Flywheel Energy Storage Study

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Acknowledgements

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SDG&E and ASWB would like to thank the flywheel vendor for their assistance and cooperation. Without their gracious assistance, this study would not have been possible. Thanks and acknowledgements are due to the technology vendor for their support, dedication to energy conservation, and ongoing efforts to provide energy efficiency products to the marketplace.

Contact ETinfo@sdge.com for more information on this project.

Disclaimer

EXECUTIVE SUMMARY

The purpose of this study is to determine the capabilities and cost-effectiveness of a lower-cost-of-manufacture Flywheel Energy Storage (FES) System. The core of this particular FES System technology involves the development of a lower-cost steel flywheel, which will reduce the first cost of the energy storage device, while delivering the required energy storage. This report is necessary to help determine if the technology can be used effectively for grid stabilization, over-generation mitigation and conventional energy storage uses. It appears that this technology may result in significant energy system benefits worthy of adoption into the California Center for Sustainable Energy's (CSE) Self-Generation Incentive Program (SGIP).

The demonstration project was to evaluate the "round trip" energy efficiency of this lower-cost flywheel system and investigate the system's capabilities to provide services such as demand shifting and ancillary services (for grid stabilization such as providing frequency regulation).

The testing location was originally intended to be in SDG&E service territory, however the original site was unable to move forward and so the test was relocated to the manufacturer's testing facility in Alameda, California. All power, energy and efficiency measurements were taken at the DC bus, to allow evaluation of the FES system to be agnostic to the grid inverter.

The testing procedure included recording of data gathered during execution of the following steps:

1. Charge FES unit to 100% SOC.
2. Discharge at maximum discharge power to 0% SOC.
3. Recharge to 100% SOC.
4. Discharge at 66% discharge power to achieve 0% SOC in 6 hours.
5. Recharge to 100% SOC.
6. Let the FES coast (without input power to overcome losses) at 100%, 75%, 50%, 25%, and 0% SOC levels for 30 minutes at each state of charge.
7. Recharge FES to 100% SOC.
8. Allow the FES to coast for 24 hours starting from 100% SOC.

(The following steps were performed to evaluate frequency regulation applications)

9. Discharge the FES to 50% SOC.
10. Vary the discharge between 75% and 25% power every 60 seconds for 10 minutes.
11. Vary the discharge between 75% and 25% power every 15 seconds for 10 minutes.
12. Vary the discharge between 75% and 25% power every 4 seconds for 40 minutes.

Table-ES 1 presents the round trip efficiency of the FES system during a charge and discharge cycle at maximum power. This efficiency includes system losses, and excludes station power (off loader magnet, motor field winding, and controls power).

TABLE-ES 1. FES SYSTEM EFFICIENCY

ENERGY INPUT KWH	ENERGY OUTPUT KWH	ROUND TRIP EFFICIENCY
30.42	26.46	87.00%

In order to monetize the load shift associated with the FES System, a Time of Use (TOU) utility rate is necessary. At the request of the SDG&E project manager, this report used the AL-TOU-Secondary rate from SDG&E. A breakdown of this rate can be found in Appendix C.

Because the AL-TOU-Secondary rate has a seven hour summer On-Peak period, and the FES System can only discharge at max power for four hours, two scenarios were considered for evaluation. Scenario A assumes that the discharge rate was lowered so the discharge period spans the full seven hour summer On-Peak period. Scenario B uses the maximum discharge rate for four of the seven On-Peak hours. Scenario B produced better results than Scenario A, but at a greater risk of setting higher peak demand levels in the remaining three On-Peak hours where the FES is no longer discharging.

Both Scenario A and Scenario B were evaluated with 1.) no incentive, 2.) a hypothetical Permanent Load Shifting (PLS) incentive[1], and 3.) a hypothetical SGIP incentive[2]. Table-ES 2 demonstrates the simple payback financial analysis of the study.

TABLE-ES 2. SUMMARY OF SIMPLE PAYBACK ANALYSIS

SCENARIO	IMPLEMENTATION COST	ANNUAL ENERGY COST SAVINGS	ANNUAL DEMAND COST SAVINGS	TOTAL ANNUAL COST SAVINGS	SIMPLE PAYBACK (YEARS)
A - Without Incentive	$900,000	($7,998)	$52,503	$44,506	20.22
A - With PLS Incentive	$658,672	($7,998)	$52,503	$44,506	14.80
A - With SGIP Incentive	$141,264	($7,998)	$52,503	$44,506	3.17
B - Without Incentive	$900,000	($9,199)	$76,655	$67,456	13.34
B - With PLS Incentive	$477,676	($9,199)	$76,655	$67,456	7.08
B - With SGIP Incentive	$141,264	($9,199)	$76,655	$67,456	2.09

[1] http://www.sdge.com/business/demand-response/permanent-load-shifting

[2] https://energycenter.org/program/self-generation-incentive-program

Table-ES 3 summarizes the Life Cycle Cost Analysis (LCCA) results obtained by this study.

TABLE-ES 3. LCC ANALYSIS

SCENARIO	NET PRESENT VALUE	PAYBACK (YEARS)	SAVINGS INVESTMENT RATIO	INTERNAL RATE OF RETURN	RETURN ON INVESTMENT
A - Without Incentive	($91,182)	18.01	-0.10	4%	-110%
A - With PLS Incentive	$150,147	14.02	0.28	7%	-77%
A - With SGIP Incentive	$667,554	3.11	4.73	33%	373%
B - Without Incentive	$556,791	12.57	0.62	8%	-38%
B - With PLS Incentive	$775,534	6.69	1.62	15%	62%
B - With SGIP Incentive	$1,111,946	2.07	7.87	49%	687%

This methodology assumes a 2% annual escalation rate on the electricity and demand charges of the AL-TOU secondary rate, as well as an assumed discount rate of 5%. Maintenance costs were incurred in Years 10 and 20. A life expectancy of 30 years was assumed for this study, which was taken directly from vendor product literature. The energy and demand prices are dependent on Time of Use and can be found in Appendix C of this report. With the SGIP incentive, both Scenario A and Scenario B have reasonable LCCA paybacks less than 5 years. The FES System under study effectively shifts load in a cost effective manner, and this technology is recommended for adoption into the SGIP program.

Demand response (DR) may be another possibility, both traditional demand response (similar to batteries) and “fast” demand response, as well as possible over-generation mitigation.

While DR is a possible use of this emerging technology, it appears that the value of the FES may be realized to greater extent using SGIP incentives. It does appear that the FES technology may be used in a number of grid services, thus participating in multiple markets.

ABBREVIATIONS AND ACRONYMS

CSE	Center for Sustainable Energy
DR	Demand Response
ETP	Emerging Technologies Program
EUL	Economic Useful Life
FES	Flywheel Energy Storage
LCCA	Life Cycle Cost Analysis
M&V	Measurement and Verification
OBF	On-Bill Financing
PLS	Permanent Load Shifting
RPM	Revolutions per Minute
RPS	Revolutions per Second
SGIP	Self-Generation Incentive Program
SOC	State of Charge
TES	Thermal Energy Storage
TOU	Time of Use (electric rate structure)

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FIGURES

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INTRODUCTION

ASWB was directed by SDG&E Emerging Technologies Program (ETP) to conduct a Measurement and Verification (M&V) analysis for the Flywheel Energy Storage (FES) System produced by the manufacturer. The analysis was performed to determine the applicability of this emerging technology to various sectors of the energy distribution grid. SDG&E worked with the FES System vendor and after evaluating several possible installation sites, arranged for field testing at a test site in Alameda, California.

FES Systems use electrical energy to accelerate a large-mass rotor to very high speeds. By accelerating to and maintaining these high speeds, the electrical energy is converted and stored as kinetic rotational energy. This kinetic energy can then be converted back into electrical energy as needed by decelerating the rotor using a generation asset. The FES System utilizes low-loss conventional bearings and a high-vacuum enclosure to minimize energy losses due to friction and air resistance. Because of the resultant low drag (air resistance) on the rotor, relatively little energy is required to maintain rotor speed until the system is ready to deliver the stored energy. The FES System has some advantages over traditional chemical battery storage, such as the following:

- Full charge and discharge power available at all levels of charge.
- Can be cycled frequently with no impact to performance.
- Less damaging to the environment as it is fully recyclable.
- Significantly longer life.
- Lower levelized cost of energy storage vs. other technologies
- Minimal maintenance.
- Ability to operate at a much wider temperature range.
- Passive air cooling.
- The exact amount of energy stored can be determined by a simple measurement of the rotational speed.

However, the current understanding of the FES System does have some disadvantages when compared to traditional electric battery storage, such as:

- Larger space requirements.
- Higher cost.
- Installation site must allow either below-grade installation, or addition of earth berms for above grade installation.

BACKGROUND

HISTORY

The concept of storing rotational energy has been around for thousands of years, in the form of spindles and pottery wheels for example. However, significant advances in flywheels did not occur until the industrial revolution, when cast iron flywheels were manufactured for use in steam engines. Methods were developed to transform the reciprocating motion of a steam engine into rotary motion through the use of a crank and flywheel combination.[3] The first generation of flywheels utilized for actual energy storage applications were made from steel and rotated on mechanical bearings. Subsequent generations of flywheels utilized rotors made from carbon-fiber (or other) composites as well as magnetic bearings for high speed and high density. This approach resulted in FES Systems with a much higher initial cost, and thus is not found to be cost effective in certain application scenarios. The FES System being evaluated in this study is relatively low cost due to its steel composition and conventional mechanical bearings.

While mechanical bearings are the most cost effective for this application, the benefits of magnetic bearings are discussed for further background information. The magnetic bearing does not actually make contact; as such it eliminates the energy losses associated with bearing friction. FES systems with mechanical bearings lose energy at a somewhat faster rate than those with magnetic bearings. Another benefit from the lack of physical contact associated with magnetic bearings is that there is no wear on the bearing, greatly extending the life of the FES and almost eliminating the need for maintenance completely.

As with the mechanical bearings, the steel rotor can be shown to have the lowest cost per energy stored. The benefits of composite rotors are explained here as well. In order to maximize the specific energy (energy per unit mass), the flywheel must spin as fast as possible (the velocity is squared, whereas the mass remains linear). However, increased rotational speed has the effect of increasing the "centrifugal" forces acting on the rotor. The amount of force that the flywheel can withstand is dependent on the tensile strength of the material used in its construction. The maximum specific energy (a unit roughly equivalent to energy per pound-mass) of the FES is directly proportional to the ratio of the tensile strength and the material density. The increased tensile strength of the composite material when compared to steel (as well as the lower density) allows it to withstand higher angular velocities and thus store more specific energy.

[3] https://en.wikipedia.org/wiki/Flywheel#History

Site Description

Test Site:

The testing for this study was performed at a private testing facility in Alameda, California. The testing facility contains two identical flywheels that are located in separate underground concrete bunkers, with an on-site monitoring and control room inside of a separate structure. The monitoring and control room has camera surveillance inside the bunkers to monitor for any issues. The flywheels can be controlled both from the on-site control center as well as from the flywheel manufacturer's office. Data is sent from the testing facility to the cloud using a wireless hotspot.

In the picture below, the bunkers are located under the steel plates on either side of the shipping container. The shipping container houses the monitoring and control room.

Figure 1. – Flywheel Testing Facility

Figure 2. – Flywheel Bunker Camera Feed

The photo above shows the security feed that the manufacturer uses to see inside the bunker. This allows them to monitor the FES without removing the steel plates.

EMERGING TECHNOLOGY/PRODUCT

The FES System converts electricity into rotational energy, which can be stored and converted back into electrical energy at a later time, presumably when electricity is more expensive and/or is in short supply. Losses in the unit's rotational energy are reduced through the use of low friction bearings and a high vacuum enclosure to reduce air resistance on the steel rotor mass. While many competing FES systems focus on high power, short duration applications, this particular FES System under study was designed to take a low power, long duration approach. Similar to other flywheel systems the FES system under study operates between set minimum and maximum speeds in order to avoid harmful resonant frequencies.

The FES system under evaluation in this study is described in the table below per manufacturer specifications. Refer to Appendix D for more information.

TABLE 4. FES SYSTEM SPECIFICATIONS

FEATURE	VALUE
Power	+/- 6.25 kW
Energy	25 kWh
Duration	4 Hours
Efficiency	>88% (Round trip excluding self discharge)
Daily Cycling Limitations	None
Calendar Life	30 Years
GHG Emissions	None
Self Discharge	<65 W
Input/Output Voltage	800 Vdc
Frequency	50 Hz or 60 Hz
Response Time	<1 second
Rotor Material	Steel
Dimensions	52" x 54" (h x diameter)
Installation	Above/Below Grade
Weight (estimate)	9,800 lbs

VENDORS

This report intentionally does not identify the manufacturer of the FES System that was evaluated for anonymity purposes, but some FES System vendors are listed below, alphabetically:

- Active Power
- Amber Kinetics
- Beacon Power
- Energiestro
- Kinetech Power Systems
- PowerThru
- Vycon Inc

ASSESSMENT OBJECTIVES

This project is an emerging technologies assessment that provides analysis of the load shifting potential for FES systems. Specifically, the assessment objectives are:

- Using the manufacturer's data monitoring systems, monitor various FES metrics throughout the testing procedures, including rotational speed and energy usage.
- Confirm maximum energy capacity.
- Confirm maximum Charge/Discharge rates.
- Confirm manufacturer efficiency claims.
- Calculate cost savings associated with load shifting based on SDG&E's AL-TOU Secondary rate.
- Determine flywheel ancillary services potential.
- Conduct a Life Cycle Cost Analysis.

TECHNOLOGY/PRODUCT EVALUATION

This emerging technology evaluation project studied a particular Flywheel Energy Storage system. The FES System is a 25 kWh-capacity flywheel utilizing a steel rotor, low-loss bearings and a high-vacuum, sealed enclosure. The evaluation was conducted at the manufacturer's testing facility in Alameda California, as this was determined to be the most cost-effective location to complete the study. The FES system evaluated in this study was not associated with an actual facility's day to day operation, and as such, this analysis should be considered to be a laboratory evaluation performed in the field. A laboratory evaluation was deemed sufficient as the FES system would have little to no interactive effects with a facility's other energy uses. As a result, the FES performance can be monitored independent of an energy-using facility. This evaluation was designed to look at the load-shifting opportunities that may be made feasible using this technology.

ASWB Engineering was selected to perform this assessment by SDG&E. ASWB has performed multiple Emerging Technology Assessments for various utilities in the past, and has extensive experience planning and implementing Measurement and Verification projects.

TECHNICAL APPROACH/TEST METHODOLOGY

TESTING OF TECHNOLOGY

SDG&E proposed verifications for this technology to monitor and evaluate the storage capabilities of the FES system. The verifications were conducted at the manufacturer's testing facility in Alameda, California. Two of the manufacturer's flywheels are located at this testing facility, however only one flywheel was utilized for the purposes of generating data for this study. This location was selected as the infrastructure required to conduct the study was already in place. Existing manufacturer owned data monitoring technology was utilized for this study.

TEST PLAN

Testing took place from December 13th,2016 to December 17th, 2016 using one of the two flywheels located at the testing facility. The following sequence of operations describes the testing procedure used for this study.

1. Charge FES unit to 100% SOC.
2. Discharge at maximum discharge power to 0% SOC.
3. Recharge to 100% SOC.
4. Discharge at 66% discharge power to achieve 0% SOC in 6 hours.
5. Recharge to 100% SOC.
6. Let the FES coast (without input power to overcome losses) at 100%, 75%, 50%, 25%, and 0% SOC levels for 30 minutes at each state of charge.
7. Recharge FES to 100% SOC.
8. Allow the FES to coast for 24 hours starting from 100% SOC.

(The following steps were performed to evaluate frequency regulation applications)

9. Discharge the FES to 50% SOC.
10. Vary the discharge between 75% and 25% power every 60 seconds for 10 minutes.
11. Vary the discharge between 75% and 25% power every 15 seconds for 10 minutes.
12. Vary the discharge between 75% and 25% power every 4 seconds for 40 minutes.

Demand response capabilities were tested by association, as having the FES discharge over a period of 6 hours demonstrates the ability to provide a supplemental capacity or DR equivalent in a demand response event.

INSTRUMENTATION PLAN

It was determined that the existing manufacturer owned monitoring equipment would be utilized for the analysis of this study, as implementing third party verification equipment would be redundant and expensive and would not be able to capture all of the data necessary. Existing instrumentation provided the data, and chain-of-custody procedures were used to ensure data integrity. All measurements came from the flywheel unit's onboard instrumentation. The manufacturer claims accuracy within 1%, and sampling has been used in the past to verify this.

RESULTS

DATA PROCESSING

The data was recorded every quarter (0.25) second and converted to spreadsheet format. Data from each of the five tests performed were stored separate data files. The technique used by ASWB involved using a pivot table to convert the quarter second data into average one-minute data for every test except for the Ancillary Services test. Since the other four tests spent relatively long periods of time in charging, discharging, maintaining, and coasting operational modes at consistent power levels, quarter second data granularity was not necessary. By converting to average minute data, the data files were shrunk to 1/240th of the original size, allowing for all four tests to be analyzed in the same spreadsheet workbook.

The data for the ancillary services test was not converted to average minute data, because a portion of this test called for varying power levels every 4 seconds. As such, the data was left in quarter second format to retain the granularity required for observation.

Per the manufacturer's sign convention in the data file received, positively signed power measurements represent increasing the FES System speed (Charging) while negatively signed power measurements represent decreasing the FES System speed (Discharging).

It is important to note that all power, energy and efficiency measurements below were taken at the DC bus. This allows evaluation of the FES system to be agnostic to the grid inverter, which may vary in performance according to customer needs and preferences.

Station power, which is the power associated with the off loader magnet, motor field winding, and controls, was not included in these tests. The station power is not included in the efficiency analysis, because each customer or site may handle it differently. Disaggregating allows the possibility for separate metering and a different rate schedule to be applied. For this reason, station power was excluded from the performance tests and efficiency calculations. However, the station power was included in the financial analysis.

Another clarification should be made on the difference between SOC and mechanical energy. The SOC was how the level of charge was tracked during these tests, however the mechanical energy was what was used to calculate efficiencies. The SOC and mechanical energy are fairly similar. The mechanical energy is a measure of the stored kinetic energy in the spinning rotor relative to the minimum operating speed, while the SOC is an attempt at indicating to the user how much energy is actually available for discharge. By multiplying the mechanical energy by the discharge efficiency, the result is the SOC. Thus, the mechanical energy will always be higher than the SOC. For the purposes of these tests, the SOC was provided as a data field, while the mechanical energy was calculated based on the frequencies and moment of inertia of the spinning rotor.

TESTING

TEST 1: FOUR HOUR DISCHARGE

The Four Hour Discharge test was designed to observe the FES System charge and discharge at the maximum power of 6.25 kW. Due to the fact that the FES System is designed to store 25 kWh, it would take 4 hours at 6.25 kW to fully charge or discharge assuming no losses. The FES System operator was instructed to charge the flywheel from minimum to maximum speed, maintain the maximum speed for four or more hours in order to evaluate the effect of system losses, and then to discharge back down to the minimum speed. Both the charging and discharging was done at the maximum rate for this test.

The table below shows the results from the Four Hour Discharge Test.

TABLE 5. FOUR HOUR DISCHARGE TEST SUMMARY

FES System Mode	Duration (h)	Avg Power (W)	Change in Electrical Energy (kWh)	Change in Mechanical Energy (kWh)	Efficiency (SOC/Energy)
Charging	4.87	6,249.58	30.42	28.54	93.83%
Maintaining	4.77	244.95	1.17	0.00	N/A
Discharging	4.23	-6,249.99	-26.46	-28.49	92.87%

The charging and discharging modes of operation each took longer than 4 hours to complete. This is due to two main factors: The first and most obvious is that the Net State of Charge (SOC at end of operation – SOC at beginning of operation) was actually 26.25 kWh (or 28.54 kWh in mechanical energy) compared to the 25 kWh maximum originally quoted. Extra margin beyond 25 kWh was added to account for efficiency, so the system can always provide 4 hours of discharge. The second factor is system losses, which explains why it took longer to charge the FES system than it did to discharge.

The figure below presents the concurrent graph of the Mechanical Energy and RPM of the FES System throughout the Four Hour Discharge Test.

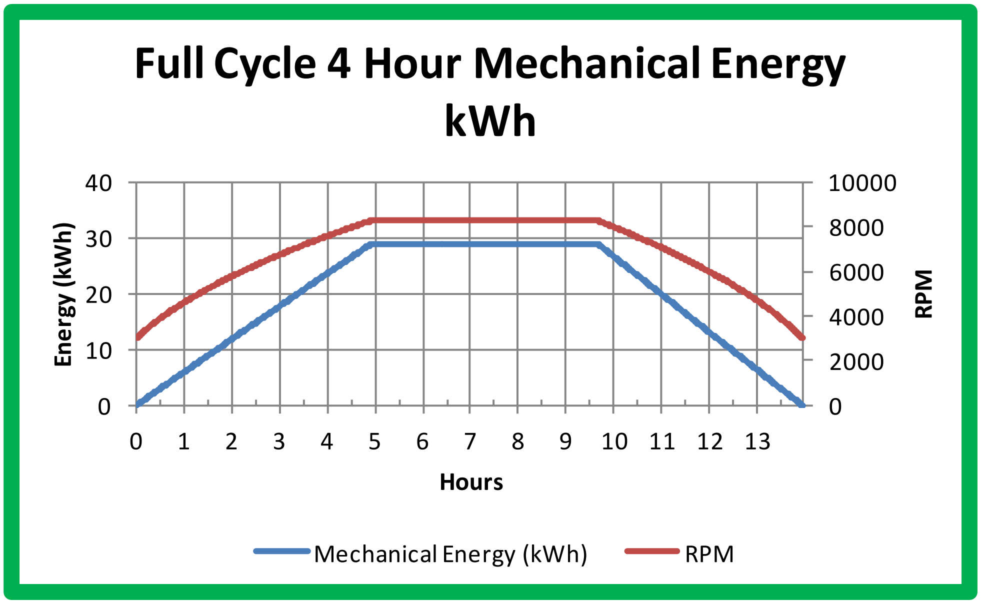

FIGURE 3. – FULL CYCLE 4 HOUR STATE OF CHARGE

Figure 4 represents the power (as measured at the DC bus) used to charge and discharge the FES during the Four Hour Discharge Test. Positively signed power represents charging, while negatively signed power represents discharging.

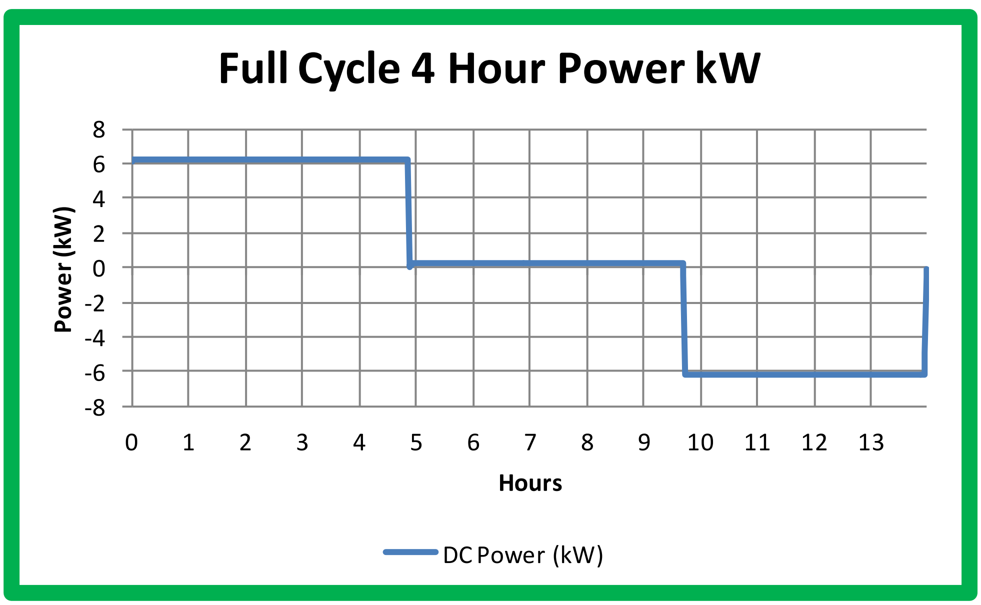

FIGURE 4. – FULL CYCLE 4 HOUR POWER KW

TEST 2: SIX HOUR DISCHARGE

The Six Hour Discharge test was designed to observe the FES System discharge at 4.00 kW rather than the maximum power of 6.25 kW. By discharging at a lower power level, the time required to discharge the FES System is greater. This is useful because in a real world application, there may be times where a facility needs to pull energy from an FES system or systems for periods longer than 4 hours (Power outages, DR events, etc.). The FES System operator was instructed to charge the flywheel from minimum to maximum speed at full power and then discharge back down to the minimum speed at a lower discharge rate with a goal of at least a 6 hour discharge process. Because the Four Hour Discharge Test already maintained the FES System at full speed, that step was not repeated in length for this test.

The table below shows the results from the Six Hour Discharge Test, as measured at the DC bus.

TABLE 6. SIX HOUR DISCHARGE TEST SUMMARY

FES SYSTEM MODE	DURATION (H)	AVG POWER (W)	CHANGE IN ELECTRICAL ENERGY (KWH)	CHANGE IN MECHANICAL ENERGY (KWH)	EFFICIENCY (SOC/ENERGY)
Charging	4.87	6,249.49	30.42	28.55	93.87%
Maintaining (max speed)	0.07	241.82	0.02	0.00	NA
Discharging	6.62	-3,999.80	-26.47	-28.65	92.39%
Maintaining (min speed)	0.03	173.89	0.01	0.00	NA

The rate of discharge for the Six Hour Discharge Test on average rounds from 3.999 kW to 4 kW. This means that the FES System was able to deliver 4 kW of power for 6.62 hours, as opposed to the Four Hour Discharge Test where the FES System delivered 6.25 kW for 4.23 hours. Different discharge rates can be utilized depending on the situation.

While the Charging efficiencies and durations were approximately the same in both tests, the Six Hour Discharge Test efficiency was decreased by nearly half a percentage point when compared to the Four Hour Discharge Test (92.39% vs 92.87%). This suggests a lower discharge rate is slightly less efficient, as the longer discharge period is prone to more system losses.

It is also interesting to note that, while not left in this condition for long, the Six Hour Test data file included a period of time where the FES System was maintained at its minimum speed. As seen in the table above, it took approximately 174 W to keep the FES System spinning at the lowest speed, compared to the 240-245 W required to keep the FES System at maximum speed.

The figure below presents the concurrent graph of the Mechanical Energy and RPM of the FES System throughout the Six Hour Discharge Test.

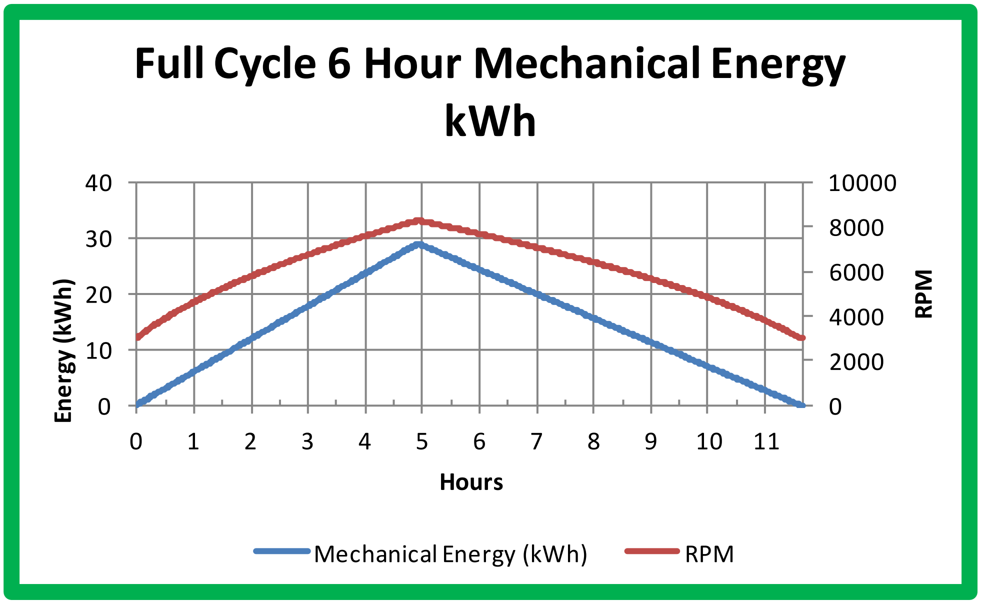

FIGURE 5. – FULL CYCLE 6 HOUR STATE OF CHARGE KWH

The figure below represents the power used to charge and discharge the FES during the Six Hour Discharge Test. Positively signed power represents charging, while negatively signed power represents discharging.

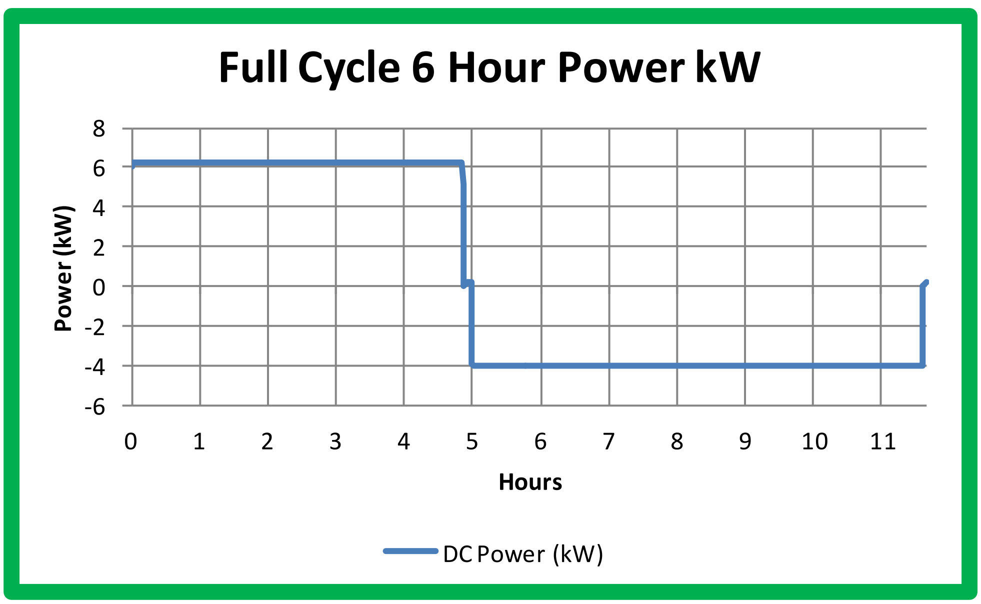

FIGURE 6. – FULL CYCLE 6 HOUR POWER KW

TEST 3: 24 HOUR COAST LOSS

The 24 Hour Coast Loss Test was designed to determine the losses of the FES System from maximum speed when not providing additional power to maintain speed. The operator was instructed to charge the FES System to maximum speed, and then cut power to the FES System, allowing it to continue spinning unaided for 24 hours. The data file starts the moment that the power is cut to the FES System.

TABLE 7. 24 HOUR COAST LOSS TEST SUMMARY

FES System Mode	Duration (h)	Initial Mechanical Energy kWh	Final Mechanical Energy kWh	Net Mechanical Energy kWh	% Loss
Coasting	24	28.72	26.61	-2.11	7.4%

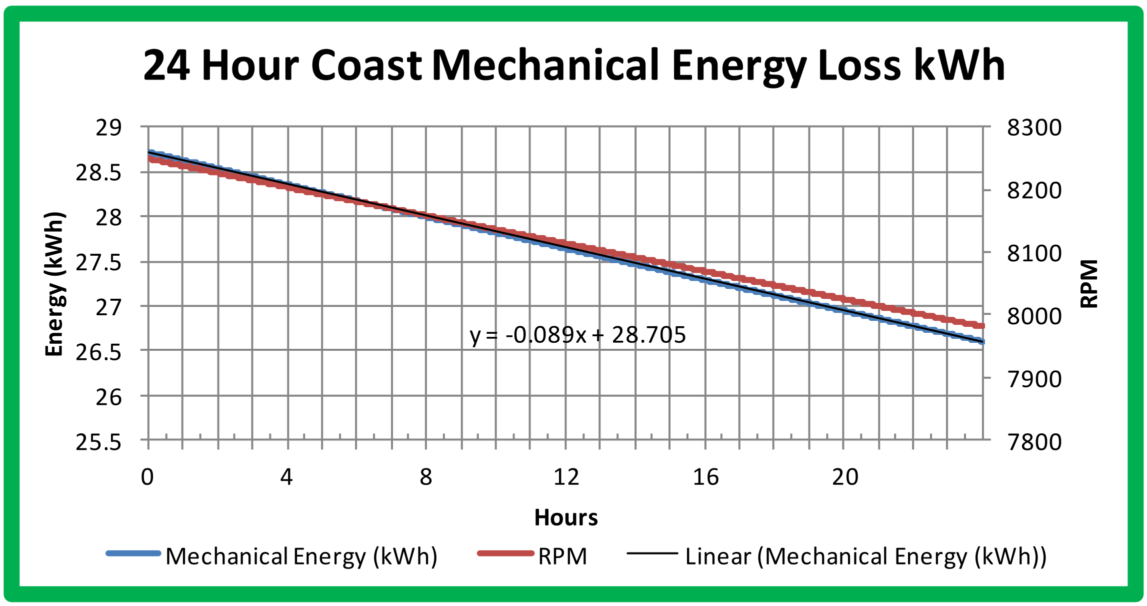

FIGURE 7. – 24 HOUR COAST STATE OF CHARGE LOSS KWH

In the Four Hour Discharge Test, it was determined that it takes on average, 245.95 W to maintain the FES System at maximum speed. If this were maintained for 24 hours, it would use 5.88 kWh. The 2.11 kWh loss over the 24 hour period is significantly less than the 5.88 kWh consumed to keep the FES System running at max speed, because the inverter is no longer running at a low-efficiency operating point. This information could be useful when determining the optimal FES System strategy for a facility, for example by maintaining speed with a duty-cycling rather than trickle-charging approach.

TEST 4: COASTING LOSSES AT VARIOUS STATES OF CHARGE

In the Coasting Losses at Various States of Charge Test, the idea of coasting losses explored in the 24 Hour Coast Loss Test was further expanded to identify the magnitude of losses at different SOC levels (and therefore different speeds). The operator was instructed to fully charge the FES System, and then allow the system to coast for 30 minutes. Once 30 minutes of coasting at 100% SOC was complete, the system then discharged to 75% SOC and coasted for another 30 minutes. This was done for 100%, 75%, 50%, 25%, and 0% SOC levels. The results from this test are shown in the following table.

TABLE 8. COASTING LOSSES AT VARIOUS STATES OF CHARGE TEST SUMMARY

FES SYSTEM MODE	DURATION (H)	NET MECH. ENERGY KWH	ENERGY LOSS PER HOUR (KWH/H)	LOSS % OF TOTAL CAPACITY
Coast from 100% SOC	0.50	-0.045	0.090	-0.31
Coast from 75% SOC	0.50	-0.038	0.077	-0.27
Coast from 50% SOC	0.48	-0.029	0.060	-0.21
Coast from 25% SOC	0.52	-0.022	0.044	-0.15
Coast from 0% SOC	0.50	-0.012	0.024	-0.09

The coasting losses were normalized by dividing by the duration of each coast test in hours, resulting in the "kWh loss per hour" column. The kWh losses per hour at various states of charge are shown in the figure below. The unit of kWh per hour can also be expressed simply as power (kW), but leaving it as kWh per hour better describes the methodology behind the process of calculating the loss.

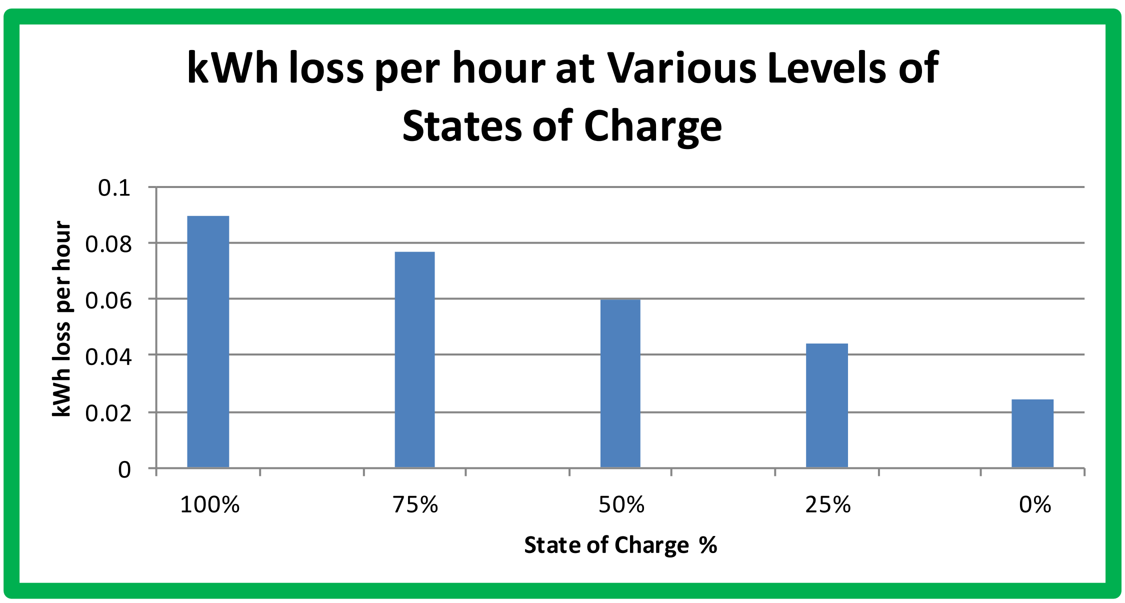

FIGURE 8. – KWH LOSS PER HOUR AT VARIOUS STATES OF CHARGE

As expected, the losses coasting losses diminish at lower SOC levels. As the RPM decreases, so does the air resistance and bearing friction that the FES System must overcome.

The Coasting Losses at Various States of Charge test is shown graphically in the following two figures. These figures include the charging and discharging necessary to achieve coasting tests at the various states of charge, even though they were excluded from the previous table.

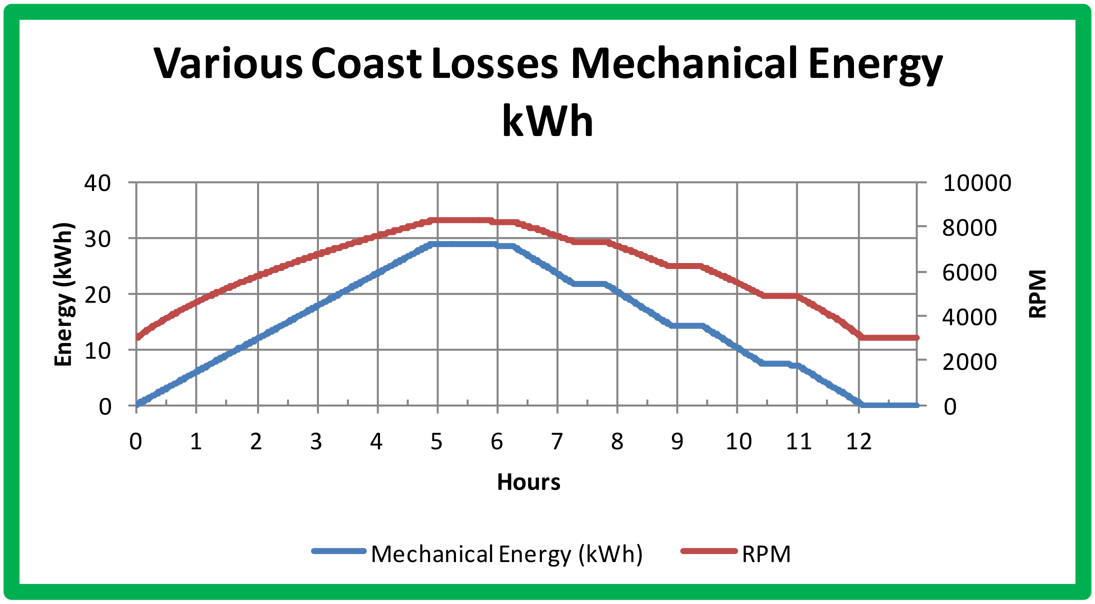

FIGURE 9. – VARIOUS COAST LOSSES STATE OF CHARGE KWH

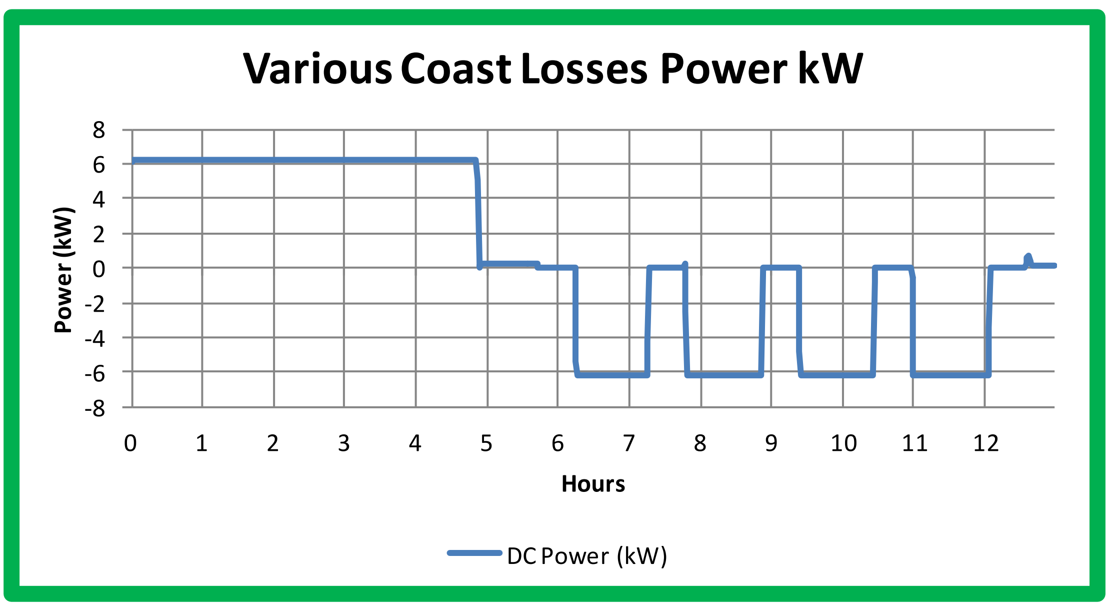

FIGURE 10. – VARIOUS COAST LOSSES POWER KW

Test 5: Ancillary Services

Ancillary Services are defined as those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. Examples of Ancillary Services include scheduling and dispatch, reactive power and voltage control, frequency control, and operating reserves.

The Ancillary Services test was designed to vary the discharge rate of the FES System between two power levels over set periods of transition time. This test is to simulate response time for load following, as well as regulation of voltage and frequency. Load following is the ability to compensate for either too much or too little grid capacity compared to the projected load within a few minutes notice. Grid frequency and voltage are required to stay within a specific range of the nominal values, and being able to vary the power level output within a certain time period will allow the FES Systems to modulate as necessary to keep the frequency and voltage within the desired range (four seconds is a common response time).

The test was conducted starting at approximately 50% SOC. The first portion of the test involved alternating the discharge rate between 75% and 25% of max power every 60 seconds. The second portion of the test involved the same power variation occurring every 15 seconds. The third and final portion of the test shortened that charge-discharge transition to 4 seconds. The three portions of this test are plotted below. Note how the system RPM decreases in a jagged slope as the discharge rate alternates between two values.

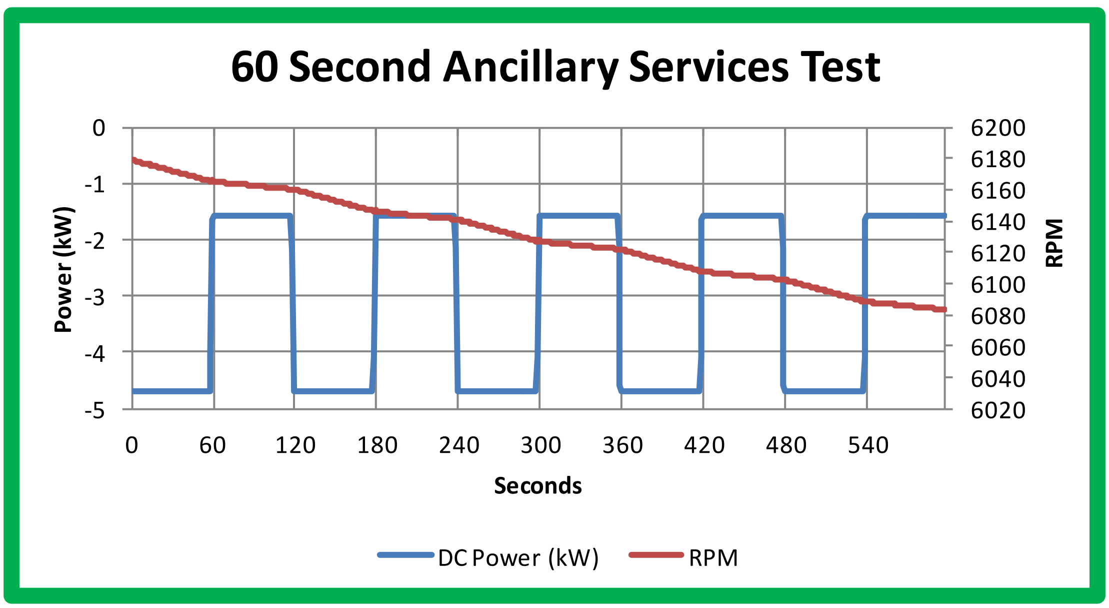

Figure 11. – 60 Second Ancillary Services Test

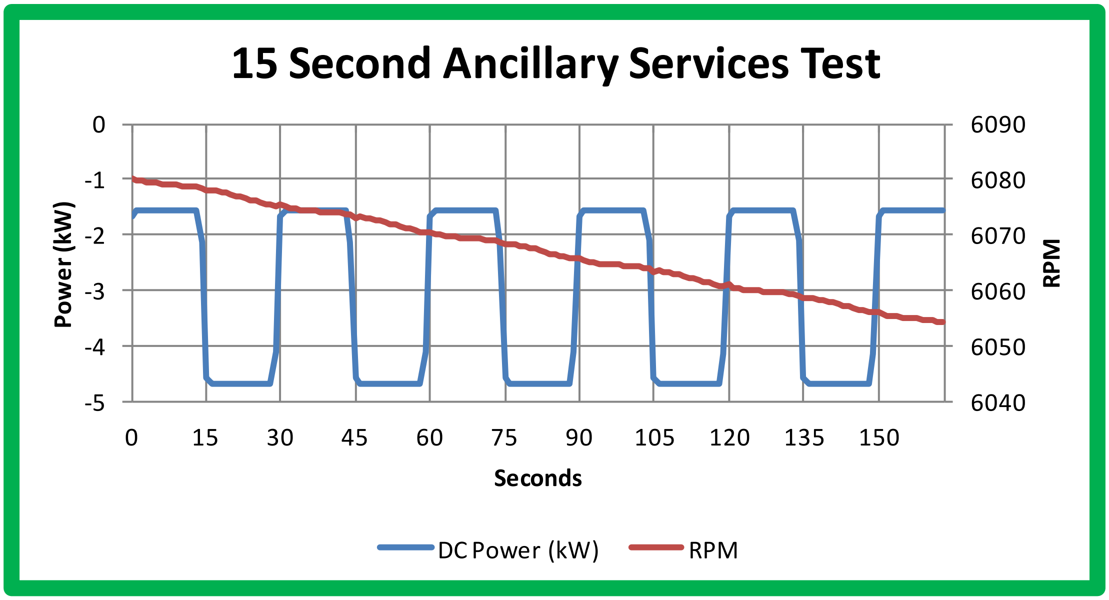

FIGURE 12. – 15 SECOND ANCILLARY SERVICES TEST

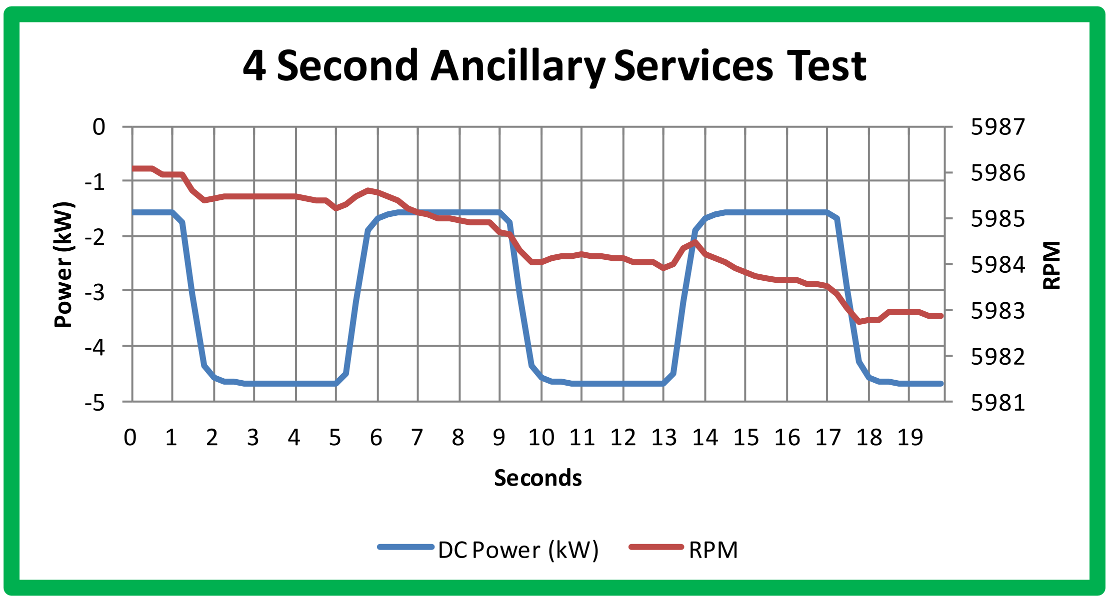

FIGURE 13. – 4 SECOND ANCILLARY SERVICES TEST

FINANCIAL ANALYSIS

ASSUMPTIONS AND METHODOLOGY

In order to provide financial analysis for this FES System, an installation scenario with actual tariff rates was needed. The assumed installation was a 500 kW, 2 MWh FES bank consisting of 80 FES systems of 6.25 kW, 25 kWh capacity each to accurately reflect a "real world" scenario. Estimated costs for this installation scenario were provided by the manufacturer as follows:

Flywheel (DC):	$350/kWh
PCS Inverter:	$60/kWh
Installation:	$40/kWh
Total:	$450/kWh

With an installed cost of $450/kWh, the total pre-incentive cost of the assumed installation is $900,000.

Estimated maintenance costs were provided by the manufacturer at $348 per flywheel for parts, and $320 per flywheel for labor, for a total of $668 per flywheel. These maintenance costs are expected to be incurred every 10 years.

The tariff used for analysis was SDG&E's AL-TOU Secondary rate. AL-TOU Secondary is a Time Of Use rate, which has Summer and Winter rates for three different time periods: On-Peak, Semi-Peak, and Off-Peak.

	Summer – May 1 – October 31	Winter – All Other
On-Peak	11 a.m. - 6 p.m. Weekdays	5 p.m. - 8 p.m. Weekdays
Semi-Peak	6 a.m. - 11 a.m. Weekdays	6 a.m. - 5 p.m. Weekdays
	6 p.m. - 10 p.m. Weekdays	8 p.m. - 10 p.m. Weekdays
Off-Peak	10 p.m. - 6 a.m. Weekdays	10 p.m. - 6 a.m. Weekdays
	Plus Weekends & Holidays	Plus Weekends & Holidays

More information can be found about this rate in Appendix C of this report.

Annual cost savings were determined through spreadsheet-based calculations, starting with an 8,760 hour annual profile. 2017 was the calendar year used. Based on the definitions of the AL-TOU Secondary rate, each of the 8,760 hours was classified as either Summer On-Peak, Summer Semi-Peak, Summer Off-Peak, Winter On-Peak, Winter Semi-Peak, or Winter Off-Peak. By using these classifications, the $/kWh rate could be determined for each of the 8,760 hours of the year.

After the applicable rate for each hour was determined, the next step determined what mode of operation the FES System would be in for each hour of the year. Four different daily profiles were created: Summer Weekday, Summer Weekend/Holiday, Winter Weekday, and Winter Weekend/Holiday. This allowed for the FES System to be evaluated with optimized behavior for the four different types of days that occur under the AL-TOU Secondary rate. The FES Systems were modeled to charge in the Off-Peak periods for 4.62 hours (the time required to fully charge), to maintain maximum speed through the Semi-Peak period, and then discharge through the entire On-Peak period. The FES system was then modeled to maintain minimum speed until charging was called for again. For both Weekend and Holiday profiles, the FES systems were modeled at minimum speed operation for the entire 24 hour profile.

Scenarios Analyzed

The Summer On-Peak period for the modeled tariff lasts for 7 hours; however the maximum discharge power of 6.25 kW depletes the 25 kWh storage capacity of the FES system in only 4 hours. Because of this, two different scenarios were employed.

Scenario A: To make sure the discharge occurred throughout the entire On-Peak period, the discharge rate was multiplied by a factor of 4/7 and applied to all 7 On-Peak hours. This did not occur in the Winter On-Peak, as the Winter On-Peak is only 3 hours long. The full discharge power was used in the winter, and the fourth hour covered a Winter Semi-Peak hour. This is a conservative scenario that minimizes the risk of setting new peak demands.

Scenario B: The discharge period occurred for only 4 of the 7 hours in the summer On-Peak period. This reduced energy savings, but greatly increased demand savings. The greater demand savings also increase the PLS incentive. However, this scenario is risky, because by only covering 4 of the 7 hours, there is a greater possibility of setting a new demand peak during the 3 hours of On-Peak that does NOT receive assistance from the FES System.

Refer to the Summer and Winter Operation schedules in Appendix B for Scenarios A and B.

Station Power, Scaling, and Grid Inverter Efficiency

Station power was defined earlier in this report as the power for the off loader magnet, motor field winding, and controls of the FES System. The station power was kept separate from the DC bus power for the FES in the previous tests, as each customer or site may handle the station power differently. Disaggregating allows separate metering and the possibility of a different rate schedule to be applied, for example. As such, station power was excluded from the FES System operation tests as well as the efficiency calculations.

However, the station power does need to be included in the financial analysis. The station power was added together with the DC bus power to calculate the total power of the FES System. For the purposes of this analysis, the two different power readings were aggregated and analyzed on the same meter. This affects the power levels for the different FES System operations that were observed in the tests. The following table shows the effects of including station power.

TABLE 9. EFFECTS OF INCLUDING STATION POWER

FES SYSTEM MODE	AVERAGE DC POWER (KW)	AVERAGE STATION POWER (KW)	TOTAL AVERAGE POWER (KW)
Maintain 0% SOC	0.170	0.165	0.335
Maintain 100% SOC	0.245	0.062	0.307
Charge at Full Power	6.250	0.084	6.333
Discharge at Full Power	-6.250	0.084	-6.166

An interesting result of including station power is that it now takes more power to maintain the minimum speed than it does to maintain the maximum speed. This is because station power includes the motor field winding, which requires more power at lower speeds.

In order to replicate a 500 kW FES System, 80 units would be required. However, simply multiplying the values by a factor of 80 would not be enough, as there is a grid inverter requirement for a 500 kW system. This inverter efficiency was provided by the manufacturer as 98.2% max and 97.5% CEC. The average between the two efficiencies was applied to power values after scaling them with the factor of 80.

ANNUAL COST SAVINGS AND INCENTIVES

Total average power measurements (shown in previous table) for each mode of operation were acquired from the test data, and were then multiplied by 80 (to represent 80 FES units), and the inverter efficiency, to replicate a 500 kW FES system. The resultant power values were multiplied by the hourly $/kWh rates (based on the mode of operation) for each hour of the year in order to determine the energy cost savings for that particular hour. These hourly results were summed to obtain an increase in the Annual Energy Cost of $7,998 for Scenario A and $9,199 for Scenario B.

Demand savings were determined monthly. The discharge rate of the 80-unit FES System was taken to be the demand savings for that month, using an ideal hypothetical load profile. The discharge rates were different for summer and winter operation due to the durations of their On-Peak periods. Multiplying the demand savings by the On-Peak demand charge for each month and summing the values for the year yielded an Annual Demand Cost Savings of $52,503 for Scenario A and $76,655 for Scenario B.

By combining the increase in annual energy cost with the decrease in annual demand cost, a total annual cost savings of $44,506 is yielded for Scenario A, and $67,456 for Scenario B.

Two incentive programs were considered for this project: Permanent Load Shifting (PLS) and Self-Generation Incentive Program (SGIP). The PLS program uses an incentive rate of $875 per kW, while the SGIP incentive rate is $1.31 per Watt. While the PLS program currently only applies to Thermal Energy Storage (TES), this analysis assumes adoption of FES Systems into the program. The PLS incentive varies between Scenario A and Scenario B, as Scenario A does not reduce the demand as much as Scenario B. However, the SGIP incentive is based on the power capacity of the technology for a minimum 2 hour period, so the full incentive is available for both Scenario A and Scenario B. SGIP also includes a 20% bonus incentive for California based technology (Refer to SGIP handbook for further details). The PLS program results in an incentive of $241,328 for Scenario A and $422,325 for Scenario B. The SGIP rate results in an incentive of $758,736 for both scenarios. This project may qualify for On Bill Financing (OBF) with the SGIP incentive. Refer to Appendix A for more information on PLS, SGIP, and OBF.

Simple Payback Analysis

The following table demonstrates the simple payback analysis for Scenarios A and B, both with and without incentives.

Table 10. 500 kW FES System Simple Analysis

Scenario	Implementation Cost	Annual Energy Cost Savings	Annual Demand Cost Savings	Total Annual Cost Savings	Simple Payback (Years)
A - Without Incentive	$900,000	($7,998)	$52,503	$44,506	20.22
A - With PLS Incentive	$658,672	($7,998)	$52,503	$44,506	14.80
A - With SGIP Incentive	$141,264	($7,998)	$52,503	$44,506	3.17
B - Without Incentive	$900,000	($9,199)	$76,655	$67,456	13.34
B - With PLS Incentive	$477,676	($9,199)	$76,655	$67,456	7.08
B - With SGIP Incentive	$141,264	($9,199)	$76,655	$67,456	2.09

LIFE CYCLE COST (LCC) ANALYSIS

The following table demonstrates the LCC analysis for Scenarios A and B, both with and without incentives. This methodology assumes a 2% annual escalation rate on the electricity and demand charges of the AL-TOU secondary rate, as well as an assumed discount rate of 5%. A 30 year EUL was used. Maintenance costs were incurred in Years 10 and 20. First year implementation, energy, and demand cost savings are the same as presented in the Simple Payback Analysis table in the previous section.

TABLE 11. 500 KW FES SYSTEM LCC ANALYSIS

SCENARIO	NET PRESENT VALUE	PAYBACK (YEARS)	SAVINGS INVESTMENT RATIO	INTERNAL RATE OF RETURN	RETURN ON INVESTMENT
A - Without Incentive	($91,182)	18.01	-0.10	4%	-110%
A - With PLS Incentive	$150,147	14.02	0.28	7%	-77%
A - With SGIP Incentive	$667,554	3.11	4.73	33%	373%
B - Without Incentive	$556,791	12.57	0.62	8%	-38%
B - With PLS Incentive	$775,534	6.69	1.62	15%	62%
B - With SGIP Incentive	$1,111,946	2.07	7.87	49%	687%

DISCUSSION

The FES System behaved as expected for each of the tests performed. This speaks to the consistency, reliability, and simplicity of the technology. Unlike demand response or thermal storage technologies, the FES System operates independently from other potential facility loads such as lighting, HVAC, or process loads. Hence the FES System only needs to respond to the overall facility meter load profile. The load profile will determine when and for how long the FES system should discharge in order to mitigate the peak demand. Since the system in this evaluation was not connected to an actual facility, a hypothetical facility with a low load factor was assumed that would maximize the results obtained (Allowing the peak to be reduced by the full kW capacity of the FES System).

The factor that affects the FES System financial analysis most is the rate. Since this type of technology shifts rather than reduces the local load, the cost savings are mainly dependent on shifting load to take advantage of periods with low demand and low energy costs. The rate used, SDG&E's AL-TOU Secondary rate, for a 500 kW 2 MWh FES system (80 units), produced pre-incentive simple paybacks of 20 and 13 years for Scenarios A and B respectively. The payback becomes much more attractive when considering a PLS or SGIP incentive, as well as evaluating the full Life Cycle Cost Analysis of the product. The SGIP incentive is the most beneficial for this technology, resulting in a payback of 2 years for Scenario B LCCA. It should be noted that this is still an emerging technology, and the costs may be reduced as the technology improves. Other rates outside of SDG&E may result in more lucrative opportunities.

The above discussion's financial analysis focuses on the customer side of the meter. The manufacturer has expressed interest in selling on the utility side of the meter. The necessary metrics to evaluate utility side implementation were not provided, nor was it included in the scope of this report. However, utilizing this emerging technology on the supply side would provide the grid with more flexibility and load regulation opportunities.

CONCLUSIONS

The technology was able to perform as the manufacturer claimed. Based on the results of this study, the FES System is able to effectively convert between electric energy and kinetic energy while minimizing losses. This capability can be used for permanent load shifting, as well as potentially providing supplemental load during scheduled Demand Response (DR) events (assuming a PLS strategy is not already in effect, which would eliminate the DR baseline).

The cost savings, however, are heavily dependent on the facility's utility rate. As such, the cost-effectiveness of the emerging technology may vary by utility. The FES System under study appears to be more effective when applied to a TOU rate with higher demand charges and larger disparities between the cost of Off-Peak and On-Peak kilowatt-hours.

The SGIP incentive appears to be the most beneficial incentive for this technology (under the current 2016 SGIP handbook). Note that SGIP is planning to restructure its incentive program for 2017, and the changes could potentially be significant. More information on SGIP can be found at https://energycenter.org/program/self-generation-incentive-program.

RECOMMENDATIONS

Based on the results of this study, it is recommended that the FES System be adopted into the SGIP program. The assessment provides sufficient information to demonstrate the flexibility and capabilities of this technology.

APPENDIX

APPENDIX A: SDG&E CUSTOMER PROGRAMS

PERMANENT LOAD SHIFTING (PLS)

The SDG&E PLS program currently only applies to Thermal Energy Storage (TES) systems. However it is possible that FES systems could be adopted. SDG&E's Permanent Load Shifting program requires you to shift energy use for cooling during the summer peak hours to off-peak hours. The incentive is $875 per kW shifted. These incentives are open to all SDG&E customers. To be eligible you must:

- Be on a Time-of-Use (TOU) rate
- Have an SDG&E smart meter or an approved interval meter

For application instructions and additional information on the PLS Program, refer to http://www.sdge.com/business/demand-response/permanent-load-shifting

SELF-GENERATION INCENTIVE PROGRAM (SGIP)

The SDG&E SGIP offers financial incentives for the installation of clean and efficient energy technologies. If adopted into the program, FES Systems would be considered Advanced Energy Storage technology, and would qualify for a $1.31 per Watt incentive based on the 2016 Handbook. SGIP is currently reevaluating its incentive structure and this is expected to change in 2017. For application instructions and additional information on the SGIP Program, refer to

https://energycenter.org/self-generation-incentive-program

ON-BILL FINANCING

If the customer's SDG&E accounts is in good standing, has been active for the past two years, and has received a rebate or incentive through an SDG&E energy efficiency program, the customer is eligible for On-Bill Financing (OBF). OBF helps qualified commercial and government-funded customers pay for energy-efficiency business improvements through their SDG&E bill. Only equipment that qualifies for a rebate or incentive is eligible for OBF. Additionally, the loan must be at least $5,000 and have a simple payback of no more than 3 or 5 years depending on the installed equipment. The loan amount is the total project cost minus the rebate/incentive amount. For more information on the OBF program, refer to

http://www.sdge.com/business/bill-financing

APPENDIX B: FES SYSTEM OPERATION SCHEDULES

SCENARIO A:

	Summer Weekday		Summer Weekend/Holiday		Winter Weekday		Winter Weekend/Holiday	
Hour	Rate	State	Rate	State	Rate	State	Rate	State
1	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min
2	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
3	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
4	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
5	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
6	S-Off	Partial Charge	S-Off	Min	W-Off	Partial Charge	W-Off	Min
7	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
8	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
9	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
10	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
11	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
12	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
13	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
14	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
15	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
16	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
17	S-On	S-Discharge	S-Off	Min	W-Semi	W-Discharge	W-Off	Min
18	S-On	S-Discharge	S-Off	Min	W-On	W-Discharge	W-Off	Min
19	S-Semi	Min	S-Off	Min	W-On	W-Discharge	W-Off	Min
20	S-Semi	Min	S-Off	Min	W-On	W-Discharge	W-Off	Min
21	S-Semi	Min	S-Off	Min	W-Semi	Min	W-Off	Min
22	S-Semi	Min	S-Off	Min	W-Semi	Min	W-Off	Min
23	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min
0	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min

Legend:

Max – Maintain at maximum speed: 307.1 W

Min – Maintain at minimum speed: 335.0 W

Charge – Charge at maximum power: 6.33 kW

Partial Charge: 4.04 kW (This was used to recreate the extra .62 of the 4.62 hour charge time.)

S-Discharge – Summer Discharge Rate: -3.52 kW

W-Discharge – Winter Discharge Rate: -6.16 kW

SCENARIO B:

Hour	Summer Weekday		Summer Weekend/Holiday		Winter Weekday		Winter Weekend/Holiday	
	Rate	State	Rate	State	Rate	State	Rate	State
1	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min
2	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
3	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
4	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
5	S-Off	Charge	S-Off	Min	W-Off	Charge	W-Off	Min
6	S-Off	Partial Charge	S-Off	Min	W-Off	Partial Charge	W-Off	Min
7	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
8	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
9	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
10	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
11	S-Semi	Max	S-Off	Min	W-Semi	Max	W-Off	Min
12	S-On	Max	S-Off	Min	W-Semi	Max	W-Off	Min
13	S-On	Max	S-Off	Min	W-Semi	Max	W-Off	Min
14	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
15	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
16	S-On	S-Discharge	S-Off	Min	W-Semi	Max	W-Off	Min
17	S-On	S-Discharge	S-Off	Min	W-Semi	W-Discharge	W-Off	Min
18	S-On	Min	S-Off	Min	W-On	W-Discharge	W-Off	Min
19	S-Semi	Min	S-Off	Min	W-On	W-Discharge	W-Off	Min
20	S-Semi	Min	S-Off	Min	W-On	W-Discharge	W-Off	Min
21	S-Semi	Min	S-Off	Min	W-Semi	Min	W-Off	Min
22	S-Semi	Min	S-Off	Min	W-Semi	Min	W-Off	Min
23	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min
0	S-Off	Min	S-Off	Min	W-Off	Min	W-Off	Min

Legend:

Max – Maintain at maximum speed: 307.1 W

Min – Maintain at minimum speed: 335.0 W

Charge – Charge at maximum power: 6.33 kW

Partial Charge: 4.04 kW (This was used to recreate the extra .62 of the 4.62 hour charge time.)

S-Discharge – Summer Discharge Rate: -6.16 kW

W-Discharge – Winter Discharge Rate: -6.16 kW

APPENDIX C: SDG&E AL-TOU SECONDARY RATE INFORMATION

Customer Rate Information
Schedule AL-TOU Secondary

SDGE
A Sempra Energy utility

Applicability:

Applicable to all metered non-residential customers whose monthly maximum demand equals, exceeds, or is expected to equal or exceed 20 kW. This schedule is not applicable to residential customers, except for those three-phase residential customers taking service on this schedule as of April 12, 2007 who may remain on this schedule while service continues in their name at the same service address. Those three-phase residential customers remaining on this schedule who choose to switch to a residential rate schedule may not return to this schedule. This schedule is optionally
available to common use and metered non-residential customers whose Monthly Maximum Demand is less than 20 kW. Any customer whose Maximum Monthly Demand has fallen below 20 kW for three consecutive months may, at their option, elect to continue service under this schedule or be served under any other applicable schedule. This schedule is the utility's standard tariff for commercial and industrial customers with a Monthly Maximum Demand equaling or exceeding 20 kW.

Rates Effective 08/01/2016:

Customers who receive metered electric service after the voltage has been reduced from SDG&E's distribution level.

	Transm	Distr	PPP	ND	CTC	LGC	RS	TRAC	GHG	UDC Total
Basic Service Fee ($/Mth):										
0-500kW:	0.00	116.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**116.44**
>500 kW:	0.00	465.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**465.74**
Demand Charge ($/kW):										
Non-Coincident:	11.30	11.48	0.00	0.00	0.00	0.00	0.04	0.00	0.00	**22.82**
Summer On-Peak:	2.03	7.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**9.54**
Winter On-Peak:	0.61	6.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**7.01**
Energy Charge ($/kWh):										
Summer On-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**
Summer Semi-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**
Summer Off-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**
Winter On-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**
Winter Semi-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**
Winter Off-Peak:	(0.00951)	0.00279	0.01238	(0.00004)	0.00154	0.00031	0.00001	0.00000	0.00000	**0.00748**

Notes: Transmission Energy charges include the Transmission Revenue Balancing Account Adjustment (TRBAA) of $(0.00060) per kWh and the Transmission Access Charge Balancing Account Adjustment (TACBAA) of $(0.01359) per kWh. PPP rate is composed of: Low Income PPP rate (LI-PPP) $0.00709 /kWh, Non-low Income PPP rate (Non-LI-PPP) $0.00033 /kWh (pursuant to PU Code Section 399.8, the Non-LI-PPP rate may not exceed January 1, 2000 levels), and Procurement Energy Efficiency Surcharge Rate of $0.00477 /kWh.

Commodity Rates - EECC ($/kWh): (Eff. 01/01/2016)

Max demand Summer	**On-Peak kW:**	9.92				
Summer	**On-Peak:**	0.10738	**Semi-Peak:**	0.09850	**Off-Peak:**	0.07179
Max demand Winter	**On Peak kW:**	0.00				
Winter	**On-Peak:**	0.09849	**Semi-Peak:**	0.08403	**Off-Peak:**	0.06412

The Electric Energy Commodity Cost known as the EECC price that is passed through to customers who purchase their commodity from SDG&E is not included in the above UDC rates.

DWR Credit - $/kWh:	(0.00021)

Dept. of Water Resources Bond Charge (DWR-BC): (Eff. 08/01/2016)

Energy Rate - $/kWh:	0.00539

This schedule is applicable to all electric commodity customers, excluding customers receiving discounts under the California Alternate Rates for Energy (CARE) Program and customers receiving a medical baseline allowance.

Time Periods

All time periods listed are applicable to local time. The definition of time will be based upon the date service is rendered.

	Summer – May 1 – October 31	**Winter – All Other**
On-Peak	11 a.m. - 6 p.m. Weekdays	5 p.m. - 8 p.m. Weekdays
Semi-Peak	6 a.m. - 11 a.m. Weekdays	6 a.m. - 5 p.m. Weekdays
	6 p.m. - 10 p.m. Weekdays	8 p.m. - 10 p.m. Weekdays
Off-Peak	10 p.m. - 6 a.m. Weekdays	10 p.m. - 6 a.m. Weekdays
	Plus Weekends & Holidays	Plus Weekends & Holidays

APPENDIX D: MANUFACTURER SPECS

Storage Configuration	**6.25 kW | 25 kWh**		
Performance*		**Environmental**	
Max. Power	6.25 kW (min.)	Temperature (operating)	-40C to 50C
Energy	25 kWh	Temp. (storage & idle)	-40C to 60C
Discharge Duration	4 hours (min.)	Elect. Enclosure	NEMA 3
Efficiency	>88% (round trip, excludes Self Discharge)	Seismic Rating	Zone 4 USUBC
Calendar Design Life**	30 years	Humidity	100% Cond.
Daily Cycling Limitations	None		
GHG Emissions	None		
Electrical*			
Self Discharge	<65 W (average)		
Input/Output Voltage	800 Vdc (adjustable down to 700 Vdc)		
Response Time	< 1 second		
Mechanical			
Rotor Material	Steel		
Dimensions (housing)	52" x 54" (h x diameter) incl. Electronics Housings		
Installation	Above/Below grade		
System Weight	9,800 lbs		
Communications*	Set up to receive operator signal; or can be fully self-managed Monitoring Internet-based SCADA system (fully compliant with NERC standards)		
Applications	Ancillary Services Flex Capacity Renewable Firming Peak Shifting		