxiliary load during discharge from the numerator and adding it to the denominator during charge.

11.2 Response Time and Ramp Rate Test

The BESS shall have a response time and ramp rate test performed in accordance with this section to determine the amount of time required for the BESS output to transition from no discharge to full discharge rate and from no charge to full charge rate. The ramp rate of the BESS shall be determined by dividing the BESS rated power by the response time in accordance with the provisions in this section. This test is done in conjunction with the internal resistance test. The starting SOC is the maximum allowable SOC – which is 80%. The end SOC is the minimum allowable SOC – which is 20%.

11.2.1 Test Overview

The method for measuring ramp rate shall be the same for all BESSs regardless of application. The manufacturer shall provide information about rated power as required by the provisions in Section 10.2.

The response time shall be measured in accordance with Figure 11.1, starting when the signal (command) is received at the BESS boundary as established in Section 4.2 of the DOE protocol (Viswanathan et al. 2014) and continuing until the BESS discharge power output (electrical or thermal) reaches 100 ± 2% of its rated power.

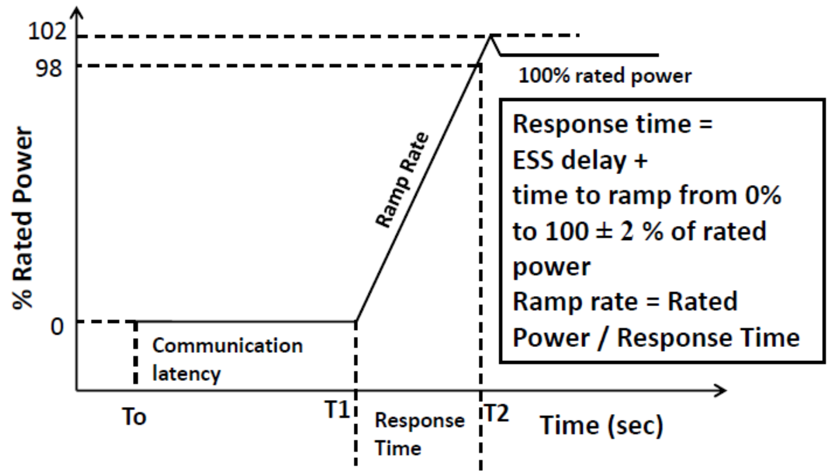


Figure 11.1. Response Time Test

11.2.2 Discharge Test Routine

The discharge response time test shall be conducted in accordance with the following procedure and the discharge response time calculated in accordance with Equation 11-4.

1. Take BESS to 90% SOC by charging at the rated power. Keep at rest for 30 minutes. Measure open circuit voltage at the end of the rest time. Go to step 6.
2. The data acquisition system (DAS) shall be configured to record a time stamp T_0 when a change in set point from rest to a discharge output command is sent to the BESS. Data is collected every second.
3. The DAS shall be configured to record a time stamp T_1 when the BESS starts responding to the discharge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the output of the BESS reaches 100 ±2% of its rated power capacity. The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the discharge ramp rate of the BESS, as determined in accordance with Equation 11-4a, and at least one intermediate data point shall be acquired as the BESS transitions from rest to full discharge.
5. The BESS shall be configured to respond to a step change in power output set point according to the BESS manufacturer's specifications.
6. The DAS shall be started and shall command to change the power output of the BESS to full rated discharge power output, and T_1 and T2 shall be measured and recorded. The BESS is maintained at rated power for 30 seconds. This is followed by 15 minutes rest.
7. The DAS shall be reset to a state to begin recording data and the BESS placed in a state of active standby.

$$RTD = T_2 - T_1 \quad (11\text{-}4)$$

where RTD is the discharge response time in seconds; T_1 is the beginning time stamp, in seconds, when the BESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the BESS reaches 100 ±2 % of its rated power output.

The discharge ramp rate RR_D shall be calculated in accordance with Equation 11-4a and expressed in megawatts per minute.

$$RR_D = [P_{T2}]/[T_2 - T_1] \times 60 \qquad (11\text{-}4a)$$

where P_{T2} is the power output of the BESS recorded at time T_2(100 ±2% of rated power capacity); T_1 is the beginning time stamp, in seconds, when the BESS starts responding to the discharge signal; and T_2 is the end time stamp, in seconds, when the output of the BESS reaches 100 ±2% of its rated power output.

The discharge ramp rate shall also be expressed as percent rated power per minute (R_{R_pct},) in accordance with Equation 11-4b.

$$R_{Rpct} = RR_D / P_R \times 100 \qquad (11\text{-}4b)$$

where P_R is the rated power of the BESS.

The response time and ramp rate will be reported in accordance with the provisions in Section 13.0. After discharge ramp rate measured, the BESS is kept at rest for 15 minutes and a similar measurement is done for charge ramp rate as described in Section 11.2.3.

The internal resistance is measured as described below.

<u>Procedure to determine current corresponding to rated power:</u>

Figure 11.2 presents the pulse discharge profile for the BESS. Chart (a) shows the OCV before pulse and the full pulse. Chart (b) shows the first 50 ms of the discharge pulse.

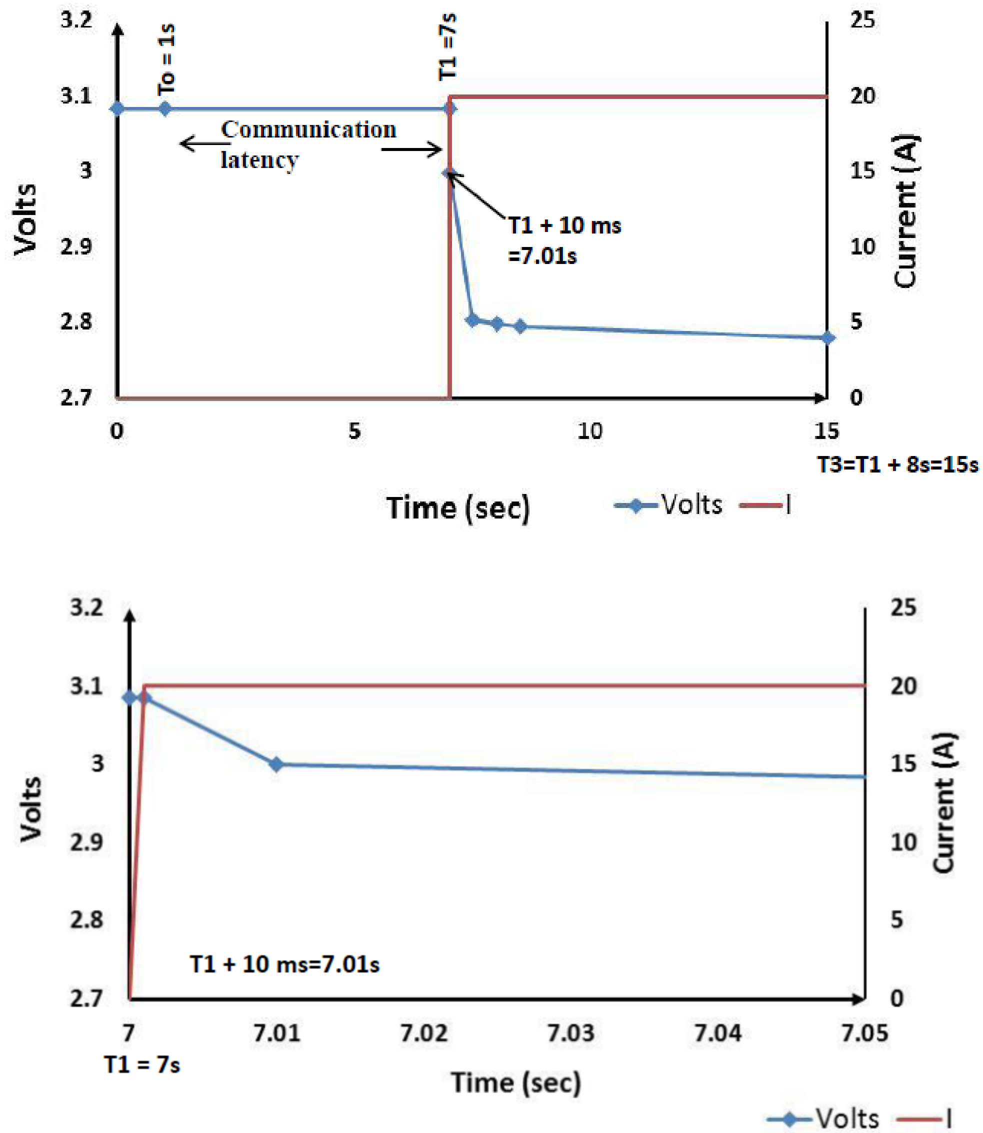


Figure 11.2. The Pulse Discharge Profile for BESS

The total resistances are calculated by the following equation:

$$R_{total\text{-}discharge} = \{ V(T_0)\text{-}V(T_1\text{+}8\ sec)\}/Idischarge \quad (11\text{-}5)$$

where T_1+8s is T_3.

If 10 ms resolution data are available, the ohmic resistance is calculated by using the voltage at 10 ms in Equation 11-5.

From the open circuit voltage data after discharge, total resistance is calculated by the following equations:

$$R_{total\text{-}discharge} = \{ V(T_3\text{+}15\ minutes)\text{-}V(T_3)\}/Idischarge \quad (11\text{-}6)$$

One-way DC discharge efficiency, ηdc_dis_{chg}, is given by

$$\eta_{dc\_discharge} = V(T_1{+}8\ sec) / V(T_o) \tag{11-7a}$$

$$\eta_{dc\_discharge} = V(T_3)/V(T_3{+}15\ minutes) \tag{11-7b}$$

Equation 11-7a gives the efficiency based on the voltage decrease during discharge, while equation 11-7b provides the efficiency based on voltage relaxation after discharge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

One-way PCS efficiency during discharge, $\eta_{PCS\_discharge}$ is given by

$$\eta_{PCS\_discharge} = \text{AC power from PCS / DC power from battery to PCS} \tag{11-8a}$$

where

$$\text{DC power from battery to PCS} = \text{DC voltage x } I_{discharge} \text{ at 8 sec} \tag{11-8b}$$

The one-way BESS discharge efficiency, η_{BESS_dis} is given by:

$$\eta_{BESS\_discharge} = \eta_{dc\_dischg} \times \eta_{PCS\_discharge} \tag{11-9}$$

11.2.3 Charge Test Routine

The charge response time test shall be conducted in accordance with the following procedure and the charge response time calculated in accordance with Equation 11-10.

1. The BESS shall be at the 90% SOC and in an active standby state.
2. The DAS shall be configured to record a time stamp T_0 when a change in set point from rest to a charge output command is sent to the BESS. Data is collected every second.
3. The DAS shall be configured to record a time stamp T_1 when the BESS starts responding to the charge command signal.
4. The DAS shall be configured to record a time stamp T_2 when the input to the system reaches a 100 ±2% of its rated power capacity. The acquisition rate of data shall be at least twice as fast as the rated power capacity divided by the ramp rate of the BESS, as determined in accordance with Equation 11-11a, and at least one intermediate data point shall be acquired as the BESS transitions from rest to full charge.
5. The BESS shall be configured to respond to a step change in power input set point according to the BESS specifications provided by the manufacturer.
6. The DAS shall be started and shall command to change the power input to the BESS to full rated charge power input, and T_1 and T_2 shall be measured and recorded. The BESS is maintained at rated power for 30 seconds. This is followed by 15 minutes rest.
7. The DAS shall be reset to a state to begin recording data and the BESS placed in a state of active standby.

$$RT_C = T_2 - T_1 \tag{11-10}$$

where RT_C is the charge response time in seconds; T_1 is the beginning time stamp, in seconds, when the BESS starts responding to the charge signal; and T_2 is the end time stamp, in seconds, when the input to the BESS reaches 100 ±2 % of its rated power output.

The charge ramp rate (RR) shall be calculated in accordance with Equation 11-11a and expressed in megawatts per minute.

$$RR_C = [P_{T2}]/[T_2 - T_1] \times 60 \tag{11-11a}$$

where P_{T2} is the power input to the BESS recorded at time T_2 (100 ±2% of rated power capacity).

The charge ramp rate shall also be expressed as percent rated power per minute (RRC_{pct}) in accordance with Equation 11-11b.

$$RRC_{pct} = RRC/\ PR \times 100 \tag{11-11b}$$

where PR is the rated power of the BESS.

The total resistances is calculated by the following equation:

$$R_{total\text{-}charge} = \{V(T_1\text{+8 sec})\text{-}V(T_0)\}/I_{charge} \tag{11-12}$$

where T_1+8s is T_3.

If 10 ms resolution data is available, the ohmic resistance are calculated by using the voltage at 10 ms in Equation 11-12.

From the open circuit voltage data after charge, the total resistance is calculated by the following equations:

$$R_{total\text{-}charge\ =} = \{V(T_3)\text{-}V(T_3\text{+15 minutes})\}/I_{charge} \tag{11-13}$$

The DC efficiency and the PCS efficiency is calculated using Figure 11.3 as guide for power flow between the DC and AC side.

One way DC charge efficiency, η_{d_cchg}, is given by the following equations:

$$\eta_{dc\_chg} = V(T_o)/V(T_1\text{+8sec})) \tag{11-14a}$$

$$\eta_{dc\_chg} = V(T_3\text{+15 minutes})/V(T_3) \tag{11-14b}$$

Equation 11-14a gives the efficiency based on the voltage increase during charge, while equation 11-14b provides the efficiency based on voltage relaxation after charge. Ideally, these two values should be equal if the charge times and relaxation times have been chosen appropriately.

One way PCS efficiency during charge, η_{PCS_charge} is given by

$$\eta_{PCS\_charge} = \text{DC power in to battery/AC power in to PCS} \tag{11-15a}$$

where

$$\text{DC power in to battery from PCS} = \text{DC voltage x } I_{charge} \text{ at 8 sec} \quad (11\text{-}15b)$$

The one way BESS charge efficiency, η_{BESS_chg} is given by:

$$\eta_{BESS\_charge} = \eta_{dc\_charge} \text{ x } \eta_{PCS\_charge} \quad (11\text{-}16)$$

The BESS RTE during the internal resistance measurement at each SOC is calculated as follows:[1]

η_{ESS_RTE} = One way BESS charge efficiency x one way BESS discharge efficiency

DC RTE = one way DC charge efficiency x one way DC discharge efficiency

PCS RTE = one way PCS efficiency during charge x one way PCS efficiency during discharge.

Figure 11.3 shows power flow in and out of the BESS (with PCS as the boundary).

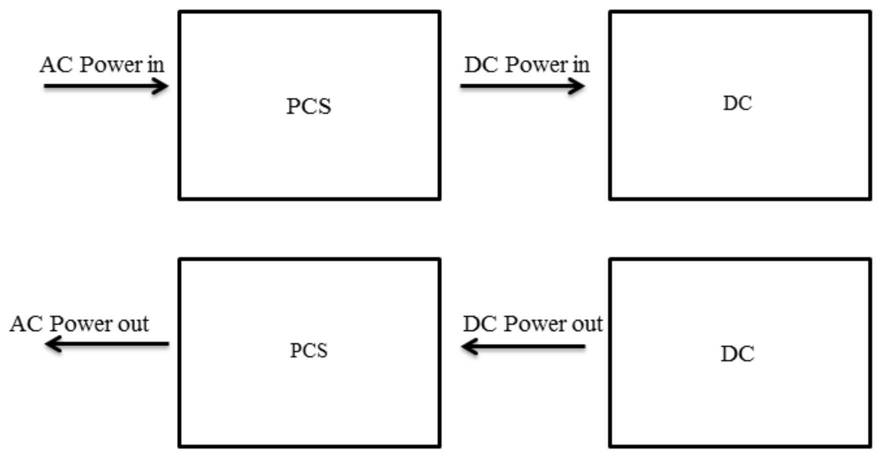


Figure 11.3. One-way DC System and PCS Efficiency during Charge and Discharge

If the BESS SOC is > or = to 30%, discharge the BESS at rated power to decrease its SOC by 10%. Then go to step 2 in Section 11.2.2. If the BESS SOC = 20%, go to step 2 in Section 11.2.2, go through the discharge and charge ramp rate/internal resistance steps, and then stop.

[1] This can be cross-checked vs. the measured round trip efficiency from the reference performance test. Note that for the latter, the charge and discharge power are the same, resulting in different currents.

12.0 PSE Peak Shaving and Frequency Regulation Test

12.1 System Ratings

Ratings for BESSs covering rated power and energy available at rated power and the performance of the BESS associated with response time, ramp rate, and RTE at the beginning of life shall be based on a set of ambient operating conditions specified by the manufacturer of the BESS. The manufacturer shall also provide an indication of how the performance of the BESS is expected to change based on age and use of the system.

12.2 Peak Shaving (Management)

Energy storage systems intended for use in peak-shaving (management) applications shall have their performance determined in accordance with this section.

12.2.1 Classification

Energy storage systems intended for peak-shaving (management) applications shall be designated by their intended classification(s) as described in Sections 12.2.1.1 through 12.2.1.11.

12.2.1.1 Energy Time Shift (Arbitrage)

Energy time shift (arbitrage) shall be considered a use classification of a BESS in a peak-shaving (management) application where the system is charged during low energy price periods and discharged during high energy price periods where the BESS owner either pays wholesale market energy rates plus a delivery charge or pays time-of-day retail rates.

12.2.1.2 Electric Supply Capacity

Electric supply capacity shall be considered a use classification of a BESS in a peak-shaving (management) application where the storage capacity of the system is used to defer the installation of new electric generation capacity, such as, but not limited to, a relatively small storage system or series of systems where growth has created a need for generation that cannot be satisfied in the short term and the storage system would be expected to supply load over the full period when the additional, incremental capacity is needed.

12.2.1.3 Load Following

Load following shall be considered a use classification of a BESS in a peak-shaving (management) application where the system is used to reduce ramp rate magnitudes so that conventional load-following generating units can better moderate cycling and be brought on at, or near, full load.

12.2.1.4 Transmission Congestion Relief

Transmission congestion relief shall be considered a use classification of a BESS in a peak-shaving (management) application that is a special case of the energy time shift use classification in Section 12.2.1.1, where electric transmission congestion leads to price differences across a transmission system at the same point in time. In this use classification, the storage system shall be located on the load side of the congested network, charged in low-price periods when the system is not congested and discharged during high-price time periods when prices have increased due to congestion.

12.2.1.5 Distribution System Upgrades Deferral

Distribution system upgrade deferral shall be considered a use classification of a BESS in a peak-shaving (management) application where the system responds to a situation where a piece of equipment on the distribution system, including power line conductors, experiences loadings that approach the distribution system equipment's rated capacity, thereby allowing the current distribution system equipment to remain online longer until other conditions necessitate that the distribution system equipment be upgraded.

12.2.1.6 Transmission System Upgrades Deferral

Transmission system upgrade deferral shall be considered a use classification of a BESS in a peak-shaving (management) application identical to the distribution upgrade deferral application covered in Section 12.2.1.4, except that it applies on higher voltages and higher power conditions found on the electric transmission system.

12.2.1.7 Retail Demand Charge Management

Retail demand charge management shall be considered a use classification of a BESS in a peak-shaving (management) application where the system is applied and used to minimize the demand charge from a utility over the course of each month.

12.2.1.8 Wind Energy Time Shift (Arbitrage)

Wind energy time shift shall be considered a use classification of a BESS in a peak-shaving (management) application where electric power generated from a wind technology during low-price periods is stored and then delivered during high-price periods.

12.2.1.9 Photovoltaic Energy Time Shift (Arbitrage)

Photovoltaic energy time shift shall be considered a use classification of a BESS in a peak-shaving (management) application where electric power generated from photovoltaic technology is stored and then delivered to the system when needed.

12.2.1.10 Renewable Capacity Firming

Renewable capacity firming shall be considered a use classification of a BESS in a peak-shaving (management) application that involves the coupling of intermittent renewable generation with a specific capacity and type of energy storage that allows for an increase in the ability of the renewable generation to participate in the capacity market.

12.2.1.11 Baseload Generation Time Shift

Baseload generation time shift shall be considered a use classification of a BESS in a peak-shaving (management) application where a BESS is configured to allow baseload units to operate at full capacity

during lighter nighttime loads, and deliver energy to the system in a way that minimizes or displaces higher-cost peaking generation.

12.2.2 System Ratings

The determination and reporting of ratings for BESSs applied in a peak-shaving (management) application shall be in accordance with IEEE Standard 1679 as expanded herein to provide more specific test procedures that apply to peak-shaving (management) applications. Such expansion shall include application of the duty cycle in Section 12.2.3 and taking measurements needed to determine the values for the metrics in Section 12.2.4 in determining and expressing the performance of BESSs for peak-shaving (management) applications.

12.2.3 Duty Cycle

The duty cycles presented in this section shall be used in the determination of the performance of systems intended for peak-shaving (management) applications and shall use charge and discharge time windows instead of normalized power levels or discharge rates to allow the duty-cycle profile to be applied the same to different technologies regardless of system size, type, age, and condition. The duty cycles applied in determining system performance shall be in accordance with Figure 12.1 and the provisions in Sections 12.2.3.1 through 12.2.3.4.

Each cycle must have a total charge time of 12 hours, a variable duration discharge window and two equal float windows that bring the total duration for each of the A, B, and C profiles to one 24-hour period. While Figure 12.1 displays these profiles for a 24-hour period with an evening peak, for the purposes of testing, any start and end time shall be permitted to be selected as long as that time period is for 24 continuous hours. When conducting performance tests using these profiles, the baseline point selected from which to start the test and representing the beginning of each duty cycle shall be the same point the system is returned to after the 24-hour duration of the test profile. This baseline point shall be at any SOC of the BESS.

12.2.3.1 Charge Window

During the charge window, the BESS shall be charged at constant power in a 12-hour time period to bring the BESS to its upper SOC limit, after which the BESS shall be maintained at that SOC limit in accordance with the BESS manufacturer’s specifications and operating instructions. As an alternate approach, the BESS will be charged at rated power of 2 kW to its upper SOC limit, followed by a one hour rest.

12.2.3.2 Float Window

During the float window, the operation of any internal support loads for the BESS such as, but not limited to, heating, ventilation, and air-conditioning systems shall continue to operate as required in accordance with the BESS manufacturer’s specifications and operating instructions. During the float window the BESS shall not be maintained at the top of charge from an external source. Discharging of the BESS that does not serve a load external to the BESS shall be permitted during the float window.

12.2.3.3 Discharge Window

During the discharge window, the BESS shall be discharged until the minimum SOC level, as specified by the BESS manufacturer, is reached. The discharge of the BESS shall be at constant power as specified by the manufacturer of the BESS to bring the BESS to its minimum SOC level as specified by the manufacturer for a peak-shaving application. While the figures below are a guide, the rest period after charge and discharge is kept at 1 hour. The discharge power for 6-hour, 4-hour and 2-hour rates are 0.73 kW, 1 kW and 2 kW respectively.

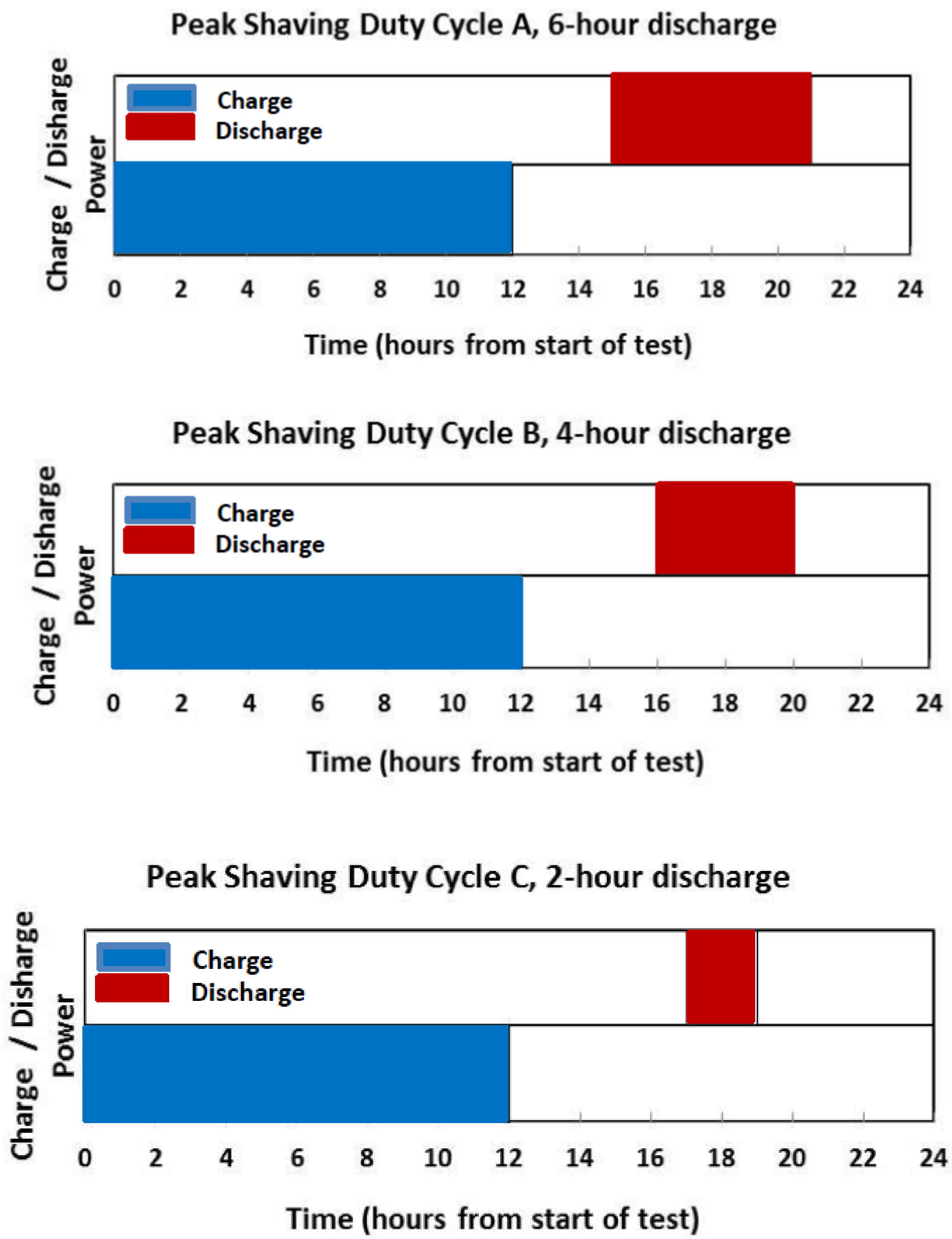


Figure 12.1. Peak-Shaving Duty Cycles

12.2.3.4 Application of the Duty Cycles

Performance testing shall consist of one application of duty-cycle A and bringing the BESS back to its initial state of charge, followed immediately by one application of duty-cycle B and then followed immediately by one application of duty-cycle C as shown in Figure 12.1, with the BESS brought back to its initial SOC after each duty cycle. These duty cycles, sequenced as required above, shall be used to calculate the metrics covered in Section 12.2.4 that are to be used as a basis for determining and reporting the operational effectiveness of a BESS in peak-shaving applications.

12.2.4 Performance Metrics

The performance of the BESS shall be expressed in accordance with the provisions of Sections 4.2.4.1 based on the application of the duty cycle provided in Section 12.2.3.3.

12.2.4.1 Duty-Cycle Roundtrip Efficiency for Peak-Shaving

The duty-cycle roundtrip efficiency of the BESS as a function of discharge power shall be determined in accordance with the provisions in this section.

PSE shall select an intended application and apply the duty cycle as provided in Section 12.2.3.3. In conducting the tests required in Section 12.2.3.3, the charge and discharge of the BESS shall be in accordance with this section using the duty cycle in Section 12.2.3.3.

1. The system shall be brought to the minimum SOC as dictated by a given $Vmin_I$, in accordance with duty-cycle A as provided in Section 12.2.3, by removing the necessary amount of charge at the rated power of the BESS as provided by the manufacturer's specifications. Alternatively, the system shall be permitted to be brought directly to the desired initial SOC by charging or discharging the BESS to the desired $V_{initial}$ at rated power.
2. The BESS shall then be subjected to the duty cycle as described in Section 12.2.3.
3. At the end of the duty cycle, the BESS shall be returned to the initial SOC as dictated by a given $V_{initial}$ by charging or discharging the BESS at rated power.
4. Steps 1 through 3 shall be repeated for duty cycles B and then C as described in Section 12.2.3.

The duty-cycle roundtrip efficiency as a function of discharge power shall be determined by dividing the energy removed from the BESS at a given power by the energy required to recharge the BESS as shown in Equation 12-1.

At the end of the test, the BESS shall be brought to the desired SOC using a procedure recommended by the manufacturer's specifications and operating instructions. If frequency regulation is the next step, the BESS is brought to 60% SOC.

12.3 PNNL Frequency Regulation

12.3.1 Frequency Regulation Performance

Energy storage systems intended for use in frequency regulation shall have their performance determined in accordance with this section. Frequency regulation shall be permitted to represent area regulation as used by a balancing authority to meet North American Electric Reliability Corporation Balancing Authority Performance Control Standards.

12.3.2 System Ratings

The determination and reporting of ratings for a BESS to be applied for frequency regulation shall be in accordance with the provisions of this section using the duty cycle in Section 12.2.3 and metrics in Section 12.4.

12.3.3 Duty Cycle

The duty cycle to be applied in determining the performance of an BESS for an FR application is shown in Figure 4.2 as power normalized with respect to the rated power of the BESS over a 24-hour time period, where positive represents charge into the BESS and negative represents discharge from the BESS as a function of time in hours. The raw data upon which Figure 12.2 is based on the regulation duty cycle developed in Balducci et al (2013).

The BESS manufacturer shall be permitted to conduct additional testing using another duty cycle. Where this is done, the manufacturer shall provide a description of and rationale for the duty cycle chosen, shall conduct all tests required herein while subjecting the BESS to the additional duty cycle chosen, and shall report all performance measures as required in Section 13.0 under the designation "alternative duty-cycle."

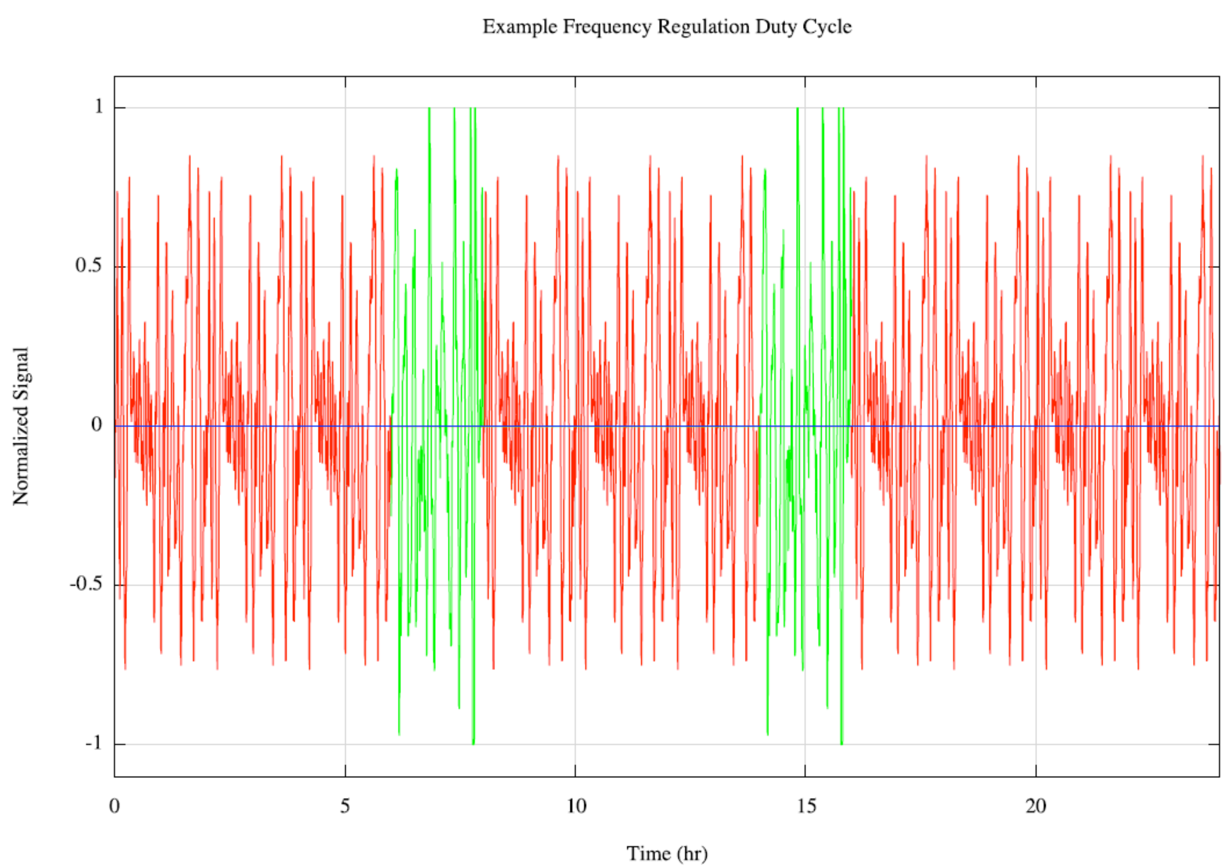


Figure 12.2. Frequency-Regulation Duty Cycle

In conducting the tests required in Section 12.3, the charge and discharge of the BESS shall be in accordance with the duty cycle described in this section.

1. The system shall be brought to the initial desired SOC of 60% as dictated by a given $V_{initial}$ by adding or removing the necessary amount of charge at the rated power of the BESS as provided by the manufacturer's specifications. Alternatively, the system shall be permitted to be brought directly to the desired initial SOC by charging or discharging the BESS to the desired $V_{initial}$ at rated power and held at that V or T for at least 10, but no more than 30, minutes.
2. The BESS shall then be subjected to the duty cycle as described in this section and shown in Figure 12.2.
3. At the end of the duty cycle, the BESS shall be returned to the initial SOC as dictated by a given $V_{initial}$ by charging or discharging at rated power.
4. At the end of this test, the BESS shall be brought to the required SOC to prepare for the next test using a procedure as recommended by the manufacturer's specifications and operating instructions. If capacity stability is the next test, the BESS shall be brought to the minimum SOC level at the rated power of the BESS as provided by the manufacturer's specifications.

12.4 Performance Metrics

The performance of the BESS shall be expressed in accordance with the provisions of Sections 12.4.1 through 12.4.4 based on the application of the duty-cycle regimen provided in Section 12.3.3.

12.4.1 Roundtrip Energy Efficiency

The RTE of the BESS shall be determined in accordance with the provisions in Section 11.1.1.3.

12.4.2 Duty-Cycle Roundtrip Efficiency

The duty-cycle roundtrip efficiency of the BESS shall be determined by dividing the energy removed (output) from the BESS by the energy required to recharge (input) the BESS.

12.4.3 Reference Signal Tracking

The ability of the BESS to respond to signal for the 24-hour duty cycle described in Section 12.3.3 shall be defined and determined by the manufacturer of the BESS in accordance with the provisions in this section. The balancing signal shall be changed every four seconds during the duty cycle.

In addition, the manufacturer of the BESS shall also determine and report separately the total percentage tracking and the times when the BESS stops tracking and restarts tracking as an indication of whether the BESS is capable of tracking high peaks and/or high-energy half cycles. The manufacturer shall also determine if the BESS can go through a 24-hour period without reaching the lower or upper SOC limits. Any time during that period when the BESS indicates an ability or inability to follow the signal, it shall be reported. An inability to follow the signal shall be considered a situation where the BESS cannot deliver or absorb required signal power during the four-second duration and cannot deliver or absorb the required signal energy during the duration when the signal remains above or below the x-axis. The total time the BESS cannot follow the signal and percentage tracked shall be determined in accordance with the provisions in this section.

The ability of the BESS to respond to a reference signal shall be recorded during the RTE test. The sum of the square of errors between the balancing signal (Psignal) and the power delivered or absorbed by the BESS (Pbess) shall be calculated in accordance with Equation 12-1 and used to estimate the inability of the BESS to track the signal.

$$\Sigma\,(\text{Psignal} - \text{Pbess})^2 \qquad (12\text{-}1)$$

where Psignal is the balancing signal and Pess is BESS power (watts).

The measurements shall be taken at every point in time that the BESS receives a change in the balancing signal. The sum of the absolute magnitude of the difference between the balancing signal and BESS power shall be calculated in accordance with Equation 12-2.

$$\Sigma|\text{Psignal} - \text{Pbess}| \qquad (12\text{-}2)$$

where Psignal is the balancing signal and Pess is BESS power (watts).

The sum of the absolute magnitude of the difference between the balancing signal energy and BESS energy shall be calculated in accordance with Equation 12-3 and reported by the manufacturer of the BESS to account for the inability for the BESS to follow the signal due to the BESS reaching the SOC limits provided in the manufacturer's specifications and operating instructions.

$$\Sigma|\text{Esignal} - \text{Ebess}| \qquad (12\text{-}3)$$

where Esignal is the signal energy for a half-cycle, with half-cycle being the signal of the same sign (above or below the x-axis), and Eess is the energy supplied to or absorbed by the BESS for each half-cycle.

When (Psignal-Pbess)/Psignal| is less than 0.02, the BESS shall be considered to track the signal. The total time the BESS cannot follow the signal and percentage tracked where (Psignal – Pess)/Psignal is less than 0.02 shall be determined in accordance with Equation 12-4.

$$\%\ \text{of time signal is tracked} = [\text{Time signal is tracked (h)}/24\ \text{h}] \times 100 \qquad (12\text{-}4)$$

12.4.4 State-of-Charge Excursions

The SOC of the BESS during testing required under the protocol shall be monitored and continuously updated by integrating the current with respect to time for each half-cycle. For the purpose of this requirement, a half-cycle shall be considered the amount of time when the current or power is of the same sign. The integrated area shall be added to the SOC as the charge half-cycle is started or subtracted from the prior SOC as the discharge cycle is started. The state-of-charge excursion shall be reported in accordance with the provisions in Section 13.6.

12.4.5 Energy Capacity Stability

After the peak shaving and frequency regulation duty cycles, the stored energy capacity test shall be repeated. After the use case testing, the stored energy capacity, response & ramp rate test and internal resistance test shall be repeated.

The energy capacity stability of the BESS shall be determined by dividing the stored energy capacity by the initial stored energy capacity of the BESS. Stored energy capacity shall be determined in accordance with Section 11.1. The capacity stability of the BESS is reported in accordance with the provisions in Section 13.2.

12.5 PSE Use Case Tests

12.5.1 Use Case 1: Energy Shifting

12.5.1.1 Energy Arbitrage

Energy arbitrage was modeled in BSET for a two-week period using historic Mid-C wholesale energy price data purchased from Powerdex for the 2011-2016 time period. PSE is expected to run the arbitrage duty cycle for only one week. The extra data allows PSE to begin the testing process on any day of the week and run it continuously for a one week period.

In running the duty cycle, the following procedures should be performed:

1. ESS shall first be brought to a SOC of 41%.
2. The ESS is then subjected to the duty cycle outlined in Appendix A. The day of the week in which the test begins should correspond to the same day of the week identified in the duty cycle. The duty cycle should then be run continuously until the completion of the seventh day of testing.

One week of the duty cycle generated by BSET is presented in Figure 12.3. The dashed line represents the modeled SOC of the battery system over the use case test. The modeled case assumes an average RTE of 87% and SOC operating limits of 20% and 80%.

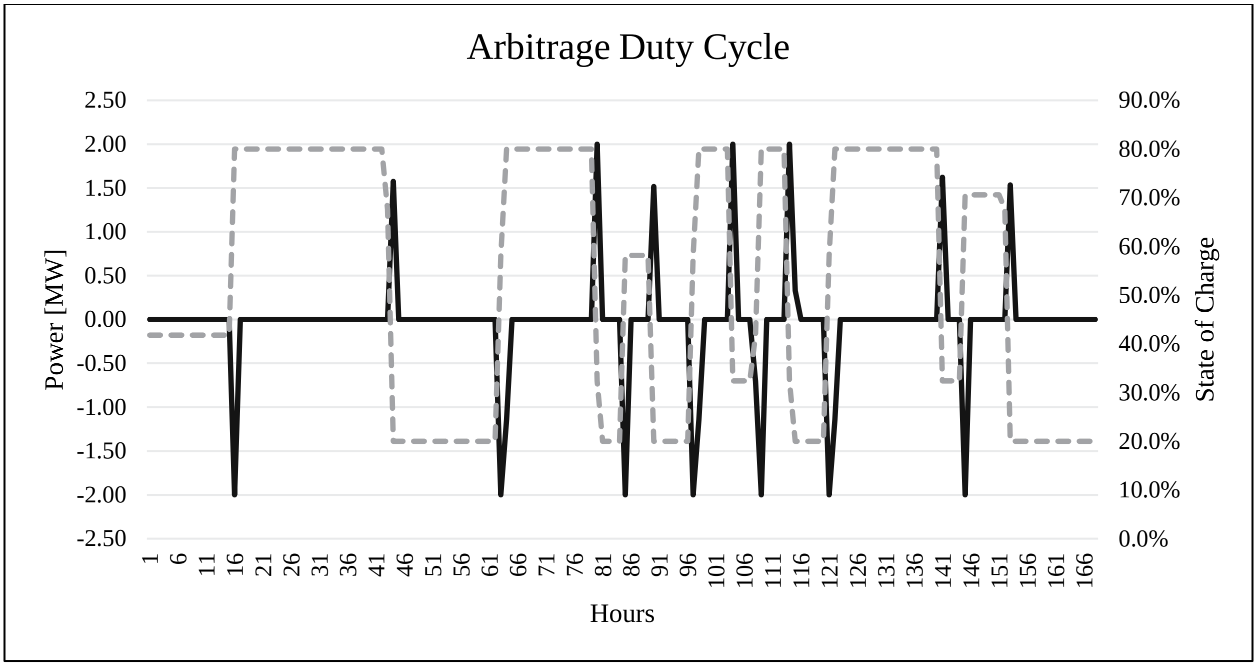


Figure 12.3. Arbitrage Duty Cycle over One-Week Period

12.5.1.2 System Capacity to Meet Adequacy Requirements

The capacity duty cycle is developed as a seven-day charging/discharging schedule with discharging periods of 1-4 hours. As this duty cycle contains a large number of resting periods, and the control system of this battery is configured in such a manner that requires the battery to discharge for providing auxiliary power, the SOC level depletes during the resting periods. Adjustments are made in the duty cycle to account for these depletions so that SOC does not cross the limits of 20% to 80%.

In running the duty cycle, the following procedures should be performed:

1. ESS shall first be brought to an SOC of 22.3%, which is a calculated SOC level considering the depletion.
2. The ESS is then subjected to the duty cycle outlined in Appendix A. The day of the week in which the test begins should correspond to the same day of the week identified in the duty cycle. The duty cycle should then be run continuously until the completion of the seventh day of testing.

The duty cycle is presented in Figure 12.4. The dashed line represents the modeled SOC of the battery system over the use case test.

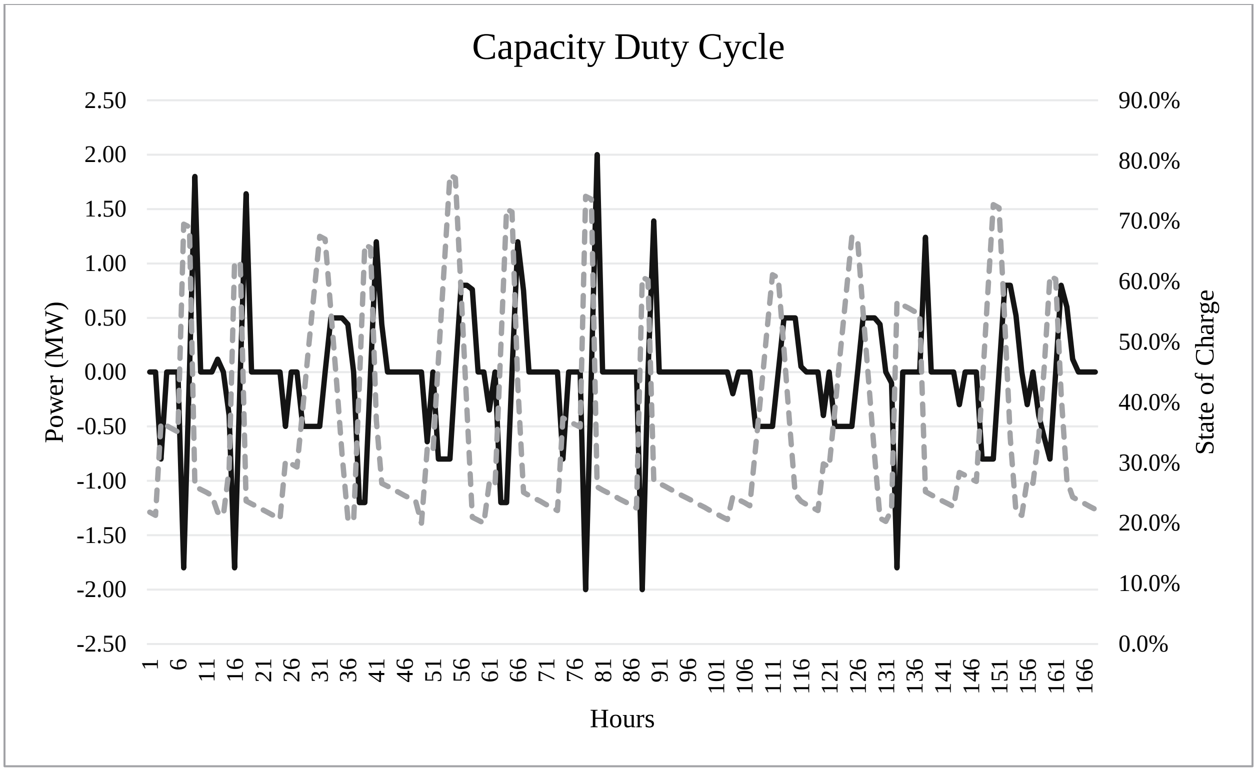


Figure 12.4. Capacity Duty Cycle over One-week Period

12.5.2 Use Case 2: Provide Grid Flexibility

12.5.2.1 Regulation

The duty cycle for this test is developed by scaling down the area control error (ACE) signal (MW) provided by PSE using a response factor (kW/MW) to match the rated power capacity of the ESS. The value of the response factor is negative to direct the ESS to act against ACE. A recent one-week sample of ACE signal was collected from PSE.

The test will be conducted with the duty cycle based on only one day's ACE signal, depending on the day of the week it starts. Three one-day runs will be performed using the same ACE, but with three response factors. Initial assumptions of these factors are made based on statistical analysis of the signal to determine the range where 99% of the ACE signal values fall (Mean ± 3σ rule). However, response factor values will be finalized by observing the resulting SOC spread.

The starting SOC of the test is determined based on the signal's energy neutrality. If the signal is charge (or discharge) intensive, starting SOC will need to be near the minimum (or maximum) limit so that the duty cycle does not cause SOC limits to be crossed at the end of each run. The ESS will be discharged (or charged) as necessary to bring the SOC down to a specific level before the start of the next run. This level will depend on the SOC spread resulting from the signal. A duty cycle for a 24-hour run of this test is shown in Figure 12.5 and data corresponding to the first 30 minutes of this duty cycle is provided in Appendix A. The particular segment of the duty cycle is selected based on PSE's preferred starting day and time and is a charge-intensive signal. Therefore, the ESS needs to be discharged after each run of the duty cycle to a desired level before the next run is started.

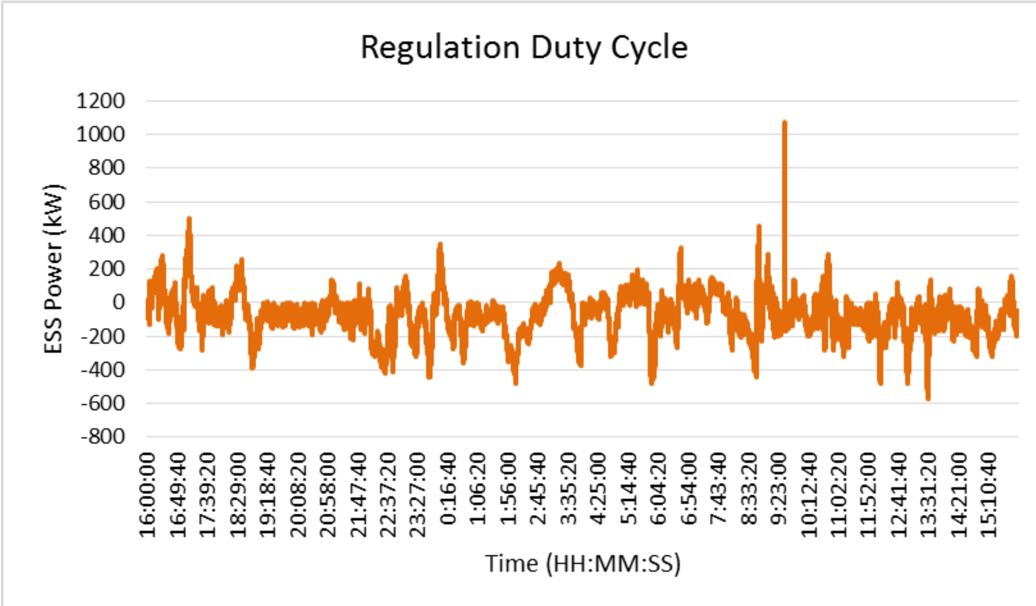


Figure 12.5. Regulation Duty Cycle over 24-hours Period

12.5.2.2 Load Following

The duty cycle for this test was developed by smoothing the regulation duty cycle. Smoothing is performed by taking the five-minute moving average of the regulation duty cycle. A load following duty cycle for a 24-hour run is shown in Figure 12.6 and data corresponding to the first 30 minutes of this duty cycle is provided in Appendix A.

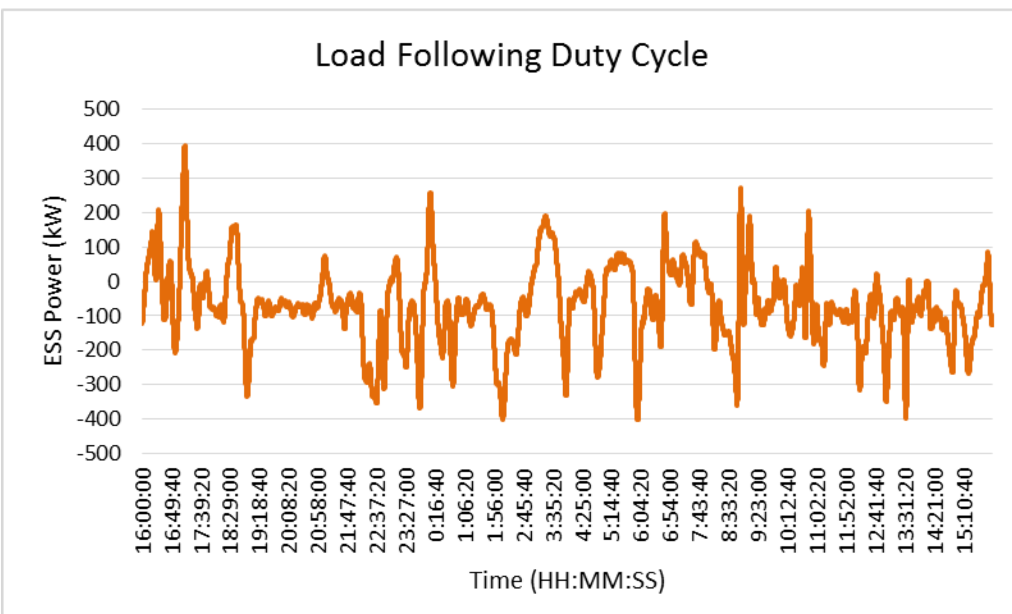


Figure 12.6. Load Following Duty Cycle over 24-hour Period

12.5.2.3 Real World Flexibility

This service is related to capacity firming of variable generation resources, such as wind or solar farms. The idea is to control ESS power such that the wind or solar farm output could be used as a "firm" generation capacity for a given period of time. The level where the output will be firmed up and for how long would depend on many aspects, including system conditions and market or hosting utility's requirements. ESS will import power (charge) from the wind/solar farm if there is over generation with respect to a given firm level and will export power (discharge) if there is under generation with the same reference firm level. For PSE, the duty cycle for this test is developed using total wind generation and system load data provided by PSE at 10-second intervals. The difference between hourly average of system load and base generation is considered as the hourly firm capacity for this duty cycle. The average of the difference between 10-second samples of system load and wind generation taken at 12-hour intervals is used as base generation for this duty cycle. The ESS output obtained using this approach is then scaled down to PSE's ESS rated power levels by retaining the signal's asymmetry (i.e., unequal maximum charge and discharge power) and maintaining the SOC limits between 20% to 80%. The duty cycle is shown in Figure 12.7 and actual data for the first one-hour duty cycle is provided in Appendix A.

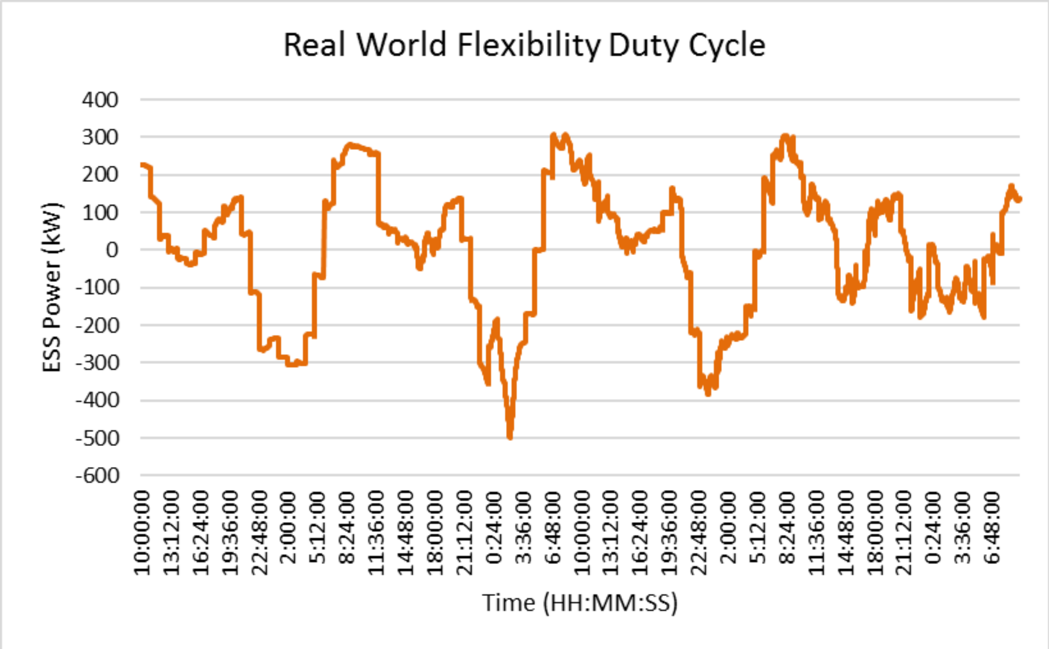


Figure 12.7. Real-World Flexibility Duty Cycle over Four Days

12.5.3 Use Case 3: Improving Distribution System Efficiency

12.5.3.1 Load Shaping

Understanding the capability of the ESS to perform this use case is important from a distribution deferment and renewable energy integration perspective. This use case could be tested using a number of different approaches. For example, a typical peak shaving approach could be used to control the battery power in such a manner that the loading of the circuit does not exceed a predefined level. This is relevant to the distribution investment deferment application. Another method could be to control ESS power to limit the load ramp rate dP/dt within a limit. This is more relevant to renewable energy penetration into the circuit.

Discussion with PSE personnel determined that there was no economic benefit associated with load shaping near Glacier, Washington, due to an absence of PV penetration and no distribution constraints. It was, however, decided that the battery tests should be conducted for this use case in order to learn if the ESS is technically able to provide this service if necessary at any later time or at any other location in the PSE area. The approach used for developing the load shaping duty cycle is described below.

Peak load shaving to defer distribution upgrades and load ramp rate control to manage renewable integration are not issues of immediate concern on the test feeder. One of the next best candidates for load shaping could be to reduce the gap between the peak and valley of the daily load profile. Distribution system operators need to engage resources (e.g. voltage regulator/tap changer/capacitor bank operation) to mitigate the impact of this gap on a daily basis. Using storage to “flatten” daily load profiles could provide some benefit by reducing voltage regulator, tap changer, and capacitor bank operation.

To achieve a flatter load profile, first a reference load is selected approximately in the mid-region between peak and valley of a daily load profile. If multiple daily load profiles have to be considered, which is the case for this duty cycle, reference load could be varied by observation. Then, the difference between the reference load and actual load is scaled down by a “flatness factor” and added (if actual load is smaller than the reference load) to, or subtracted (if actual load is greater than the reference load) from the actual load. If the flatness factor is “1”, the resultant load profile would be a constant flat load profile-same as the reference load. Therefore, to achieve a load profile which is flatter but still retains the signature of the variations in the actual load profile, a flatness factor greater than “1” is used. As the power needed to achieve this load profile would be generated/consumed by the ESS, the value of the flatness factor is tuned by observing SOC variations and considering applicable SOC limits.

To accomplish a reasonable match in time of the year for use case testing, Glacier substation load data from April 22nd to April 30th, 2016, measured at 15-minute intervals by PSE is used. A closer match in time could not be achieved due to data quality issues. Observing the nature of load variations, reference load of 0.98 MW is used for the 22nd to 25th April data and 0.82 MW is used for the 26th to 30th April data. A flatness factor of 1.8 is used, considering the SOC limits of 20% and 80% for the ESS at PSE. The duty cycle is shown in Figure 12.8 and charging/discharging power data is provided in Appendix A.

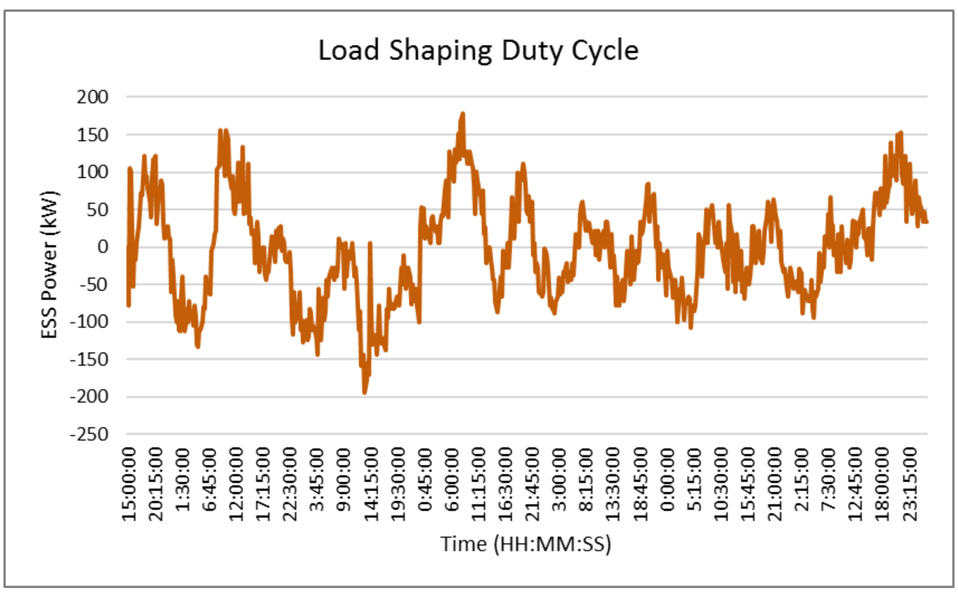


Figure 12.8. Load Shaping Duty Cycle over 6.5 Days

12.5.3.2 Deferment of Distribution Upgrade

The Glacier Substation serves only one feeder with a typical peak load of 2.5 MVA. The maximum observed load on the feeder during 2016 was 4 MVA, but that peak was mostly due to ESS charging during baseline testing. The transformer is rated at 5 MVA but could be loaded up to 6.6 MVA. The feeder circuit breaker is rated at 5 MVA. There is little load growth predicted for this feeder. The possibility of avoiding reconductoring by having an ESS is not under consideration because the ESS is adjacent to the substation site. Therefore, based on a result of a screening process undertaken with utility personnel, this use case component was not considered for economic evaluation.

To verify the technical ability of the ESS to provide this service at any later time or at any other location in PSE area, we decided to conduct the test. The same load data used for load shaping was used for this duty cycle. A typical load shaving approach was used, with a threshold of 0.95 MW. During the periods when load is lower than the threshold, ESS is charged so that stored energy is available for peak shaving. Charging is accomplished at such a rate that the total load including the charging load does not exceed 0.95 MW. Charging/discharging commands for the duty cycle are developed in a way that maintains SOC limits applicable for the ESS at PSE. The duty cycle is shown in Figure 12.9 and charging/discharging power data is provided in Table A.19.

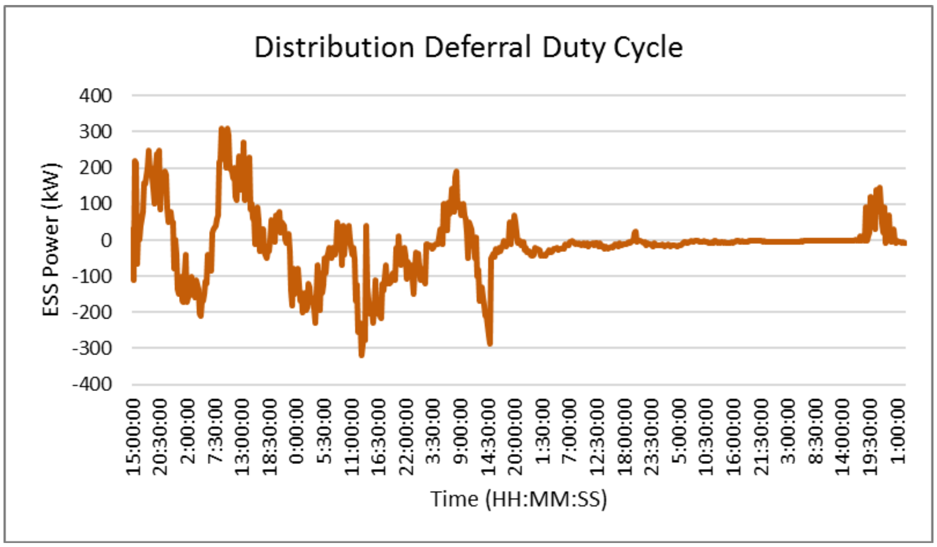


Figure 12.9. Distribution Deferral Duty Cycle over 6.5 Days

12.5.4 Use Case 4: Outage Management of Critical Loads

This use case tests the ability of an ESS to manage supply interruption to a critical load due to weather induced events or unplanned outages. PSE has the capacity to island a connected load of 510 KVA with a 350-400 KVA peak. In developing the duty cycles for this use case, PNNL obtained outage data from 2011-2015 at the Glacier site. Of the 17 outages that occurred during that time period, seven were randomly selected. Outage data for those seven outages were used to establish the outage dates and durations. Load data were obtained for the calendar days when the outage occurred (load data were from the 2016 time period). The load data for the entire feeder were reduced by 80% to account for the share of the feeder’s load that could be islanded. We then assumed that the ESS would meet the load on the island for as long a period during the outage as feasible.

Table 12.1 presents the duty cycles for Use Case 4. After each day's duty cycle is completed, the SOC should be brought back to and kept at 80% SOC prior to beginning the next day's test.

Table 12.1. Use Case 4 Duty Cycles (Load in MW)

Hour	Day of Testing						
	1	2	3	4	5	6	7
1		0.20					
2		0.40				0.20	
3		0.40		0.12		0.20	
4		0.40		0.12		0.27	
5	0.47	0.40		0.12		0.29	
6	0.50			0.13		0.35	
7	0.50			0.14		0.35	
8	0.50			0.14		0.35	
9			0.23	0.16			
10			0.36	0.14	0.50		
11					0.50		
12					0.50		0.36
13					0.46		
14					0.22		
15					0.13		
16					0.13		
17							
18							
19							
20							
21							
22							
23							
24							

13.0 Reporting PSE Performance Results

The performance of a BESS shall be reported by the manufacturer of the system in accordance with the provisions in Section 12.0 as determined in accordance with the applicable provisions of Section 11.0. PNNL will oversee all ESS testing operation and will be responsible for capturing and filling out all report documentation with support from PSE.

13.1 System Stored Energy Capacity and Roundtrip Efficiency.

The stored energy capacity of the ESS determined in accordance with the provisions in Section 11.1 and the RTE determined in accordance with the provisions in Section 11.1.1.3 shall be reported as provided in Table 13.1. Where additional testing is performed beyond the minimum required two cycles, an additional row shall be added for each cycle and the total charge and discharge energy shall be the sum of all values reported and the RTE based on those totals.

13.2 Energy Capacity and Stability

The energy capacity stability of the BESS shall be reported as a percent of initial performance as determined in accordance with Section 12.4.5 and as shown in Table 13.1, along with the date of the test upon which the reported value is based and the ambient temperature and barometric pressure during the test.

Table 13.1. Stored Energy Capacity and Roundtrip Efficiency at Rated Power – Baseline PS and FR Duty Cycles

Date					
Ambient Temperature °C					
Barometric Pressure, psia					
	Charge Energy (Wh)	Discharge Energy (Wh)	Cycle Roundtrip Efficiency	Cumulative RTE	Capacity stability (% of initial energy capacity)
Cycle 1	______	______	______		______
Cycle 2	______	______	______		______
Cycle 3	______	______	______		______
Sum cycle 1-3				______	
Sum cycle 2-3				______	

This calculation is done with and without auxiliary power, and with and without rest time. When auxiliary power is excluded, the results for with and without rest time are the same.

13.3 Response Time and Ramp Rate

The response times in seconds and ramp rates in megawatts per minute of the BESS shall be reported as determined in accordance with the provisions in Section 11.2 as shown in Table 13.2. This test is performed as part of baseline or reference performance test, and after use case tests.

Table 13.2. Response Time and Ramp Rate

Date			
Ambient Temperature °C			
Barometric Pressure, psia			
		Ramp rate	
Mode	Response time (T_2-T_1) (s)	MW/min	% rated power/min
Discharge			
Change with respect to baseline (Present – baseline)			
Charge			
Change with respect to baseline (Present – baseline)			

13.3.1 Internal Resistance Test

The internal resistance shall be reported in accordance with the provisions in Section 11.2 and as shown in Table 13.3. This test is done as part of baseline testing, and after use case tests.

Table 13.3. Internal Resistance of the BESS

Date:			
Ambient Temperature °C			
Barometric Pressure, psia			
	Internal Resistance Charge	Internal Resistance Discharge	
SOC, %			
90%			
80			
70			
60			
50			
40			
30			
20			
		NA	NA

13.4 Peak Shaving Duty-Cycle Results

The duty-cycle RTE shall be reported together with respect to discharge power and to the discharge duration based on the data collected in accordance with the provisions in Section 12.2.3. Table 13.4 shall be used to report the measured charge and discharge power and charge and discharge energy of the BESS, the percent of rated power during discharge, and the BESS duty-cycle roundtrip efficiency. The information in Table 13.4 shall also be created by PNNL in a graphical form, with the x-axis being the percentage rated power during discharge and the y-axis being the duty-cycle roundtrip efficiency.

Table 13.4. Peak Shaving Duty-Cycle Roundtrip Efficiency

Date	
Duration (h)	
RTE	
RTE, No Rest	
RTE, No Aux	
Charge Power (kW)	
Discharge Power (kW)	
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Average Charge Power (kW)	
Average Discharge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

This calculation is done with and without auxiliary power, and with and without rest time. When auxiliary power is excluded, the results for with and without rest time are the same.

13.5 Frequency-Regulation Applications

The performance of a BESS intended for a frequency regulation application shall be reported by the manufacturer in accordance with the provisions in Sections 13.6.1 and 13.6.2 as determined in accordance with the applicable provisions of Section 12.3.

13.5.1 Duty-Cycle Roundtrip Efficiency

The duty-cycle RTE shall be reported together with respect to peak discharge power divided by the energy of the BESS and to the discharge duration based on the data collected in accordance with the provisions in Section 12.4.2 (Table 13.5).

13.5.2 Reference Signal Tracking and SOC excursion

The reference signal tracking of the BESS shall be reported in accordance with the provisions in Section 12.4.3. The state-of-charge excursion shall be reported as determined in accordance with the provisions in Section 12.4.4. These results will be reported in Table 13.5.

Table 13.5. Frequency Regulation Metrics

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

13.6 Use Case Performance

Duty cycles for use case tests subject the ESS to a series of charge/discharge operations. Reporting of use case performance includes a summary of ESS operation during the period of a given test. For all of the use cases in general, information on test duration, minimum and maximum SOC, average charge/discharge power, RTE, operating temperature, and charge/discharge energy are reported. For tests that expose ESS to fast variations of real power (e.g. Regulation) or reactive power (Volt/VAR) in response to the duty cycle signal, performance reporting also includes metrics to understand how closely ESS followed the duty cycle (e.g. RMSE, Absolute Error). To avoid the impact of auxiliary consumption on these metrics, performance will be reported with and without considering auxiliary power consumption.

Performance reporting tables for each of the use case tests conducted for this utility are provided in the following subsections.

13.6.1 Use Case 1: Energy Shifting

13.6.1.1 Energy Arbitrage

The results for Energy Shifting duty cycle as described in Section 12.5.1.1 and performance metrics as described in Section 12.4 are shown in Table 13.6.

Table 13.6. Energy Arbitrage Performance

	Date
Duration (h)	
RTE	
RTE, No Rest	
RTE, No Aux	
Charge Power (kW)	
Discharge Power (kW)	
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Average Charge Power (kW)	
Average Discharge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

13.6.1.2 System Capacity to Meet Adequacy Requirements

The results for System Capacity to Meet Adequacy Requirements duty cycle as described in Section 12.5.1.2 and performance metrics as described in Section 12.4 are shown in Table 13.7.

Table 13.7. System Capacity Performance

	Date
Duration (h)	
RTE	
RTE, No Rest	
RTE, No Aux	
Charge Power (kW)	
Discharge Power (kW)	
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Average Charge Power (kW)	
Average Discharge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

13.6.2 Use Case 2: Provide Grid Flexibility

13.6.2.1 Regulation

The results for Regulation duty cycle as described in Section 12.5.2.1 and performance metrics as described in Section 12.4 are shown in Table 13.8.

Table 13.8. Regulation Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

13.6.2.2 Load Following

The results for System Capacity to Meet Adequacy Requirements duty cycle as described in Section 12.5.2.2 and performance metrics as described in Section 12.4 are shown in Table 13.9.

Table 13.9. Load Following Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW

Date
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

13.6.2.3 Real World Flexibility

The results for Real World Flexibility duty cycle as described in Section 12.5.2.3 and performance metrics as described in Section 12.4 are shown in Table 13.10.

Table 13.10. Real World Flexibility Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax

Date
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

13.6.3 Use Case 3: Improving Distribution System Efficiency

13.6.3.1 Volt/VAR

The results for Volt/VAR duty cycle as described in Section 12.5.3.1 and performance metrics as described in Section 12.4 are shown in Table 13.11.

Table 13.11. Volt/VAR Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Strings Active
Temp. °C
SOCMax
SOCMin
Maximum Reactive Power, kVAR
Reactive Power RMSE, kVAR.
Normalized Reactive Power RMSE, kVAR
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed, Reactive
% Time Signal Followed for > 10% Rated Power, Reactive
% Time Signal Followed with deviation < 1% Max Power, Reactive
Notes

13.6.3.2 Load Shaping

The results for Load Shaping duty cycle as described in Section 12.5.3.2 and performance metrics as described in Section 12.4 are shown in Table 13.12.

Table 13.12. Load Shaping Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
RMSE (kW)
RMSE, No Aux (kW)
Normalized RMSE, kW/kW
Normalized RMSE, No Aux, kW/kW
Mean Absolute Error, kW
Mean Absolute Error no Aux, (kW)
% Time Signal Followed
% Time Signal Followed, No Aux
Mean Absolute Error (kWh)
Mean Absolute Error, No Aux (kWh)
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
% Time Signal Followed for > 10% Rated Power
% Time Signal Followed for > 10% Rated Power, No Aux
% Time Signal Followed with deviation < 1% Max Power, No Aux

13.6.3.3 Deferment of Distribution Upgrade

The results for System Capacity to Meet Adequacy Requirements duty cycle as described in Section 12.5.3.2 and performance metrics as described in Section 12.4 are shown in Table 13.13.

Table 13.13. Distribution Deferral Performance

Date
Duration (h)
RTE
RTE, No Rest
RTE, No Aux
Charge Power (kW)
Discharge Power (kW)
Strings Active
Temp. °C
SOCMax
SOCMin
Average Charge Power (kW)

Date	
Average Discharge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

13.6.4 Use Case 4: Outage Management of Critical Loads

Table 13.14. Outage Mitigation Performance

Date	
Outage Duration (h)	
RTE (based on bring BESS to initial SOC)	
RTE, No Aux	
Charge Power (kW)	
Discrete Discharge Power Levels / duration (kW / h)	kW1 / T1, kW2 / T2….
# Strings Active	
Temp. °C	
SOCMax	
SOCMin	
Average Discharge Power (kW)	
Average Charge Power (kW)	
Discharge Energy (kWh)	
Charge Energy (kWh)	
Discharge Duration (h)	
Charge Duration (h)	

14.0 References

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Appendix A

Actual Charge/Discharge Power Data

Appendix A

Actual Charge/Discharge Power Data

Actual charge/discharge power data corresponding to the use case tests conducted for each of the utilities is provided in the tables below. Data for duty cycles with high resolution (e.g. 4 seconds, 10 seconds) is provided for a limited duration.

Table A.1. Duty Cycle for Arbitrage Test at Avista

DateTime*	kW	kVAR	Command
20160120T030000	399	0	End of cycle SOC: 0.367
20160120T040000	399	0	End of cycle SOC: 0.234
20160120T050000	267	0	End of cycle SOC: 0.145
20160120T060000	399	0	End of cycle SOC: 0.012
20160120T070000	36	0	End of cycle SOC: 0
20160120T080000	-600	0	End of cycle SOC: 0.128
20160120T090000	-600	0	End of cycle SOC: 0.256
20160120T100000	-600	0	End of cycle SOC: 0.384
20160120T110000	-600	0	End of cycle SOC: 0.512
20160120T120000	-600	0	End of cycle SOC: 0.64
20160120T130000	-497	0	End of cycle SOC: 0.746
20160120T140000	-596	0	End of cycle SOC: 0.873
20160120T150000	-596	0	End of cycle SOC: 1
20160120T160000	399	0	End of cycle SOC: 0.867
20160120T170000	399	0	End of cycle SOC: 0.734
20160120T180000	399	0	End of cycle SOC: 0.601
20160120T190000	0	0	End of cycle SOC: 0.601
20160120T200000	-132	0	End of cycle SOC: 0.629
20160120T210000	-600	0	End of cycle SOC: 0.757
20160120T220000	0	0	End of cycle SOC: 0.757
20160120T230000	0	0	End of cycle SOC: 0.757
20160121T000000	0	0	End of cycle SOC: 0.757
20160121T010000	-68	0	End of cycle SOC: 0.7715
20160121T020000	-472	0	End of cycle SOC: 0.872

* DateTime format: YYYYMMDDTHHMMSS

Table A.2. Duty Cycle for System Capacity to Meet Adequacy Requirements at Avista

DateTime	kW	kVAR
20161105T055000	0	0
20161105T060000	335	0
20161105T090000	0	0
20161105T091500	-330	0
20161105T153000	0	0
20161105T160000	335	0
20161105T190000	0	0
20161105T220000	-300	0
20161106T050000	0	0
20161106T060000	335	0
20161106T090000	0	0
20161106T091500	-330	0
20161106T153000	0	0
20161106T160000	335	0
20161106T190000	0	0
20161106T220000	-300	0
20161107T050000	0	0
20161107T060000	335	0
20161107T090000	0	0
20161107T091500	-330	0
20161107T153000	0	0
20161107T160000	335	0
20161107T190000	0	0
20161107T190500	OPEN	0

Table A.3. Duty Cycle for Regulation test at Avista

DateTime	kW	kVAR	DateTime	kW	kVAR
20160219T143500	-300	0	20160219T163224	42	0
20160219T143800	WAITSOC	60	20160219T163228	0	0
20160219T162000	0	0	20160219T163232	0	0
20160219T163000	359	0	20160219T163236	0	0
20160219T163004	376	0	20160219T163240	-86	0
20160219T163008	51	0	20160219T163244	0	0
20160219T163012	73	0	20160219T163248	-35	0
20160219T163016	60	0	20160219T163252	0	0
20160219T163020	0	0	20160219T163256	69	0
20160219T163024	39	0	20160219T163300	0	0
20160219T163028	55	0	20160219T163304	-30	0
20160219T163032	-49	0	20160219T163308	-32	0
20160219T163036	21	0	20160219T163312	79	0
20160219T163040	-24	0	20160219T163316	26	0
20160219T163044	24	0	20160219T163320	24	0
20160219T163048	-25	0	20160219T163324	46	0
20160219T163052	317	0	20160219T163328	50	0
20160219T163056	317	0	20160219T163332	0	0
20160219T163100	330	0	20160219T163336	-21	0
20160219T163104	302	0	20160219T163340	0	0
20160219T163108	303	0	20160219T163344	93	0
20160219T163112	209	0	20160219T163348	41	0
20160219T163116	152	0	20160219T163352	0	0
20160219T163120	-127	0	20160219T163356	29	0
20160219T163124	-52	0	20160219T163400	64	0
20160219T163128	-114	0	20160219T163404	131	0
20160219T163132	-39	0	20160219T163408	38	0
20160219T163136	-53	0	20160219T163412	25	0
20160219T163140	0	0	20160219T163416	94	0
20160219T163144	-65	0	20160219T163420	75	0
20160219T163148	-66	0	20160219T163424	209	0
20160219T163152	0	0	20160219T163428	211	0
20160219T163156	-32	0	20160219T163432	186	0
20160219T163200	-32	0	20160219T163436	170	0
20160219T163204	0	0	20160219T163440	184	0
20160219T163208	0	0	20160219T163444	37	0
20160219T163212	0	0	20160219T163448	107	0
20160219T163216	65	0	20160219T163452	167	0
20160219T163220	34	0	20160219T163456	171	0
20160219T163224	42	0	20160219T163500	26	0

Table A.4a. Duty Cycle for Load Following (5-min moving average) at Avista

DateTime	kW	kVAR	DateTime	kW	kVAR
20160221T213500	-300	0	20160221T231728	39	0
20160221T213800	WAITSOC	60	20160221T231732	39	0
20160221T230500	0	0	20160221T231736	40	0
20160221T231500	60	0	20160221T231740	40	0
20160221T231504	56	0	20160221T231744	43	0
20160221T231508	51	0	20160221T231748	44	0
20160221T231512	50	0	20160221T231752	44	0
20160221T231516	50	0	20160221T231756	44	0
20160221T231520	52	0	20160221T231800	43	0
20160221T231524	54	0	20160221T231804	42	0
20160221T231528	55	0	20160221T231808	43	0
20160221T231532	56	0	20160221T231812	43	0
20160221T231536	59	0	20160221T231816	42	0
20160221T231540	60	0	20160221T231820	41	0
20160221T231544	61	0	20160221T231824	42	0
20160221T231548	60	0	20160221T231828	42	0
20160221T231552	60	0	20160221T231832	41	0
20160221T231556	55	0	20160221T231836	42	0
20160221T231600	50	0	20160221T231840	42	0
20160221T231604	46	0	20160221T231844	42	0
20160221T231608	42	0	20160221T231848	39	0
20160221T231612	38	0	20160221T231852	37	0
20160221T231616	35	0	20160221T231856	36	0
20160221T231620	33	0	20160221T231900	35	0
20160221T231624	34	0	20160221T231904	35	0
20160221T231628	36	0	20160221T231908	34	0
20160221T231632	39	0	20160221T231912	34	0
20160221T231636	40	0	20160221T231916	33	0
20160221T231640	40	0	20160221T231920	32	0
20160221T231644	39	0	20160221T231924	31	0
20160221T231648	40	0	20160221T231928	29	0
20160221T231652	41	0	20160221T231932	26	0
20160221T231656	42	0	20160221T231936	23	0
20160221T231700	42	0	20160221T231940	20	0
20160221T231704	41	0	20160221T231944	16	0
20160221T231708	41	0	20160221T231948	14	0
20160221T231712	41	0	20160221T231952	11	0
20160221T231716	42	0	20160221T231956	6	0
20160221T231720	40	0	20160221T232000	2	0
20160221T231724	39	0			

Table A.4b. Duty Cycle for Load Following (Auto Mode) at Avista

DateTime	kW	kVAR
20160229T103400	-300	0
20160229T103500	WAITSOCGT	60
20160229T113500	0	0
20160229T113600	ACEAVGSLIM	1440
20160301T113700	-300	0
20160301T113800	WAITSOCGT	60
20160301T153700	0	0

Table A.5. Duty Cycle for Real World Flexibility at Avista

DateTime	kW	kVAR
20160314T123500	520	0
20160314T123600	WAITSOCLT	25
20160314T213500	0	0
20160314T213600	ACESLIM	2880
20160316T213700	0	0

Table A.6. Duty Cycle for Volt/VAR at Avista

DateTime	kW	kVAR
20160317T113500	0	0
20160317T114000	PFREG	1440
20160318T114100	0	0

Table A.7. Duty Cycle for Load Shaping at Avista

Date/Time	kW	kVAR	Date/Time	kW	kVAR
20160401T173500	0	0	20160401T224610	29.26	0
20160401T174000	-300	0	20160401T224620	27.794	0
20160401T174100	WAITSOCGT	85	20160401T224630	26.435	0
20160401T224000	-20.8485	0	20160401T224640	25.1995	0
20160401T224010	-18.188	0	20160401T224650	24.1	0
20160401T224020	-15.077	0	20160401T224700	23.1425	0
20160401T224030	-11.552	0	20160401T224710	22.324	0
20160401T224040	-7.6635	0	20160401T224720	21.6365	0
20160401T224050	-3.4769	0	20160401T224730	21.064	0
20160401T224100	0.927	0	20160401T224740	20.585	0
20160401T224110	5.4615	0	20160401T224750	20.177	0
20160401T224120	10.0425	0	20160401T224800	19.8205	0
20160401T224130	14.594	0	20160401T224810	19.494	0
20160401T224140	19.0415	0	20160401T224820	19.172	0
20160401T224150	23.315	0	20160401T224830	18.8275	0
20160401T224200	27.353	0	20160401T224840	18.4335	0
20160401T224210	31.1055	0	20160401T224850	17.9605	0
20160401T224220	34.531	0	20160401T224900	17.38	0
20160401T224230	37.5975	0	20160401T224910	16.6675	0
20160401T224240	40.2855	0	20160401T224920	15.809	0
20160401T224250	42.584	0	20160401T224930	14.799	0
20160401T224300	44.4875	0	20160401T224940	13.636	0
20160401T224310	45.9935	0	20160401T224950	12.3255	0
20160401T224320	47.102	0	20160401T225000	10.882	0
20160401T224330	47.8165	0			
20160401T224340	48.1455	0			
20160401T224350	48.1095	0			
20160401T224400	47.7405	0			
20160401T224410	47.0775	0			
20160401T224420	46.161	0			
20160401T224430	45.0295	0			
20160401T224440	43.723	0			
20160401T224450	42.2805	0			
20160401T224500	40.7355	0			
20160401T224510	39.1195	0			
20160401T224520	37.459	0			
20160401T224530	35.779	0			
20160401T224540	34.0975	0			
20160401T224550	32.435	0			
20160401T224600	30.8145	0			

Table A.8. Duty Cycle for Deferment of Distribution Deferral at Avista

DateTime	kW	kVAR
20160421T173500	0	0
20160421T174000	-300	0
20160421T174100	WAITSOCGT	95
20160421T224000	PKSHV (Duration: 720minutes)	-
20160422T104100	0	0
20160422T104600	OPEN	0

Table A.9a. Duty Cycle for Microgrid Test at Avista (Solar and Wind, No Regulation)

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:00:00	319	16:02:20	4	16:04:40	-4
16:00:04	316	16:02:24	4	16:04:44	-5
16:00:08	313	16:02:28	4	16:04:48	-5
16:00:12	42	16:02:32	3	16:04:52	-6
16:00:16	38	16:02:36	3	16:04:56	-7
16:00:20	35	16:02:40	2	16:05:00	-7
16:00:24	32	16:02:44	2	16:05:04	-7
16:00:28	29	16:02:48	1	16:05:08	-7
16:00:32	25	16:02:52	1	16:05:12	-7
16:00:36	22	16:02:56	1	16:05:16	-7
16:00:40	19	16:03:00	0	16:05:20	-7
16:00:44	15	16:03:04	0	16:05:24	-7
16:00:48	12	16:03:08	0	16:05:28	-7
16:00:52	9	16:03:12	0	16:05:32	-7
16:00:56	6	16:03:16	1	16:05:36	-7
16:01:00	273	16:03:20	1	16:05:40	-7
16:01:04	273	16:03:24	1	16:05:44	-7
16:01:08	273	16:03:28	1	16:05:48	-7
16:01:12	273	16:03:32	1	16:05:52	-7
16:01:16	273	16:03:36	1	16:05:56	-7
16:01:20	273	16:03:40	1	16:06:00	-7
16:01:24	273	16:03:44	1	16:06:04	-8
16:01:28	273	16:03:48	1	16:06:08	-8
16:01:32	274	16:03:52	1	16:06:12	-9
16:01:36	6	16:03:56	1	16:06:16	-10
16:01:40	6	16:04:00	2	16:06:20	-10
16:01:44	6	16:04:04	1	16:06:24	-11
16:01:48	6	16:04:08	0	16:06:28	-12
16:01:52	6	16:04:12	0	16:06:32	-13
16:01:56	6	16:04:16	-1	16:06:36	-13
16:02:00	6	16:04:20	-1	16:06:40	-14
16:02:04	6	16:04:24	-2	16:06:44	-15
16:02:08	6	16:04:28	-3	16:06:48	-15
16:02:12	5	16:04:32	-3	16:06:52	-16
16:02:16	5	16:04:36	-4	16:06:56	-17

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:07:00	-18	16:09:20	-26	16:11:40	-36
16:07:04	-18	16:09:24	-26	16:11:44	-36
16:07:08	-18	16:09:28	-27	16:11:48	-36
16:07:12	-18	16:09:32	-27	16:11:52	-37
16:07:16	-18	16:09:36	-27	16:11:56	-37
16:07:20	-18	16:09:40	-28	16:12:00	-37
16:07:24	-19	16:09:44	-28	16:12:04	-37
16:07:28	-19	16:09:48	-28	16:12:08	-37
16:07:32	-19	16:09:52	-28	16:12:12	-36
16:07:36	-19	16:09:56	-29	16:12:16	-36
16:07:40	-19	16:10:00	-29	16:12:20	-36
16:07:44	-19	16:10:04	-29	16:12:24	-36
16:07:48	-20	16:10:08	-30	16:12:28	-36
16:07:52	-20	16:10:12	-30	16:12:32	-36
16:07:56	-20	16:10:16	-31	16:12:36	-36
16:08:00	-20	16:10:20	-31	16:12:40	-36
16:08:04	-20	16:10:24	-32	16:12:44	-36
16:08:08	-21	16:10:28	-32	16:12:48	-35
16:08:12	-21	16:10:32	-32	16:12:52	-35
16:08:16	-21	16:10:36	-33	16:12:56	-35
16:08:20	-22	16:10:40	-33	16:13:00	-35
16:08:24	-22	16:10:44	-34	16:13:04	-35
16:08:28	-22	16:10:48	-34	16:13:08	-36
16:08:32	-23	16:10:52	-34	16:13:12	-36
16:08:36	-23	16:10:56	-35	16:13:16	-36
16:08:40	-23	16:11:00	-35	16:13:20	-37
16:08:44	-23	16:11:04	-35	16:13:24	-37
16:08:48	-24	16:11:08	-35	16:13:28	-37
16:08:52	-24	16:11:12	-35	16:13:32	-38
16:08:56	-24	16:11:16	-36	16:13:36	-38
16:09:00	-25	16:11:20	-36	16:13:40	-38
16:09:04	-25	16:11:24	-36	16:13:44	-39
16:09:08	-25	16:11:28	-36	16:13:48	-39
16:09:12	-26	16:11:32	-36	16:13:52	-39
16:09:16	-26	16:11:36	-36	16:13:56	-40

Table A.9b. Duty Cycle for Microgrid Test at Avista (Solar and Wind, with Regulation)

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:00:00	438	16:02:20	-80	16:04:40	6
16:00:04	429	16:02:24	-96	16:04:44	15
16:00:08	430	16:02:28	-113	16:04:48	19
16:00:12	89	16:02:32	-131	16:04:52	23
16:00:16	89	16:02:36	-149	16:04:56	28
16:00:20	90	16:02:40	-168	16:05:00	34
16:00:24	90	16:02:44	-187	16:05:04	40
16:00:28	83	16:02:48	-206	16:05:08	52
16:00:32	75	16:02:52	-224	16:05:12	64
16:00:36	63	16:02:56	-244	16:05:16	73
16:00:40	48	16:03:00	-265	16:05:20	80
16:00:44	34	16:03:04	-286	16:05:24	87
16:00:48	22	16:03:08	-292	16:05:28	97
16:00:52	11	16:03:12	-298	16:05:32	107
16:00:56	3	16:03:16	-299	16:05:36	115
16:01:00	339	16:03:20	-295	16:05:40	121
16:01:04	336	16:03:24	-291	16:05:44	127
16:01:08	342	16:03:28	-282	16:05:48	131
16:01:12	348	16:03:32	-268	16:05:52	135
16:01:16	351	16:03:36	-249	16:05:56	138
16:01:20	352	16:03:40	-226	16:06:00	142
16:01:24	352	16:03:44	-203	16:06:04	144
16:01:28	348	16:03:48	-175	16:06:08	149
16:01:32	343	16:03:52	-148	16:06:12	153
16:01:36	-2	16:03:56	-120	16:06:16	160
16:01:40	-8	16:04:00	-93	16:06:20	170
16:01:44	-13	16:04:04	-67	16:06:24	179
16:01:48	-22	16:04:08	-51	16:06:28	190
16:01:52	-31	16:04:12	-36	16:06:32	201
16:01:56	-37	16:04:16	-26	16:06:36	207
16:02:00	-42	16:04:20	-23	16:06:40	208
16:02:04	-47	16:04:24	-19	16:06:44	209
16:02:08	-51	16:04:28	-15	16:06:48	202
16:02:12	-55	16:04:32	-10	16:06:52	194
16:02:16	-65	16:04:36	-3	16:06:56	184

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:07:00	170	16:09:20	-257	16:11:40	41
16:07:04	157	16:09:24	-266	16:11:44	56
16:07:08	148	16:09:28	-274	16:11:48	74
16:07:12	140	16:09:32	-283	16:11:52	92
16:07:16	132	16:09:36	-286	16:11:56	107
16:07:20	126	16:09:40	-284	16:12:00	120
16:07:24	120	16:09:44	-282	16:12:04	133
16:07:28	112	16:09:48	-272	16:12:08	144
16:07:32	104	16:09:52	-262	16:12:12	155
16:07:36	93	16:09:56	-257	16:12:16	162
16:07:40	78	16:10:00	-253	16:12:20	167
16:07:44	63	16:10:04	-249	16:12:24	171
16:07:48	47	16:10:08	-239	16:12:28	179
16:07:52	31	16:10:12	-230	16:12:32	187
16:07:56	14	16:10:16	-220	16:12:36	194
16:08:00	-5	16:10:20	-209	16:12:40	202
16:08:04	-23	16:10:24	-198	16:12:44	209
16:08:08	-43	16:10:28	-189	16:12:48	212
16:08:12	-62	16:10:32	-180	16:12:52	216
16:08:16	-77	16:10:36	-169	16:12:56	219
16:08:20	-89	16:10:40	-157	16:13:00	221
16:08:24	-102	16:10:44	-144	16:13:04	223
16:08:28	-109	16:10:48	-127	16:13:08	226
16:08:32	-116	16:10:52	-110	16:13:12	228
16:08:36	-123	16:10:56	-93	16:13:16	234
16:08:40	-130	16:11:00	-76	16:13:20	245
16:08:44	-138	16:11:04	-59	16:13:24	256
16:08:48	-158	16:11:08	-40	16:13:28	266
16:08:52	-179	16:11:12	-21	16:13:32	276
16:08:56	-187	16:11:16	-12	16:13:36	281
16:09:00	-192	16:11:20	-8	16:13:40	281
16:09:04	-197	16:11:24	-3	16:13:44	280
16:09:08	-216	16:11:28	6	16:13:48	271
16:09:12	-235	16:11:32	15	16:13:52	262
16:09:16	-248	16:11:36	27	16:13:56	251

Table A.9c. Duty Cycle for Microgrid Test at Avista (Without Solar and Wind, No Regulation)

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:00:00	61	16:02:20	-176	16:04:40	-178
16:00:04	58	16:02:24	-176	16:04:44	-178
16:00:08	55	16:02:28	-176	16:04:48	-178
16:00:12	-145	16:02:32	-176	16:04:52	-178
16:00:16	-148	16:02:36	-176	16:04:56	-178
16:00:20	-151	16:02:40	-176	16:05:00	-178
16:00:24	-154	16:02:44	-177	16:05:04	-178
16:00:28	-156	16:02:48	-177	16:05:08	-178
16:00:32	-159	16:02:52	-177	16:05:12	-178
16:00:36	-162	16:02:56	-177	16:05:16	-178
16:00:40	-165	16:03:00	-177	16:05:20	-178
16:00:44	-167	16:03:04	-177	16:05:24	-178
16:00:48	-170	16:03:08	-177	16:05:28	-178
16:00:52	-173	16:03:12	-177	16:05:32	-178
16:00:56	-175	16:03:16	-177	16:05:36	-178
16:01:00	22	16:03:20	-177	16:05:40	-178
16:01:04	22	16:03:24	-177	16:05:44	-178
16:01:08	22	16:03:28	-177	16:05:48	-178
16:01:12	22	16:03:32	-177	16:05:52	-178
16:01:16	22	16:03:36	-177	16:05:56	-179
16:01:20	22	16:03:40	-177	16:06:00	-179
16:01:24	22	16:03:44	-177	16:06:04	-179
16:01:28	22	16:03:48	-177	16:06:08	-179
16:01:32	22	16:03:52	-177	16:06:12	-179
16:01:36	-176	16:03:56	-177	16:06:16	-179
16:01:40	-176	16:04:00	-177	16:06:20	-179
16:01:44	-176	16:04:04	-177	16:06:24	-179
16:01:48	-176	16:04:08	-177	16:06:28	-179
16:01:52	-176	16:04:12	-177	16:06:32	-179
16:01:56	-176	16:04:16	-177	16:06:36	-179
16:02:00	-176	16:04:20	-178	16:06:40	-179
16:02:04	-176	16:04:24	-178	16:06:44	-179
16:02:08	-176	16:04:28	-178	16:06:48	-179
16:02:12	-176	16:04:32	-178	16:06:52	-179
16:02:16	-176	16:04:36	-178	16:06:56	-179

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:07:00	-179	16:09:20	-181	16:11:40	-182
16:07:04	-179	16:09:24	-181	16:11:44	-182
16:07:08	-179	16:09:28	-181	16:11:48	-182
16:07:12	-179	16:09:32	-181	16:11:52	-182
16:07:16	-179	16:09:36	-181	16:11:56	-182
16:07:20	-179	16:09:40	-181	16:12:00	-182
16:07:24	-179	16:09:44	-181	16:12:04	-182
16:07:28	-179	16:09:48	-181	16:12:08	-182
16:07:32	-180	16:09:52	-181	16:12:12	-182
16:07:36	-180	16:09:56	-181	16:12:16	-182
16:07:40	-180	16:10:00	-181	16:12:20	-183
16:07:44	-180	16:10:04	-181	16:12:24	-183
16:07:48	-180	16:10:08	-181	16:12:28	-183
16:07:52	-180	16:10:12	-181	16:12:32	-183
16:07:56	-180	16:10:16	-181	16:12:36	-183
16:08:00	-180	16:10:20	-181	16:12:40	-183
16:08:04	-180	16:10:24	-181	16:12:44	-183
16:08:08	-180	16:10:28	-181	16:12:48	-183
16:08:12	-180	16:10:32	-181	16:12:52	-183
16:08:16	-180	16:10:36	-181	16:12:56	-183
16:08:20	-180	16:10:40	-181	16:13:00	-183
16:08:24	-180	16:10:44	-182	16:13:04	-183
16:08:28	-180	16:10:48	-182	16:13:08	-183
16:08:32	-180	16:10:52	-182	16:13:12	-183
16:08:36	-180	16:10:56	-182	16:13:16	-183
16:08:40	-180	16:11:00	-182	16:13:20	-183
16:08:44	-180	16:11:04	-182	16:13:24	-183
16:08:48	-180	16:11:08	-182	16:13:28	-183
16:08:52	-180	16:11:12	-182	16:13:32	-183
16:08:56	-180	16:11:16	-182	16:13:36	-183
16:09:00	-180	16:11:20	-182	16:13:40	-183
16:09:04	-180	16:11:24	-182	16:13:44	-183
16:09:08	-181	16:11:28	-182	16:13:48	-183
16:09:12	-181	16:11:32	-182	16:13:52	-183
16:09:16	-181	16:11:36	-182	16:13:56	-184

Table A.10. Duty Cycle for Arbitrage Test at SnoPUD MESA1

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
1	-0.95	36	0.00	71	0.00
2	0.00	37	0.00	72	0.00
3	0.00	38	-0.95	73	0.00
4	0.00	39	0.00	74	-0.95
5	0.00	40	0.00	75	0.00
6	0.00	41	0.00	76	0.00
7	0.00	42	0.00	77	0.00
8	0.00	43	0.00	78	0.00
9	0.80	44	0.80	79	0.00
10	0.00	45	0.00	80	0.80
11	0.00	46	0.00	81	0.00
12	-0.95	47	0.00	82	0.00
13	0.00	48	0.00	83	0.00
14	0.00	49	0.00	84	0.00
15	0.00	50	-0.95	85	0.00
16	0.00	51	0.00	86	0.00
17	0.00	52	0.00	87	-0.95
18	0.00	53	0.00	88	0.00
19	0.80	54	0.00	89	0.00
20	0.00	55	0.00	90	0.00
21	0.00	56	0.00	91	0.80
22	0.00	57	0.80	92	0.00
23	0.00	58	0.00	93	0.00
24	0.00	59	0.00	94	0.00
25	-0.95	60	0.00	95	0.00
26	0.00	61	0.00	96	0.00
27	0.00	62	0.00	97	0.00
28	0.00	63	0.00	98	0.00
29	0.00	64	-0.95	99	0.00
30	0.00	65	0.00	100	0.00
31	0.00	66	0.80	101	0.00
32	0.80	67	0.00	102	0.00
33	0.00	68	0.00	103	0.00
34	0.00	69	0.00	104	-0.95
35	0.00	70	0.00	105	0.00

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
106	0.00	141	0.80		
107	0.80	142	0.00		
108	0.00	143	0.00		
109	0.00	144	0.00		
110	0.00	145	0.00		
111	0.00	146	0.00		
112	0.00	147	-0.95		
113	-0.95	148	0.00		
114	0.00	149	0.00		
115	0.00	150	0.00		
116	0.80	151	0.00		
117	0.00	152	0.80		
118	0.00	153	0.00		
119	0.00	154	0.00		
120	0.00	155	0.00		
121	0.00	156	0.00		
122	0.00	157	0.00		
123	0.00	158	0.00		
124	-0.95	159	0.00		
125	0.80	160	-0.95		
126	-0.95	161	0.00		
127	0.00	162	0.80		
128	0.00	163	0.00		
129	0.00	164	0.00		
130	0.00	165	0.00		
131	0.00	166	0.00		
132	0.00	167	0.00		
133	0.80	168	0.00		
134	-0.95				
135	0.00				
136	0.00				
137	0.00				
138	0.00				
139	0.00				
140	0.00				

Table A.11. Duty Cycle for Capacity Test at SnoPUD MESA1

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
1	0.00	36	0.00	71	0.00
2	0.00	37	0.00	72	0.00
3	0.00	38	0.00	73	0.00
4	0.00	39	0.00	74	0.00
5	0.00	40	0.00	75	0.00
6	0.00	41	0.00	76	-0.42
7	0.00	42	0.40	77	-0.44
8	0.00	43	0.33	78	0.00
9	0.00	44	0.00	79	0.00
10	0.00	45	0.00	80	0.00
11	0.00	46	0.00	81	0.00
12	0.40	47	0.00	82	0.00
13	0.20	48	0.00	83	0.00
14	0.00	49	0.00	84	0.00
15	-0.70	50	0.00	85	0.00
16	0.00	51	-0.40	86	0.00
17	0.00	52	-0.30	87	0.00
18	0.20	53	-0.15	88	0.00
19	0.40	54	0.00	89	0.00
20	0.00	55	0.00	90	0.40
21	0.00	56	0.00	91	0.30
22	0.00	57	0.24	92	0.00
23	0.00	58	0.24	93	0.00
24	0.00	59	0.24	94	-0.40
25	0.00	60	0.00	95	-0.42
26	0.00	61	-0.40	96	0.00
27	0.00	62	-0.44	97	0.00
28	-0.30	63	0.00	98	0.00
29	-0.40	64	0.00	99	0.00
30	0.00	65	0.18	100	0.00
31	0.00	66	0.18	101	0.00
32	0.00	67	0.18	102	0.00
33	0.00	68	0.18	103	0.00
34	0.00	69	0.00	104	0.24
35	0.00	70	0.00	105	0.24

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
106	0.24	141	0.00		
107	0.00	142	0.00		
108	0.00	143	0.00		
109	-0.85	144	0.00		
110	0.00	145	0.00		
111	0.00	146	0.00		
112	0.00	147	0.00		
113	0.00	148	-0.42		
114	0.73	149	-0.42		
115	0.00	150	0.00		
116	0.00	151	0.00		
117	0.00	152	0.00		
118	0.00	153	0.00		
119	0.00	154	0.00		
120	0.00	155	0.00		
121	0.00	156	0.00		
122	0.00	157	0.00		
123	0.00	158	0.00		
124	-0.42	159	0.00		
125	-0.42	160	0.00		
126	0.00	161	0.00		
127	0.00	162	0.00		
128	0.18	163	0.40		
129	0.18	164	0.20		
130	0.18	165	0.10		
131	0.18	166	0.00		
132	0.00	167	0.00		
133	-0.42	168	0.00		
134	-0.42				
135	0.00				
136	0.00				
137	0.18				
138	0.18				
139	0.18				
140	0.17				

Table A.12. Duty Cycle for BPA Balancing (Load Shaping) Test at SnoPUD MESA1

Duty Cycle		**Duty Cycle**		**Duty Cycle**	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
1	0.00	36	0.00	71	0.80
2	0.00	37	0.00	72	0.00
3	0.00	38	0.00	73	0.00
4	-0.95	39	0.00	74	0.00
5	0.00	40	0.00	75	0.00
6	0.00	41	0.00	76	0.00
7	0.00	42	0.00	77	-0.95
8	0.00	43	0.00	78	0.62
9	0.00	44	0.00	79	0.02
10	0.00	45	0.00	80	0.00
11	0.00	46	0.80	81	0.13
12	0.00	47	0.00	82	0.02
13	0.80	48	0.00	83	0.01
14	-0.95	49	0.00	84	0.00
15	0.00	50	0.00	85	0.00
16	0.00	51	-0.02	86	-0.95
17	0.00	52	-0.93	87	0.00
18	0.00	53	0.00	88	0.72
19	0.00	54	0.80	89	0.08
20	0.00	55	0.00	90	-0.95
21	0.00	56	0.00	91	0.00
22	0.00	57	0.00	92	0.14
23	0.00	58	0.00	93	0.20
24	0.00	59	0.00	94	0.05
25	0.00	60	0.00	95	0.33
26	0.80	61	0.00	96	0.05
27	-0.02	62	-0.95	97	0.00
28	-0.04	63	0.00	98	0.02
29	-0.02	64	0.00	99	0.02
30	-0.01	65	0.00	100	0.01
31	-0.01	66	0.00	101	0.00
32	-0.85	67	0.00	102	0.00
33	0.00	68	0.00	103	0.00
34	0.00	69	0.00	104	-0.95
35	0.00	70	0.00	105	0.78

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
106	0.00	141	-0.95	176	0.00
107	0.02	142	0.00	177	0.02
108	0.00	143	0.00	178	0.02
109	0.00	144	0.00	179	0.01
110	0.00	145	0.00	180	0.00
111	0.00	146	0.00	181	0.00
112	0.00	147	0.00	182	0.00
113	-0.95	148	0.00	183	-0.95
114	0.00	149	0.00	184	0.78
115	0.00	150	0.80	185	0.00
116	0.00	151	0.00	186	0.02
117	0.00	152	0.00	187	0.00
118	0.00	153	0.00	188	0.00
119	0.00	154	0.00	189	0.00
120	0.00	155	0.00	190	0.00
121	0.80	156	-0.95	191	0.00
122	0.00	157	0.62	192	-0.95
123	-0.15	158	0.02	193	0.00
124	0.06	159	0.00		
125	0.02	160	0.13		
126	0.00	161	0.02		
127	0.00	162	0.01		
128	0.05	163	0.00		
129	0.00	164	0.00		
130	0.00	165	-0.95		
131	0.00	166	0.00		
132	0.00	167	0.72		
133	0.00	168	0.08		
134	-0.95	169	-0.95		
135	0.00	170	0.00		
136	0.00	171	0.14		
137	0.00	172	0.20		
138	0.00	173	0.05		
139	0.00	174	0.33		
140	0.00	175	0.05		

Table A.13. Duty Cycle for Arbitrage Test at PSE

Duty Cycle		**Duty Cycle**		**Duty Cycle**	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
1	0.00	36	0.00	71	0.00
2	0.00	37	0.00	72	0.00
3	0.00	38	0.00	73	0.00
4	0.00	39	0.00	74	0.00
5	0.00	40	0.00	75	0.00
6	0.00	41	0.00	76	0.00
7	0.00	42	0.00	77	0.00
8	0.00	43	0.00	78	0.00
9	0.00	44	1.58	79	0.00
10	0.00	45	0.00	80	2.00
11	0.00	46	0.00	81	0.00
12	0.00	47	0.00	82	0.00
13	0.00	48	0.00	83	0.00
14	0.00	49	0.00	84	0.00
15	0.00	50	0.00	85	-2.00
16	-2.00	51	0.00	86	0.00
17	0.00	52	0.00	87	0.00
18	0.00	53	0.00	88	0.00
19	0.00	54	0.00	89	0.00
20	0.00	55	0.00	90	1.52
21	0.00	56	0.00	91	0.00
22	0.00	57	0.00	92	0.00
23	0.00	58	0.00	93	0.00
24	0.00	59	0.00	94	0.00
25	0.00	60	0.00	95	0.00
26	0.00	61	0.00	96	0.00
27	0.00	62	0.00	97	-2.00
28	0.00	63	-2.00	98	-1.14
29	0.00	64	-1.14	99	0.00
30	0.00	65	0.00	100	0.00
31	0.00	66	0.00	101	0.00
32	0.00	67	0.00	102	0.00
33	0.00	68	0.00	103	0.00
34	0.00	69	0.00	104	2.00
35	0.00	70	0.00	105	0.00

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
106	0.00	141	1.62		
107	0.00	142	0.00		
108	-0.70	143	0.00		
109	-2.00	144	0.00		
110	0.00	145	-2.00		
111	0.00	146	0.00		
112	0.00	147	0.00		
113	0.00	148	0.00		
114	2.00	149	0.00		
115	0.33	150	0.00		
116	0.00	151	0.00		
117	0.00	152	0.00		
118	0.00	153	1.54		
119	0.00	154	0.00		
120	0.00	155	0.00		
121	-2.00	156	0.00		
122	-1.14	157	0.00		
123	0.00	158	0.00		
124	0.00	159	0.00		
125	0.00	160	0.00		
126	0.00	161	0.00		
127	0.00	162	0.00		
128	0.00	163	0.00		
129	0.00	164	0.00		
130	0.00	165	0.00		
131	0.00	166	0.00		
132	0.00	167	0.00		
133	0.00	168	0.00		
134	0.00				
135	0.00				
136	0.00				
137	0.00				
138	0.00				
139	0.00				
140	0.00				

Table A.14. Duty Cycle for Capacity Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
1	0.00	36	0.44	71	0.00
2	0.00	37	0.00	72	0.00
3	-0.80	38	-1.20	73	0.00
4	0.00	39	-1.20	74	-0.80
5	0.00	40	0.00	75	0.00
6	0.00	41	1.20	76	0.00
7	-1.80	42	0.44	77	0.00
8	0.00	43	0.00	78	-2.00
9	1.80	44	0.00	79	0.00
10	0.00	45	0.00	80	2.00
11	0.00	46	0.00	81	0.00
12	0.00	47	0.00	82	0.00
13	0.12	48	0.00	83	0.00
14	0.00	49	0.00	84	0.00
15	-0.40	50	-0.64	85	0.00
16	-1.80	51	0.00	86	0.00
17	0.00	52	-0.80	87	0.00
18	1.64	53	-0.80	88	-2.00
19	0.00	54	-0.80	89	0.00
20	0.00	55	0.00	90	1.39
21	0.00	56	0.80	91	0.00
22	0.00	57	0.80	92	0.00
23	0.00	58	0.76	93	0.00
24	0.00	59	0.00	94	0.00
25	-0.50	60	0.00	95	0.00
26	0.00	61	-0.35	96	0.00
27	0.00	62	0.00	97	0.00
28	-0.50	63	-1.20	98	0.00
29	-0.50	64	-1.20	99	0.00
30	-0.50	65	0.00	100	0.00
31	-0.50	66	1.20	101	0.00
32	0.00	67	0.75	102	0.00
33	0.50	68	0.00	103	0.00
34	0.50	69	0.00	104	-0.20
35	0.50	70	0.00	105	0.00

Duty Cycle		Duty Cycle		Duty Cycle	
Time (h)	Power (kW)	Time (h)	Power (kW)	Time (h)	Power (kW)
106	0.00	141	0.00		
107	0.00	142	0.00		
108	-0.50	143	0.00		
109	-0.50	144	-0.30		
110	-0.50	145	0.00		
111	-0.50	146	0.00		
112	0.00	147	0.00		
113	0.50	148	-0.80		
114	0.50	149	-0.80		
115	0.50	150	-0.80		
116	0.05	151	0.00		
117	0.00	152	0.80		
118	0.00	153	0.80		
119	0.00	154	0.52		
120	-0.40	155	0.00		
121	0.00	156	-0.30		
122	-0.50	157	0.00		
123	-0.50	158	-0.40		
124	-0.50	159	-0.60		
125	-0.50	160	-0.80		
126	0.00	161	0.00		
127	0.50	162	0.80		
128	0.50	163	0.60		
129	0.50	164	0.12		
130	0.44	165	0.00		
131	0.00	166	0.00		
132	-0.10	167	0.00		
133	-1.80	168	0.00		
134	0.00				
135	0.00				
136	0.00				
137	0.00				
138	1.24				
139	0.00				
140	0.00				

Table A.15. Duty Cycle for Regulation Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:00:00	-86	16:02:20	-28	16:04:40	0
16:00:04	-80	16:02:24	-17	16:04:44	20
16:00:08	-80	16:02:28	-39	16:04:48	28
16:00:12	-77	16:02:32	-41	16:04:52	37
16:00:16	-59	16:02:36	-35	16:04:56	18
16:00:20	-72	16:02:40	-48	16:05:00	16
16:00:24	-78	16:02:44	-37	16:05:04	48
16:00:28	-62	16:02:48	-36	16:05:08	-128
16:00:32	-46	16:02:52	-32	16:05:12	48
16:00:36	-29	16:02:56	-23	16:05:16	39
16:00:40	-29	16:03:00	-28	16:05:20	65
16:00:44	-7	16:03:04	-21	16:05:24	87
16:00:48	17	16:03:08	-29	16:05:28	75
16:00:52	-15	16:03:12	-63	16:05:32	67
16:00:56	-29	16:03:16	-42	16:05:36	79
16:01:00	-25	16:03:20	-38	16:05:40	77
16:01:04	-17	16:03:24	-32	16:05:44	90
16:01:08	-48	16:03:28	0	16:05:48	74
16:01:12	-78	16:03:32	0	16:05:52	89
16:01:16	-91	16:03:36	-8	16:05:56	102
16:01:20	-65	16:03:40	12	16:06:00	127
16:01:24	-62	16:03:44	0	16:06:04	113
16:01:28	-79	16:03:48	-22	16:06:08	84
16:01:32	-75	16:03:52	0	16:06:12	73
16:01:36	-58	16:03:56	28	16:06:16	53
16:01:40	-46	16:04:00	10	16:06:20	45
16:01:44	-77	16:04:04	17	16:06:24	49
16:01:48	-48	16:04:08	48	16:06:28	67
16:01:52	-48	16:04:12	46	16:06:32	81
16:01:56	-40	16:04:16	22	16:06:36	76
16:02:00	-51	16:04:20	24	16:06:40	67
16:02:04	-50	16:04:24	22	16:06:44	83
16:02:08	-40	16:04:28	23	16:06:48	84
16:02:12	-41	16:04:32	14	16:06:52	92
16:02:16	-38	16:04:36	0	16:06:56	95

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:07:00	98	16:09:20	67	16:11:40	95
16:07:04	106	16:09:24	49	16:11:44	104
16:07:08	41	16:09:28	58	16:11:48	130
16:07:12	39	16:09:32	88	16:11:52	116
16:07:16	39	16:09:36	106	16:11:56	104
16:07:20	20	16:09:40	116	16:12:00	112
16:07:24	18	16:09:44	92	16:12:04	106
16:07:28	32	16:09:48	90	16:12:08	91
16:07:32	29	16:09:52	104	16:12:12	91
16:07:36	31	16:09:56	89	16:12:16	85
16:07:40	49	16:10:00	92	16:12:20	87
16:07:44	76	16:10:04	90	16:12:24	116
16:07:48	76	16:10:08	73	16:12:28	100
16:07:52	51	16:10:12	62	16:12:32	64
16:07:56	35	16:10:16	73	16:12:36	59
16:08:00	56	16:10:20	96	16:12:40	60
16:08:04	40	16:10:24	95	16:12:44	67
16:08:08	11	16:10:28	71	16:12:48	65
16:08:12	-35	16:10:32	86	16:12:52	64
16:08:16	-22	16:10:36	89	16:12:56	82
16:08:20	0	16:10:40	86	16:13:00	105
16:08:24	19	16:10:44	77	16:13:04	120
16:08:28	16	16:10:48	61	16:13:08	133
16:08:32	22	16:10:52	88	16:13:12	111
16:08:36	62	16:10:56	81	16:13:16	103
16:08:40	63	16:11:00	70	16:13:20	102
16:08:44	54	16:11:04	85	16:13:24	91
16:08:48	72	16:11:08	103	16:13:28	106
16:08:52	77	16:11:12	96	16:13:32	113
16:08:56	88	16:11:16	108	16:13:36	124
16:09:00	89	16:11:20	116	16:13:40	122
16:09:04	105	16:11:24	126	16:13:44	112
16:09:08	105	16:11:28	136	16:13:48	120
16:09:12	81	16:11:32	122	16:13:52	110
16:09:16	65	16:11:36	110	16:13:56	104
16:14:00	102	16:16:20	188	16:18:40	73

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:14:04	112	16:16:24	184	16:18:44	14
16:14:08	149	16:16:28	155	16:18:48	0
16:14:12	154	16:16:32	152	16:18:52	0
16:14:16	127	16:16:36	168	16:18:56	0
16:14:20	134	16:16:40	154	16:19:00	-21
16:14:24	142	16:16:44	184	16:19:04	-33
16:14:28	162	16:16:48	181	16:19:08	-11
16:14:32	121	16:16:52	185	16:19:12	-12
16:14:36	105	16:16:56	173	16:19:16	-43
16:14:40	95	16:17:00	155	16:19:20	-37
16:14:44	123	16:17:04	169	16:19:24	-49
16:14:48	129	16:17:08	152	16:19:28	-62
16:14:52	158	16:17:12	158	16:19:32	-45
16:14:56	131	16:17:16	178	16:19:36	-62
16:15:00	113	16:17:20	188	16:19:40	-49
16:15:04	116	16:17:24	163	16:19:44	-63
16:15:08	122	16:17:28	195	16:19:48	-62
16:15:12	152	16:17:32	202	16:19:52	-52
16:15:16	170	16:17:36	184	16:19:56	-67
16:15:20	166	16:17:40	189	16:20:00	-98
16:15:24	156	16:17:44	155	16:20:04	-79
16:15:28	145	16:17:48	145	16:20:08	-67
16:15:32	173	16:17:52	142	16:20:12	-34
16:15:36	159	16:17:56	140	16:20:16	-22
16:15:40	142	16:18:00	129	16:20:20	-30
16:15:44	132	16:18:04	128	16:20:24	-21
16:15:48	123	16:18:08	98	16:20:28	-13
16:15:52	139	16:18:12	71	16:20:32	-40
16:15:56	132	16:18:16	78	16:20:36	-35
16:16:00	149	16:18:20	85	16:20:40	-37
16:16:04	150	16:18:24	74	16:20:44	-20
16:16:08	151	16:18:28	79	16:20:48	-24
16:16:12	171	16:18:32	72	16:20:52	0
16:16:16	190	16:18:36	58	16:20:56	-35
16:21:00	0	16:23:20	156	16:25:40	206
16:21:04	15	16:23:24	148	16:25:44	231

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:21:08	0	16:23:28	117	16:25:48	229
16:21:12	16	16:23:32	126	16:25:52	239
16:21:16	31	16:23:36	143	16:25:56	226
16:21:20	7	16:23:40	169	16:26:00	214
16:21:24	0	16:23:44	165	16:26:04	221
16:21:28	13	16:23:48	192	16:26:08	228
16:21:32	47	16:23:52	201	16:26:12	219
16:21:36	64	16:23:56	213	16:26:16	215
16:21:40	42	16:24:00	220	16:26:20	235
16:21:44	27	16:24:04	233	16:26:24	242
16:21:48	20	16:24:08	251	16:26:28	243
16:21:52	6	16:24:12	232	16:26:32	251
16:21:56	16	16:24:16	231	16:26:36	284
16:22:00	17	16:24:20	213	16:26:40	271
16:22:04	19	16:24:24	211	16:26:44	264
16:22:08	35	16:24:28	227	16:26:48	238
16:22:12	19	16:24:32	232	16:26:52	214
16:22:16	13	16:24:36	227	16:26:56	251
16:22:20	-13	16:24:40	202	16:27:00	252
16:22:24	-16	16:24:44	222	16:27:04	234
16:22:28	-16	16:24:48	218	16:27:08	211
16:22:32	-26	16:24:52	232	16:27:12	203
16:22:36	-27	16:24:56	261	16:27:16	226
16:22:40	12	16:25:00	238	16:27:20	217
16:22:44	48	16:25:04	215	16:27:24	223
16:22:48	51	16:25:08	213	16:27:28	200
16:22:52	81	16:25:12	217	16:27:32	197
16:22:56	82	16:25:16	207	16:27:36	165
16:23:00	102	16:25:20	189	16:27:40	167
16:23:04	171	16:25:24	212	16:27:44	174
16:23:08	156	16:25:28	224	16:27:48	205
16:23:12	151	16:25:32	195	16:27:52	186
16:23:16	175	16:25:36	210	16:27:56	145
16:28:00	145				
16:28:04	149				
16:28:08	133				

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:28:12	149				
16:28:16	134				
16:28:20	96				
16:28:24	81				
16:28:28	77				
16:28:32	88				
16:28:36	70				
16:28:40	99				
16:28:44	89				
16:28:48	81				
16:28:52	93				
16:28:56	91				
16:29:00	81				
16:29:04	88				
16:29:08	125				
16:29:12	78				
16:29:16	47				
16:29:20	36				
16:29:24	40				
16:29:28	37				
16:29:32	34				
16:29:36	10				
16:29:40	16				
16:29:44	17				
16:29:48	42				
16:29:52	61				
16:29:56	75				
16:30:00	75				

Table A.16. Duty Cycle for Load Following Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:00:00	-124	16:02:20	-91	16:04:40	-33
16:00:04	-123	16:02:24	-89	16:04:44	-31
16:00:08	-123	16:02:28	-87	16:04:48	-30
16:00:12	-122	16:02:32	-85	16:04:52	-29
16:00:16	-121	16:02:36	-83	16:04:56	-28
16:00:20	-120	16:02:40	-81	16:05:00	-27
16:00:24	-120	16:02:44	-79	16:05:04	-25
16:00:28	-120	16:02:48	-77	16:05:08	-26
16:00:32	-119	16:02:52	-75	16:05:12	-24
16:00:36	-119	16:02:56	-73	16:05:16	-22
16:00:40	-118	16:03:00	-71	16:05:20	-21
16:00:44	-116	16:03:04	-69	16:05:24	-19
16:00:48	-114	16:03:08	-67	16:05:28	-17
16:00:52	-113	16:03:12	-66	16:05:32	-15
16:00:56	-112	16:03:16	-64	16:05:36	-13
16:01:00	-110	16:03:20	-63	16:05:40	-12
16:01:04	-109	16:03:24	-62	16:05:44	-10
16:01:08	-108	16:03:28	-60	16:05:48	-9
16:01:12	-107	16:03:32	-59	16:05:52	-8
16:01:16	-107	16:03:36	-58	16:05:56	-7
16:01:20	-105	16:03:40	-56	16:06:00	-5
16:01:24	-104	16:03:44	-55	16:06:04	-3
16:01:28	-104	16:03:48	-54	16:06:08	-2
16:01:32	-103	16:03:52	-52	16:06:12	0
16:01:36	-102	16:03:56	-51	16:06:16	2
16:01:40	-102	16:04:00	-49	16:06:20	3
16:01:44	-102	16:04:04	-48	16:06:24	5
16:01:48	-101	16:04:08	-45	16:06:28	7
16:01:52	-101	16:04:12	-43	16:06:32	9
16:01:56	-100	16:04:16	-42	16:06:36	11
16:02:00	-99	16:04:20	-40	16:06:40	12
16:02:04	-98	16:04:24	-38	16:06:44	14
16:02:08	-96	16:04:28	-36	16:06:48	16
16:02:12	-95	16:04:32	-35	16:06:52	18
16:02:16	-93	16:04:36	-34	16:06:56	20

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:07:00	22	16:09:20	52	16:11:40	71
16:07:04	24	16:09:24	53	16:11:44	71
16:07:08	25	16:09:28	53	16:11:48	72
16:07:12	26	16:09:32	54	16:11:52	72
16:07:16	27	16:09:36	55	16:11:56	72
16:07:20	28	16:09:40	57	16:12:00	73
16:07:24	28	16:09:44	58	16:12:04	73
16:07:28	29	16:09:48	59	16:12:08	73
16:07:32	30	16:09:52	60	16:12:12	73
16:07:36	31	16:09:56	61	16:12:16	74
16:07:40	32	16:10:00	62	16:12:20	74
16:07:44	34	16:10:04	62	16:12:24	76
16:07:48	35	16:10:08	63	16:12:28	77
16:07:52	36	16:10:12	65	16:12:32	77
16:07:56	37	16:10:16	66	16:12:36	78
16:08:00	38	16:10:20	66	16:12:40	78
16:08:04	39	16:10:24	67	16:12:44	78
16:08:08	39	16:10:28	67	16:12:48	78
16:08:12	39	16:10:32	67	16:12:52	78
16:08:16	40	16:10:36	67	16:12:56	78
16:08:20	41	16:10:40	67	16:13:00	79
16:08:24	41	16:10:44	67	16:13:04	80
16:08:28	42	16:10:48	67	16:13:08	81
16:08:32	42	16:10:52	67	16:13:12	83
16:08:36	43	16:10:56	67	16:13:16	84
16:08:40	44	16:11:00	66	16:13:20	86
16:08:44	44	16:11:04	66	16:13:24	87
16:08:48	45	16:11:08	66	16:13:28	88
16:08:52	47	16:11:12	66	16:13:32	90
16:08:56	48	16:11:16	66	16:13:36	91
16:09:00	49	16:11:20	67	16:13:40	92
16:09:04	50	16:11:24	68	16:13:44	92
16:09:08	51	16:11:28	69	16:13:48	93
16:09:12	51	16:11:32	70	16:13:52	94
16:09:16	52	16:11:36	70	16:13:56	94
16:14:00	94	16:16:20	121	16:18:40	140

Duty Cycle		**Duty Cycle**		**Duty Cycle**	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:14:04	95	16:16:24	121	16:18:44	139
16:14:08	95	16:16:28	122	16:18:48	137
16:14:12	96	16:16:32	122	16:18:52	136
16:14:16	97	16:16:36	123	16:18:56	134
16:14:20	97	16:16:40	123	16:19:00	133
16:14:24	98	16:16:44	124	16:19:04	131
16:14:28	100	16:16:48	125	16:19:08	129
16:14:32	101	16:16:52	126	16:19:12	127
16:14:36	101	16:16:56	127	16:19:16	124
16:14:40	101	16:17:00	128	16:19:20	122
16:14:44	101	16:17:04	128	16:19:24	120
16:14:48	101	16:17:08	129	16:19:28	117
16:14:52	102	16:17:12	130	16:19:32	114
16:14:56	103	16:17:16	131	16:19:36	112
16:15:00	103	16:17:20	132	16:19:40	110
16:15:04	103	16:17:24	133	16:19:44	108
16:15:08	104	16:17:28	134	16:19:48	105
16:15:12	105	16:17:32	136	16:19:52	103
16:15:16	106	16:17:36	137	16:19:56	100
16:15:20	107	16:17:40	139	16:20:00	97
16:15:24	108	16:17:44	140	16:20:04	95
16:15:28	109	16:17:48	141	16:20:08	92
16:15:32	110	16:17:52	142	16:20:12	90
16:15:36	111	16:17:56	143	16:20:16	88
16:15:40	112	16:18:00	144	16:20:20	85
16:15:44	112	16:18:04	144	16:20:24	83
16:15:48	113	16:18:08	144	16:20:28	81
16:15:52	114	16:18:12	143	16:20:32	78
16:15:56	115	16:18:16	143	16:20:36	75
16:16:00	115	16:18:20	142	16:20:40	73
16:16:04	117	16:18:24	142	16:20:44	71
16:16:08	117	16:18:28	142	16:20:48	69
16:16:12	118	16:18:32	141	16:20:52	67
16:16:16	120	16:18:36	141	16:20:56	65
16:21:00	63	16:23:20	10	16:25:40	113
16:21:04	61	16:23:24	10	16:25:44	117

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:21:08	59	16:23:28	11	16:25:48	120
16:21:12	57	16:23:32	12	16:25:52	123
16:21:16	56	16:23:36	12	16:25:56	126
16:21:20	53	16:23:40	14	16:26:00	130
16:21:24	51	16:23:44	15	16:26:04	132
16:21:28	48	16:23:48	17	16:26:08	135
16:21:32	47	16:23:52	20	16:26:12	138
16:21:36	46	16:23:56	23	16:26:16	141
16:21:40	44	16:24:00	26	16:26:20	143
16:21:44	43	16:24:04	29	16:26:24	147
16:21:48	40	16:24:08	33	16:26:28	150
16:21:52	38	16:24:12	36	16:26:32	153
16:21:56	36	16:24:16	39	16:26:36	156
16:22:00	34	16:24:20	43	16:26:40	159
16:22:04	32	16:24:24	46	16:26:44	162
16:22:08	30	16:24:28	50	16:26:48	164
16:22:12	29	16:24:32	53	16:26:52	167
16:22:16	27	16:24:36	57	16:26:56	170
16:22:20	24	16:24:40	60	16:27:00	173
16:22:24	21	16:24:44	64	16:27:04	176
16:22:28	19	16:24:48	68	16:27:08	179
16:22:32	16	16:24:52	72	16:27:12	181
16:22:36	13	16:24:56	76	16:27:16	184
16:22:40	11	16:25:00	80	16:27:20	186
16:22:44	9	16:25:04	84	16:27:24	189
16:22:48	8	16:25:08	88	16:27:28	192
16:22:52	7	16:25:12	91	16:27:32	195
16:22:56	6	16:25:16	95	16:27:36	198
16:23:00	5	16:25:20	97	16:27:40	200
16:23:04	6	16:25:24	101	16:27:44	202
16:23:08	6	16:25:28	104	16:27:48	204
16:23:12	7	16:25:32	107	16:27:52	206
16:23:16	8	16:25:36	110	16:27:56	207
16:28:00	208				
16:28:04	208				
16:28:08	208				

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
16:28:12	208				
16:28:16	208				
16:28:20	206				
16:28:24	205				
16:28:28	205				
16:28:32	204				
16:28:36	203				
16:28:40	203				
16:28:44	202				
16:28:48	201				
16:28:52	199				
16:28:56	198				
16:29:00	196				
16:29:04	194				
16:29:08	193				
16:29:12	191				
16:29:16	188				
16:29:20	186				
16:29:24	184				
16:29:28	181				
16:29:32	179				
16:29:36	176				
16:29:40	173				
16:29:44	171				
16:29:48	168				
16:29:52	166				
16:29:56	164				
16:30:00	162				

Table A.17. Duty Cycle for Real World Flexibility Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:00:00	226	10:05:50	225	10:11:40	226
10:00:10	225	10:06:00	225	10:11:50	226
10:00:20	225	10:06:10	225	10:12:00	226
10:00:30	225	10:06:20	225	10:12:10	226
10:00:40	225	10:06:30	225	10:12:20	226
10:00:50	225	10:06:40	226	10:12:30	226
10:01:00	225	10:06:50	226	10:12:40	226
10:01:10	225	10:07:00	226	10:12:50	226
10:01:20	225	10:07:10	226	10:13:00	226
10:01:30	225	10:07:20	226	10:13:10	226
10:01:40	225	10:07:30	226	10:13:20	226
10:01:50	225	10:07:40	226	10:13:30	226
10:02:00	225	10:07:50	225	10:13:40	226
10:02:10	225	10:08:00	225	10:13:50	226
10:02:20	225	10:08:10	225	10:14:00	226
10:02:30	225	10:08:20	225	10:14:10	226
10:02:40	225	10:08:30	226	10:14:20	226
10:02:50	225	10:08:40	226	10:14:30	226
10:03:00	225	10:08:50	226	10:14:40	226
10:03:10	225	10:09:00	226	10:14:50	226
10:03:20	225	10:09:10	226	10:15:00	226
10:03:30	225	10:09:20	226	10:15:10	226
10:03:40	225	10:09:30	226	10:15:20	226
10:03:50	225	10:09:40	226	10:15:30	226
10:04:00	225	10:09:50	226	10:15:40	226
10:04:10	225	10:10:00	226	10:15:50	226
10:04:20	225	10:10:10	226	10:16:00	226
10:04:30	225	10:10:20	226	10:16:10	226
10:04:40	225	10:10:30	226	10:16:20	226
10:04:50	225	10:10:40	226	10:16:30	226
10:05:00	226	10:10:50	226	10:16:40	226
10:05:10	225	10:11:00	226	10:16:50	226
10:05:20	225	10:11:10	226	10:17:00	227
10:05:30	225	10:11:20	226	10:17:10	227
10:05:40	225	10:11:30	226	10:17:20	227

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:17:30	227	10:23:20	226	10:29:10	225
10:17:40	227	10:23:30	225	10:29:20	225
10:17:50	227	10:23:40	225	10:29:30	225
10:18:00	227	10:23:50	226	10:29:40	225
10:18:10	226	10:24:00	226	10:29:50	225
10:18:20	226	10:24:10	225	10:30:00	224
10:18:30	226	10:24:20	225	10:30:10	224
10:18:40	226	10:24:30	225	10:30:20	224
10:18:50	226	10:24:40	225	10:30:30	224
10:19:00	226	10:24:50	225	10:30:40	225
10:19:10	226	10:25:00	225	10:30:50	225
10:19:20	226	10:25:10	225	10:31:00	225
10:19:30	226	10:25:20	226	10:31:10	225
10:19:40	226	10:25:30	226	10:31:20	225
10:19:50	226	10:25:40	225	10:31:30	224
10:20:00	226	10:25:50	225	10:31:40	224
10:20:10	226	10:26:00	225	10:31:50	224
10:20:20	226	10:26:10	225	10:32:00	224
10:20:30	226	10:26:20	225	10:32:10	224
10:20:40	226	10:26:30	225	10:32:20	224
10:20:50	226	10:26:40	225	10:32:30	224
10:21:00	226	10:26:50	225	10:32:40	224
10:21:10	226	10:27:00	225	10:32:50	224
10:21:20	226	10:27:10	226	10:33:00	224
10:21:30	226	10:27:20	226	10:33:10	224
10:21:40	226	10:27:30	225	10:33:20	224
10:21:50	226	10:27:40	225	10:33:30	224
10:22:00	226	10:27:50	225	10:33:40	224
10:22:10	226	10:28:00	225	10:33:50	224
10:22:20	226	10:28:10	225	10:34:00	224
10:22:30	226	10:28:20	225	10:34:10	224
10:22:40	226	10:28:30	225	10:34:20	224
10:22:50	226	10:28:40	224	10:34:30	224
10:23:00	226	10:28:50	224	10:34:40	224
10:23:10	226	10:29:00	225	10:34:50	224
10:35:00	224	10:40:50	223	10:46:40	220

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:35:10	224	10:41:00	222	10:46:50	220
10:35:20	223	10:41:10	222	10:47:00	220
10:35:30	223	10:41:20	222	10:47:10	220
10:35:40	223	10:41:30	222	10:47:20	220
10:35:50	223	10:41:40	222	10:47:30	220
10:36:00	223	10:41:50	222	10:47:40	220
10:36:10	223	10:42:00	222	10:47:50	220
10:36:20	224	10:42:10	222	10:48:00	220
10:36:30	223	10:42:20	222	10:48:10	220
10:36:40	223	10:42:30	222	10:48:20	220
10:36:50	223	10:42:40	222	10:48:30	220
10:37:00	223	10:42:50	222	10:48:40	220
10:37:10	223	10:43:00	222	10:48:50	220
10:37:20	224	10:43:10	221	10:49:00	220
10:37:30	223	10:43:20	221	10:49:10	220
10:37:40	223	10:43:30	221	10:49:20	220
10:37:50	223	10:43:40	221	10:49:30	220
10:38:00	223	10:43:50	221	10:49:40	220
10:38:10	223	10:44:00	221	10:49:50	220
10:38:20	223	10:44:10	221	10:50:00	220
10:38:30	223	10:44:20	221	10:50:10	219
10:38:40	223	10:44:30	221	10:50:20	219
10:38:50	223	10:44:40	221	10:50:30	219
10:39:00	223	10:44:50	221	10:50:40	219
10:39:10	223	10:45:00	221	10:50:50	219
10:39:20	223	10:45:10	221	10:51:00	219
10:39:30	223	10:45:20	221	10:51:10	220
10:39:40	223	10:45:30	221	10:51:20	220
10:39:50	223	10:45:40	221	10:51:30	220
10:40:00	223	10:45:50	221	10:51:40	219
10:40:10	223	10:46:00	221	10:51:50	219
10:40:20	223	10:46:10	221	10:52:00	219
10:40:30	223	10:46:20	221	10:52:10	219
10:40:40	223	10:46:30	220	10:52:20	219
10:52:30	219	10:58:20	219		
10:52:40	219	10:58:30	219		

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:52:50	219	10:58:40	219		
10:53:00	219	10:58:50	219		
10:53:10	220	10:59:00	219		
10:53:20	220	10:59:10	219		
10:53:30	219	10:59:20	219		
10:53:40	219	10:59:30	219		
10:53:50	219	10:59:40	219		
10:54:00	219	10:59:50	219		
10:54:10	219				
10:54:20	219				
10:54:30	220				
10:54:40	220				
10:54:50	220				
10:55:00	220				
10:55:10	220				
10:55:20	220				
10:55:30	220				
10:55:40	219				
10:55:50	219				
10:56:00	219				
10:56:10	219				
10:56:20	219				
10:56:30	219				
10:56:40	219				
10:56:50	219				
10:57:00	219				
10:57:10	219				
10:57:20	219				
10:57:30	219				
10:57:40	219				
10:57:50	219				
10:58:00	219				
10:58:10	219				

Table A.18. Duty Cycle for Load Following Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:00:00	226	10:05:50	225	10:11:40	226
10:00:10	225	10:06:00	225	10:11:50	226
10:00:20	225	10:06:10	225	10:12:00	226
10:00:30	225	10:06:20	225	10:12:10	226
10:00:40	225	10:06:30	225	10:12:20	226
10:00:50	225	10:06:40	226	10:12:30	226
10:01:00	225	10:06:50	226	10:12:40	226
10:01:10	225	10:07:00	226	10:12:50	226
10:01:20	225	10:07:10	226	10:13:00	226
10:01:30	225	10:07:20	226	10:13:10	226
10:01:40	225	10:07:30	226	10:13:20	226
10:01:50	225	10:07:40	226	10:13:30	226
10:02:00	225	10:07:50	225	10:13:40	226
10:02:10	225	10:08:00	225	10:13:50	226
10:02:20	225	10:08:10	225	10:14:00	226
10:02:30	225	10:08:20	225	10:14:10	226
10:02:40	225	10:08:30	226	10:14:20	226
10:02:50	225	10:08:40	226	10:14:30	226
10:03:00	225	10:08:50	226	10:14:40	226
10:03:10	225	10:09:00	226	10:14:50	226
10:03:20	225	10:09:10	226	10:15:00	226
10:03:30	225	10:09:20	226	10:15:10	226
10:03:40	225	10:09:30	226	10:15:20	226
10:03:50	225	10:09:40	226	10:15:30	226
10:04:00	225	10:09:50	226	10:15:40	226
10:04:10	225	10:10:00	226	10:15:50	226
10:04:20	225	10:10:10	226	10:16:00	226
10:04:30	225	10:10:20	226	10:16:10	226
10:04:40	225	10:10:30	226	10:16:20	226
10:04:50	225	10:10:40	226	10:16:30	226
10:05:00	226	10:10:50	226	10:16:40	226
10:05:10	225	10:11:00	226	10:16:50	226
10:05:20	225	10:11:10	226	10:17:00	227
10:05:30	225	10:11:20	226	10:17:10	227
10:05:40	225	10:11:30	226	10:17:20	227

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:17:30	227	10:23:20	226	10:29:10	225
10:17:40	227	10:23:30	225	10:29:20	225
10:17:50	227	10:23:40	225	10:29:30	225
10:18:00	227	10:23:50	226	10:29:40	225
10:18:10	226	10:24:00	226	10:29:50	225
10:18:20	226	10:24:10	225	10:30:00	224
10:18:30	226	10:24:20	225	10:30:10	224
10:18:40	226	10:24:30	225	10:30:20	224
10:18:50	226	10:24:40	225	10:30:30	224
10:19:00	226	10:24:50	225	10:30:40	225
10:19:10	226	10:25:00	225	10:30:50	225
10:19:20	226	10:25:10	225	10:31:00	225
10:19:30	226	10:25:20	226	10:31:10	225
10:19:40	226	10:25:30	226	10:31:20	225
10:19:50	226	10:25:40	225	10:31:30	224
10:20:00	226	10:25:50	225	10:31:40	224
10:20:10	226	10:26:00	225	10:31:50	224
10:20:20	226	10:26:10	225	10:32:00	224
10:20:30	226	10:26:20	225	10:32:10	224
10:20:40	226	10:26:30	225	10:32:20	224
10:20:50	226	10:26:40	225	10:32:30	224
10:21:00	226	10:26:50	225	10:32:40	224
10:21:10	226	10:27:00	225	10:32:50	224
10:21:20	226	10:27:10	226	10:33:00	224
10:21:30	226	10:27:20	226	10:33:10	224
10:21:40	226	10:27:30	225	10:33:20	224
10:21:50	226	10:27:40	225	10:33:30	224
10:22:00	226	10:27:50	225	10:33:40	224
10:22:10	226	10:28:00	225	10:33:50	224
10:22:20	226	10:28:10	225	10:34:00	224
10:22:30	226	10:28:20	225	10:34:10	224
10:22:40	226	10:28:30	225	10:34:20	224
10:22:50	226	10:28:40	224	10:34:30	224
10:23:00	226	10:28:50	224	10:34:40	224
10:23:10	226	10:29:00	225	10:34:50	224
10:35:00	224	10:40:50	223	10:46:40	220

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:35:10	224	10:41:00	222	10:46:50	220
10:35:20	223	10:41:10	222	10:47:00	220
10:35:30	223	10:41:20	222	10:47:10	220
10:35:40	223	10:41:30	222	10:47:20	220
10:35:50	223	10:41:40	222	10:47:30	220
10:36:00	223	10:41:50	222	10:47:40	220
10:36:10	223	10:42:00	222	10:47:50	220
10:36:20	224	10:42:10	222	10:48:00	220
10:36:30	223	10:42:20	222	10:48:10	220
10:36:40	223	10:42:30	222	10:48:20	220
10:36:50	223	10:42:40	222	10:48:30	220
10:37:00	223	10:42:50	222	10:48:40	220
10:37:10	223	10:43:00	222	10:48:50	220
10:37:20	224	10:43:10	221	10:49:00	220
10:37:30	223	10:43:20	221	10:49:10	220
10:37:40	223	10:43:30	221	10:49:20	220
10:37:50	223	10:43:40	221	10:49:30	220
10:38:00	223	10:43:50	221	10:49:40	220
10:38:10	223	10:44:00	221	10:49:50	220
10:38:20	223	10:44:10	221	10:50:00	220
10:38:30	223	10:44:20	221	10:50:10	219
10:38:40	223	10:44:30	221	10:50:20	219
10:38:50	223	10:44:40	221	10:50:30	219
10:39:00	223	10:44:50	221	10:50:40	219
10:39:10	223	10:45:00	221	10:50:50	219
10:39:20	223	10:45:10	221	10:51:00	219
10:39:30	223	10:45:20	221	10:51:10	220
10:39:40	223	10:45:30	221	10:51:20	220
10:39:50	223	10:45:40	221	10:51:30	220
10:40:00	223	10:45:50	221	10:51:40	219
10:40:10	223	10:46:00	221	10:51:50	219
10:40:20	223	10:46:10	221	10:52:00	219
10:40:30	223	10:46:20	221	10:52:10	219
10:40:40	223	10:46:30	220	10:52:20	219
10:52:30	219	10:58:20	219		
10:52:40	219	10:58:30	219		

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
10:52:50	219	10:58:40	219		
10:53:00	219	10:58:50	219		
10:53:10	220	10:59:00	219		
10:53:20	220	10:59:10	219		
10:53:30	219	10:59:20	219		
10:53:40	219	10:59:30	219		
10:53:50	219	10:59:40	219		
10:54:00	219	10:59:50	219		
10:54:10	219				
10:54:20	219				
10:54:30	220				
10:54:40	220				
10:54:50	220				
10:55:00	220				
10:55:10	220				
10:55:20	220				
10:55:30	220				
10:55:40	219				
10:55:50	219				
10:56:00	219				
10:56:10	219				
10:56:20	219				
10:56:30	219				
10:56:40	219				
10:56:50	219				
10:57:00	219				
10:57:10	219				
10:57:20	219				
10:57:30	219				
10:57:40	219				
10:57:50	219				
10:58:00	219				
10:58:10	219				

Table A.19. Duty Cycle for Load Shaping Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
15:00:00	0	23:45:00	-17	8:30:00	104
15:15:00	-78	0:00:00	-39	8:45:00	107
15:30:00	106	0:15:00	-92	9:00:00	156
15:45:00	101	0:30:00	-100	9:15:00	137
16:00:00	-53	0:45:00	-72	9:30:00	111
16:15:00	0	1:00:00	-111	9:45:00	122
16:30:00	-17	1:15:00	-112	10:00:00	95
16:45:00	6	1:30:00	-67	10:15:00	156
17:00:00	17	1:45:00	-39	10:30:00	144
17:15:00	28	2:00:00	-113	10:45:00	95
17:30:00	72	2:15:00	-104	11:00:00	89
17:45:00	70	2:30:00	-83	11:15:00	78
18:00:00	95	2:45:00	-101	11:30:00	95
18:15:00	122	3:00:00	-72	11:45:00	50
18:30:00	89	3:15:00	-89	12:00:00	44
18:45:00	95	3:30:00	-89	12:15:00	78
19:00:00	78	3:45:00	-106	12:30:00	113
19:15:00	61	4:00:00	-78	12:45:00	61
19:30:00	39	4:15:00	-93	13:00:00	106
19:45:00	95	4:30:00	-131	13:15:00	67
20:00:00	117	4:45:00	-133	13:30:00	133
20:15:00	117	5:00:00	-111	13:45:00	44
20:30:00	121	5:15:00	-111	14:00:00	56
20:45:00	31	5:30:00	-100	14:15:00	46
21:00:00	78	5:45:00	-80	14:30:00	111
21:15:00	67	6:00:00	-83	14:45:00	31
21:30:00	89	6:15:00	-39	15:00:00	39
21:45:00	83	6:30:00	-59	15:15:00	17
22:00:00	32	6:45:00	-60	15:30:00	22
22:15:00	11	7:00:00	-64	15:45:00	-22
22:30:00	21	7:15:00	-6	16:00:00	15
22:45:00	28	7:30:00	0	16:15:00	33
23:00:00	11	7:45:00	6	16:30:00	15
23:15:00	11	8:00:00	17	16:45:00	-33
23:30:00	-61	8:15:00	22	17:00:00	-11

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
17:15:00	0	2:00:00	-124	10:45:00	6
17:30:00	0	2:15:00	-120	11:00:00	-16
17:45:00	-36	2:30:00	-83	11:15:00	-39
18:00:00	-44	2:45:00	-89	11:30:00	-28
18:15:00	-31	3:00:00	-111	11:45:00	-47
18:30:00	-33	3:15:00	-106	12:00:00	-111
18:45:00	-17	3:30:00	-114	12:15:00	-86
19:00:00	14	3:45:00	-122	12:30:00	-159
19:15:00	3	4:00:00	-144	12:45:00	-152
19:30:00	0	4:15:00	-56	13:00:00	-144
19:45:00	-19	4:30:00	-89	13:15:00	-194
20:00:00	22	4:45:00	-125	13:30:00	-178
20:15:00	0	5:00:00	-68	13:45:00	-154
20:30:00	24	5:15:00	-98	14:00:00	-171
20:45:00	28	5:30:00	-86	14:15:00	6
21:00:00	-6	5:45:00	-44	14:30:00	-89
21:15:00	11	6:00:00	-67	14:45:00	-130
21:30:00	6	6:15:00	-43	15:00:00	-117
21:45:00	-17	6:30:00	-37	15:15:00	-122
22:00:00	-20	6:45:00	-28	15:30:00	-144
22:15:00	-20	7:00:00	-39	15:45:00	-117
22:30:00	-7	7:15:00	-44	16:00:00	-78
22:45:00	-33	7:30:00	-28	16:15:00	-122
23:00:00	-94	7:45:00	-39	16:30:00	-129
23:15:00	-117	8:00:00	-28	16:45:00	-122
23:30:00	-61	8:15:00	11	17:00:00	-133
23:45:00	-100	8:30:00	0	17:15:00	-137
0:00:00	-89	8:45:00	4	17:30:00	-83
0:15:00	-83	9:00:00	-6	17:45:00	-94
0:30:00	-61	9:15:00	-56	18:00:00	-56
0:45:00	-111	9:30:00	6	18:15:00	-83
1:00:00	-98	9:45:00	-39	18:30:00	-75
1:15:00	-128	10:00:00	-17	18:45:00	-83
1:30:00	-114	10:15:00	-6	19:00:00	-81
1:45:00	-97	10:30:00	-15	19:15:00	-72
19:30:00	-67	4:15:00	43	13:00:00	-22

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
19:45:00	-67	4:30:00	42	13:15:00	0
20:00:00	-78	4:45:00	76	13:30:00	0
20:15:00	-28	5:00:00	89	13:45:00	-17
20:30:00	-50	5:15:00	44	14:00:00	-28
20:45:00	-11	5:30:00	39	14:15:00	-44
21:00:00	-39	5:45:00	128	14:30:00	-44
21:15:00	-56	6:00:00	117	14:45:00	-74
21:30:00	-39	6:15:00	106	15:00:00	-87
21:45:00	-28	6:30:00	87	15:15:00	-74
22:00:00	-41	6:45:00	131	15:30:00	-54
22:15:00	-77	7:00:00	113	15:45:00	-39
22:30:00	-50	7:15:00	122	16:00:00	-67
22:45:00	-64	7:30:00	152	16:15:00	-6
23:00:00	-72	7:45:00	117	16:30:00	-28
23:15:00	-56	8:00:00	169	16:45:00	-28
23:30:00	-78	8:15:00	178	17:00:00	6
23:45:00	-100	8:30:00	122	17:15:00	-28
0:00:00	28	8:45:00	128	17:30:00	0
0:15:00	53	9:00:00	128	17:45:00	28
0:30:00	48	9:15:00	111	18:00:00	67
0:45:00	52	9:30:00	111	18:15:00	11
1:00:00	11	9:45:00	128	18:30:00	56
1:15:00	28	10:00:00	111	18:45:00	46
1:30:00	17	10:15:00	106	19:00:00	99
1:45:00	11	10:30:00	83	19:15:00	33
2:00:00	6	10:45:00	44	19:30:00	87
2:15:00	38	11:00:00	100	19:45:00	89
2:30:00	41	11:15:00	89	20:00:00	111
2:45:00	30	11:30:00	70	20:15:00	100
3:00:00	20	11:45:00	69	20:30:00	83
3:15:00	28	12:00:00	44	20:45:00	48
3:30:00	6	12:15:00	76	21:00:00	44
3:45:00	6	12:30:00	17	21:15:00	69
4:00:00	33	12:45:00	26	21:30:00	33
21:45:00	60	6:30:00	0	15:15:00	-70
22:00:00	-11	6:45:00	17	15:30:00	-44

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
22:15:00	6	7:00:00	0	15:45:00	-72
22:30:00	-33	7:15:00	44	16:00:00	-56
22:45:00	-22	7:30:00	56	16:15:00	-6
23:00:00	-28	7:45:00	61	16:30:00	-24
23:15:00	-60	8:00:00	35	16:45:00	-11
23:30:00	-63	8:15:00	22	17:00:00	-50
23:45:00	-67	8:30:00	33	17:15:00	14
0:00:00	-59	8:45:00	22	17:30:00	-22
0:15:00	-2	9:00:00	32	17:45:00	-44
0:30:00	-6	9:15:00	22	18:00:00	-6
0:45:00	-11	9:30:00	6	18:15:00	-22
1:00:00	-25	9:45:00	11	18:30:00	-19
1:15:00	-78	10:00:00	22	18:45:00	0
1:30:00	-68	10:15:00	-11	19:00:00	33
1:45:00	-83	10:30:00	-6	19:15:00	17
2:00:00	-83	10:45:00	22	19:30:00	22
2:15:00	-88	11:00:00	-17	19:45:00	47
2:30:00	-74	11:15:00	17	20:00:00	61
2:45:00	-67	11:30:00	6	20:15:00	83
3:00:00	-41	11:45:00	22	20:30:00	85
3:15:00	-63	12:00:00	0	20:45:00	33
3:30:00	-61	12:15:00	33	21:00:00	58
3:45:00	-61	12:30:00	33	21:15:00	63
4:00:00	-33	12:45:00	20	21:30:00	71
4:15:00	-33	13:00:00	-28	21:45:00	33
4:30:00	-21	13:15:00	17	22:00:00	0
4:45:00	-46	13:30:00	-22	22:15:00	28
5:00:00	-33	13:45:00	-11	22:30:00	-44
5:15:00	-39	14:00:00	-33	22:45:00	6
5:30:00	-43	14:15:00	-78	23:00:00	-28
5:45:00	-22	14:30:00	-39	23:15:00	-10
6:00:00	-37	14:45:00	-78	23:30:00	-17
6:15:00	17	15:00:00	-50	23:45:00	-39
0:00:00	-65	8:45:00	50	17:30:00	-22
0:15:00	-6	9:00:00	56	17:45:00	1
0:30:00	-28	9:15:00	25	18:00:00	22

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
0:45:00	-39	9:30:00	6	18:15:00	-11
1:00:00	-44	9:45:00	20	18:30:00	-17
1:15:00	-68	10:00:00	0	18:45:00	-22
1:30:00	-56	10:15:00	33	19:00:00	-8
1:45:00	-44	10:30:00	12	19:15:00	22
2:00:00	-65	10:45:00	6	19:30:00	39
2:15:00	-100	11:00:00	-17	19:45:00	61
2:30:00	-56	11:15:00	-26	20:00:00	50
2:45:00	-63	11:30:00	-33	20:15:00	43
3:00:00	-41	11:45:00	6	20:30:00	7
3:15:00	-67	12:00:00	-56	20:45:00	50
3:30:00	-98	12:15:00	56	21:00:00	63
3:45:00	-74	12:30:00	33	21:15:00	42
4:00:00	-76	12:45:00	17	21:30:00	35
4:15:00	-67	13:00:00	-47	21:45:00	19
4:30:00	-69	13:15:00	-17	22:00:00	0
4:45:00	-108	13:30:00	-61	22:15:00	22
5:00:00	-79	13:45:00	17	22:30:00	-20
5:15:00	-78	14:00:00	0	22:45:00	-33
5:30:00	-85	14:15:00	-44	23:00:00	-30
5:45:00	-78	14:30:00	-6	23:15:00	-43
6:00:00	-33	14:45:00	-60	23:30:00	-56
6:15:00	17	15:00:00	-42	23:45:00	-67
6:30:00	11	15:15:00	-69	0:00:00	-50
6:45:00	-12	15:30:00	-43	0:15:00	-28
7:00:00	-39	15:45:00	-28	0:30:00	-44
7:15:00	-2	16:00:00	-50	0:45:00	-56
7:30:00	17	16:15:00	-39	1:00:00	-47
7:45:00	50	16:30:00	-22	1:15:00	-50
8:00:00	6	16:45:00	28	1:30:00	-45
8:15:00	39	17:00:00	28	1:45:00	-61
8:30:00	43	17:15:00	17	2:00:00	-30
2:15:00	-35	11:00:00	-22	19:45:00	139
2:30:00	-89	11:15:00	9	20:00:00	94
2:45:00	-67	11:30:00	-11	20:15:00	106
3:00:00	-58	11:45:00	-28	20:30:00	122

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
3:15:00	-66	12:00:00	-17	20:45:00	89
3:30:00	-66	12:15:00	35	21:00:00	150
3:45:00	-72	12:30:00	33	21:15:00	147
4:00:00	-72	12:45:00	33	21:30:00	150
4:15:00	-44	13:00:00	0	21:45:00	153
4:30:00	-83	13:15:00	28	22:00:00	96
4:45:00	-94	13:30:00	17	22:15:00	84
5:00:00	-61	13:45:00	33	22:30:00	122
5:15:00	-67	14:00:00	44	22:45:00	33
5:30:00	-56	14:15:00	50	23:00:00	89
5:45:00	-8	14:30:00	13	23:15:00	72
6:00:00	-47	14:45:00	11	23:30:00	111
6:15:00	-33	15:00:00	8	23:45:00	65
6:30:00	-11	15:15:00	-11	0:00:00	44
6:45:00	-28	15:30:00	25	0:15:00	72
7:00:00	14	15:45:00	24	0:30:00	89
7:15:00	3	16:00:00	-17	0:45:00	58
7:30:00	44	16:15:00	28	1:00:00	28
7:45:00	0	16:30:00	53	1:15:00	67
8:00:00	67	16:45:00	72	1:30:00	56
8:15:00	25	17:00:00	56	1:45:00	52
8:30:00	29	17:15:00	72	2:00:00	33
8:45:00	-11	17:30:00	43	2:15:00	46
9:00:00	6	17:45:00	78	2:30:00	33
9:15:00	-33	18:00:00	52	2:45:00	33
9:30:00	17	18:15:00	78		
9:45:00	10	18:30:00	53		
10:00:00	-33	18:45:00	122		
10:15:00	28	19:00:00	58		
10:30:00	0	19:15:00	78		
10:45:00	0	19:30:00	83		

Table A.20. Duty Cycle for Distribution Deferral Test at PSE

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
15:00:00	30	23:45:00	0	8:30:00	217
15:15:00	-110	0:00:00	-40	8:45:00	223
15:30:00	220	0:15:00	-136	9:00:00	310
15:45:00	213	0:30:00	-150	9:15:00	277
16:00:00	-65	0:45:00	-100	9:30:00	230
16:15:00	30	1:00:00	-170	9:45:00	250
16:30:00	0	1:15:00	-172	10:00:00	200
16:45:00	40	1:30:00	-90	10:15:00	310
17:00:00	60	1:45:00	-40	10:30:00	289
17:15:00	80	2:00:00	-173	10:45:00	200
17:30:00	160	2:15:00	-157	11:00:00	190
17:45:00	155	2:30:00	-120	11:15:00	170
18:00:00	200	2:45:00	-152	11:30:00	200
18:15:00	250	3:00:00	-100	11:45:00	120
18:30:00	190	3:15:00	-130	12:00:00	110
18:45:00	200	3:30:00	-130	12:15:00	170
19:00:00	170	3:45:00	-160	12:30:00	233
19:15:00	140	4:00:00	-110	12:45:00	140
19:30:00	100	4:15:00	-138	13:00:00	220
19:45:00	200	4:30:00	-205	13:15:00	150
20:00:00	240	4:45:00	-210	13:30:00	270
20:15:00	240	5:00:00	-170	13:45:00	110
20:30:00	248	5:15:00	-170	14:00:00	130
20:45:00	85	5:30:00	-150	14:15:00	113
21:00:00	170	5:45:00	-113	14:30:00	230
21:15:00	150	6:00:00	-120	14:45:00	85
21:30:00	190	6:15:00	-40	15:00:00	100
21:45:00	180	6:30:00	-76	15:15:00	60
22:00:00	87	6:45:00	-78	15:30:00	70
22:15:00	50	7:00:00	-85	15:45:00	-10
22:30:00	68	7:15:00	20	16:00:00	57
22:45:00	80	7:30:00	30	16:15:00	90
23:00:00	50	7:45:00	40	16:30:00	57
23:15:00	50	8:00:00	60	16:45:00	-30
23:30:00	-80	8:15:00	70	17:00:00	10

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
17:15:00	30	2:00:00	-193	10:45:00	40
17:30:00	30	2:15:00	-187	11:00:00	2
17:45:00	-35	2:30:00	-120	11:15:00	-40
18:00:00	-50	2:45:00	-130	11:30:00	-20
18:15:00	-27	3:00:00	-170	11:45:00	-54
18:30:00	-30	3:15:00	-160	12:00:00	-170
18:45:00	0	3:30:00	-175	12:15:00	-125
19:00:00	55	3:45:00	-190	12:30:00	-257
19:15:00	35	4:00:00	-230	12:45:00	-243
19:30:00	30	4:15:00	-70	13:00:00	-230
19:45:00	-5	4:30:00	-130	13:15:00	-320
20:00:00	70	4:45:00	-195	13:30:00	-290
20:15:00	30	5:00:00	-92	13:45:00	-247
20:30:00	73	5:15:00	-147	14:00:00	-278
20:45:00	80	5:30:00	-125	14:15:00	40
21:00:00	20	5:45:00	-50	14:30:00	-130
21:15:00	50	6:00:00	-90	14:45:00	-204
21:30:00	40	6:15:00	-47	15:00:00	-180
21:45:00	0	6:30:00	-37	15:15:00	-190
22:00:00	-7	6:45:00	-20	15:30:00	-230
22:15:00	-7	7:00:00	-40	15:45:00	-180
22:30:00	18	7:15:00	-49	16:00:00	-110
22:45:00	-30	7:30:00	-20	16:15:00	-190
23:00:00	-140	7:45:00	-40	16:30:00	-202
23:15:00	-180	8:00:00	-20	16:45:00	-190
23:30:00	-80	8:15:00	50	17:00:00	-210
23:45:00	-150	8:30:00	30	17:15:00	-217
0:00:00	-130	8:45:00	37	17:30:00	-120
0:15:00	-120	9:00:00	20	17:45:00	-140
0:30:00	-80	9:15:00	-70	18:00:00	-70
0:45:00	-170	9:30:00	40	18:15:00	-120
1:00:00	-147	9:45:00	-40	18:30:00	-105
1:15:00	-200	10:00:00	0	18:45:00	-120
1:30:00	-175	10:15:00	20	19:00:00	-117
1:45:00	-145	10:30:00	3	19:15:00	-100
19:30:00	-90	4:15:00	-10	13:00:00	-170

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
19:45:00	-90	4:30:00	-10	13:15:00	-130
20:00:00	-110	4:45:00	8	13:30:00	-130
20:15:00	-20	5:00:00	30	13:45:00	-160
20:30:00	-60	5:15:00	-9	14:00:00	-180
20:45:00	10	5:30:00	-11	14:15:00	-210
21:00:00	-40	5:45:00	100	14:30:00	-210
21:15:00	-70	6:00:00	80	14:45:00	-263
21:30:00	-40	6:15:00	60	15:00:00	-287
21:45:00	-20	6:30:00	27	15:15:00	-51
22:00:00	-43	6:45:00	105	15:30:00	-43
22:15:00	-108	7:00:00	73	15:45:00	-38
22:30:00	-60	7:15:00	90	16:00:00	-46
22:45:00	-85	7:30:00	143	16:15:00	-26
23:00:00	-100	7:45:00	80	16:30:00	-33
23:15:00	-70	8:00:00	173	16:45:00	-32
23:30:00	-110	8:15:00	190	17:00:00	-21
23:45:00	-150	8:30:00	90	17:15:00	-32
0:00:00	-80	8:45:00	100	17:30:00	-23
0:15:00	-35	9:00:00	100	17:45:00	-14
0:30:00	-43	9:15:00	70	18:00:00	-2
0:45:00	-37	9:30:00	70	18:15:00	-19
1:00:00	-110	9:45:00	100	18:30:00	-5
1:15:00	-80	10:00:00	70	18:45:00	-8
1:30:00	-100	10:15:00	60	19:00:00	48
1:45:00	-110	10:30:00	20	19:15:00	-12
2:00:00	-120	10:45:00	-50	19:30:00	27
2:15:00	-12	11:00:00	50	19:45:00	30
2:30:00	-11	11:15:00	30	20:00:00	70
2:45:00	-15	11:30:00	-3	20:15:00	50
3:00:00	-18	11:45:00	-7	20:30:00	20
3:15:00	-15	12:00:00	-50	20:45:00	-8
3:30:00	-23	12:15:00	7	21:00:00	-9
3:45:00	-22	12:30:00	-100	21:15:00	-1
4:00:00	-13	12:45:00	-83	21:30:00	-13
21:45:00	-4	6:30:00	-15	15:15:00	-22
22:00:00	-28	6:45:00	-11	15:30:00	-18

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
22:15:00	-22	7:00:00	-15	15:45:00	-22
22:30:00	-34	7:15:00	-6	16:00:00	-19
22:45:00	-30	7:30:00	-3	16:15:00	-11
23:00:00	-32	7:45:00	-2	16:30:00	-14
23:15:00	-41	8:00:00	-7	16:45:00	-12
23:30:00	-42	8:15:00	-10	17:00:00	-17
23:45:00	-42	8:30:00	-8	17:15:00	-8
0:00:00	-39	8:45:00	-10	17:30:00	-13
0:15:00	-22	9:00:00	-8	17:45:00	-16
0:30:00	-23	9:15:00	-10	18:00:00	-11
0:45:00	-24	9:30:00	-13	18:15:00	-13
1:00:00	-28	9:45:00	-12	18:30:00	-12
1:15:00	-42	10:00:00	-10	18:45:00	-9
1:30:00	-39	10:15:00	-16	19:00:00	-5
1:45:00	-42	10:30:00	-15	19:15:00	-7
2:00:00	-42	10:45:00	-9	19:30:00	-6
2:15:00	-42	11:00:00	-17	19:45:00	-3
2:30:00	-38	11:15:00	-10	20:00:00	-1
2:45:00	-35	11:30:00	-12	20:15:00	20
3:00:00	-28	11:45:00	-9	20:30:00	23
3:15:00	-33	12:00:00	-13	20:45:00	-5
3:30:00	-32	12:15:00	-7	21:00:00	-2
3:45:00	-32	12:30:00	-7	21:15:00	-1
4:00:00	-25	12:45:00	-9	21:30:00	0
4:15:00	-24	13:00:00	-18	21:45:00	-5
4:30:00	-21	13:15:00	-10	22:00:00	-10
4:45:00	-27	13:30:00	-16	22:15:00	-6
5:00:00	-24	13:45:00	-14	22:30:00	-15
5:15:00	-24	14:00:00	-18	22:45:00	-9
5:30:00	-25	14:15:00	-25	23:00:00	-13
5:45:00	-20	14:30:00	-18	23:15:00	-10
6:00:00	-23	14:45:00	-24	23:30:00	-11
6:15:00	-12	15:00:00	-19	23:45:00	-14
0:00:00	-17	8:45:00	-2	17:30:00	-5
0:15:00	-9	9:00:00	-1	17:45:00	-4
0:30:00	-12	9:15:00	-4	18:00:00	-3

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
0:45:00	-13	9:30:00	-5	18:15:00	-4
1:00:00	-13	9:45:00	-4	18:30:00	-5
1:15:00	-16	10:00:00	-5	18:45:00	-5
1:30:00	-14	10:15:00	-3	19:00:00	-4
1:45:00	-13	10:30:00	-4	19:15:00	-3
2:00:00	-15	10:45:00	-5	19:30:00	-2
2:15:00	-18	11:00:00	-6	19:45:00	-1
2:30:00	-13	11:15:00	-7	20:00:00	-1
2:45:00	-14	11:30:00	-7	20:15:00	-1
3:00:00	-11	11:45:00	-5	20:30:00	-3
3:15:00	-14	12:00:00	-9	20:45:00	-1
3:30:00	-17	12:15:00	-1	21:00:00	0
3:45:00	-14	12:30:00	-3	21:15:00	-1
4:00:00	-14	12:45:00	-4	21:30:00	-2
4:15:00	-13	13:00:00	-8	21:45:00	-3
4:30:00	-13	13:15:00	-6	22:00:00	-3
4:45:00	-16	13:30:00	-9	22:15:00	-2
5:00:00	-13	13:45:00	-4	22:30:00	-4
5:15:00	-13	14:00:00	-5	22:45:00	-5
5:30:00	-13	14:15:00	-7	23:00:00	-5
5:45:00	-12	14:30:00	-5	23:15:00	-5
6:00:00	-9	14:45:00	-8	23:30:00	-6
6:15:00	-4	15:00:00	-7	23:45:00	-6
6:30:00	-5	15:15:00	-8	0:00:00	-5
6:45:00	-7	15:30:00	-7	0:15:00	-4
7:00:00	-9	15:45:00	-6	0:30:00	-5
7:15:00	-6	16:00:00	-7	0:45:00	-5
7:30:00	-4	16:15:00	-6	1:00:00	-5
7:45:00	-2	16:30:00	-5	1:15:00	-5
8:00:00	-5	16:45:00	-2	1:30:00	-5
8:15:00	-3	17:00:00	-2	1:45:00	-5
8:30:00	-2	17:15:00	-3	2:00:00	-4
2:15:00	-4	11:00:00	-2	19:45:00	120
2:30:00	-6	11:15:00	-2	20:00:00	40
2:45:00	-5	11:30:00	-2	20:15:00	60
3:00:00	-5	11:45:00	-2	20:30:00	90
3:15:00	-5	12:00:00	-2	20:45:00	30

Duty Cycle		Duty Cycle		Duty Cycle	
Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)	Time (hh:mm:ss)	Power (kW)
3:30:00	-5	12:15:00	-1	21:00:00	140
3:45:00	-5	12:30:00	-1	21:15:00	135
4:00:00	-5	12:45:00	-1	21:30:00	140
4:15:00	-4	13:00:00	-2	21:45:00	145
4:30:00	-5	13:15:00	-1	22:00:00	43
4:45:00	-5	13:30:00	-1	22:15:00	22
5:00:00	-4	13:45:00	-1	22:30:00	90
5:15:00	-4	14:00:00	-1	22:45:00	-7
5:30:00	-4	14:15:00	-1	23:00:00	30
5:45:00	-2	14:30:00	-1	23:15:00	0
6:00:00	-4	14:45:00	-1	23:30:00	70
6:15:00	-3	15:00:00	-1	23:45:00	-1
6:30:00	-2	15:15:00	-2	0:00:00	-6
6:45:00	-3	15:30:00	-1	0:15:00	0
7:00:00	-2	15:45:00	-1	0:30:00	30
7:15:00	-2	16:00:00	-2	0:45:00	-3
7:30:00	-1	16:15:00	-1	1:00:00	-9
7:45:00	-2	16:30:00	0	1:15:00	-1
8:00:00	0	16:45:00	0	1:30:00	-3
8:15:00	-1	17:00:00	0	1:45:00	-4
8:30:00	-1	17:15:00	0	2:00:00	-8
8:45:00	-2	17:30:00	-1	2:15:00	-5
9:00:00	-2	17:45:00	10	2:30:00	-8
9:15:00	-3	18:00:00	0	2:45:00	-8
9:30:00	-1	18:15:00	10		
9:45:00	-2	18:30:00	0		
10:00:00	-3	18:45:00	90		
10:15:00	-1	19:00:00	-1		
10:30:00	-2	19:15:00	10		
10:45:00	-2	19:30:00	20		

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