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Benefit Analysis of Energy Storage for Cordova Electric Cooperative

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Abstract

This report is a follow on to a previous study performed by Sandia National Labs and Alaska Center for Energy and Power which investigated the use of an energy storage system (ESS) providing spinning reserve within the Cordova Electric Cooperative (CEC) grid. The study provided the savings using the ESS as spinning reserve through reduced fossil fuel consumption and runtime on the diesel generators. In this report, the saving values are used from the previous study to determine the benefit-to-cost ratio for various ratings of ESS performing spinning reserve and quantifying other applications that are applicable to CEC.

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NOMENCLATURE

Abbreviation	Definition
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ACEP	Alaska Center for Energy and Power
CEC	Cordova Electric Cooperative
ES	Energy Storage
ESS	Energy Storage System
MW	Mega Watts
MWh	Mega Watt Hours
Sandia	Sandia National Labs

1. INTRODUCTION

The community of Cordova, Alaska currently uses diesel and run-of-river hydro generation for its electricity needs. In the past, 60% of Cordova's summer load was supplied by the run-of-river generation. When the run-of-river generation was not able to supply 100% of the load demand it was supplemented by diesel generation. This white paper explores the opportunity to apply an energy storage system (ESS) to support the existing generation while maintaining adequate levels of spinning reserve and frequency regulation when running solely on hydropower, and allowing the available diesel generators to operate more efficiently.

Frequency regulation during hydro-only operation is currently accomplished with a custom retrofit governor on both of the run-of-river power plants allowing either one to deflect a selected amount of potential generation and hold it in reserve. This has two effects detrimental to optimal operation. First, the hydropower generators' governor system is subject to excessive wear, as the core hardware was not designed for fast frequency regulation. Second, providing frequency regulation with this prime-generating asset requires curtailing 0.5 MW (17% of nameplate capacity) for spinning reserve. An energy storage system with inverters of suitable size and functionality could resolve both equipment wear and waste of hydropower capacity. Diesel generators at Cordova Electric Cooperative's (CEC) Orca Power Plant are scheduled and dispatched based on reliability measures empirically driven through past experiences. Operating the diesel generators in this manner is not optimal for fuel consumption. Energy storage can be used as a spinning reserve to allow generators to operate less frequently and at a more optimal set point reducing fuel consumption and maintenance cost.

In a previous study, Sandia National Labs (Sandia), Alaska Center for Energy and Power (ACEP) and CEC collaborated to determine the optimal size range for an ESS when applied as a spinning reserve and smoothing the ramp rate on the diesel and run-of-river. This document intends to build on this past work to further develop the case for energy storage (ES) utilized in this application. The results from that report are used in this report to determine the cost benefit analysis that is outlined in this document.

2. ENERGY BALANCE MODELING

To evaluate the potential savings from the deployment of energy storage, the Alaska Center for Energy and Power (ACEP) performed an energy balance model also known as a production cost modeling analysis using 2011 load data. During this study the production cost model performed multiple simulations varying the MW and MWh rating of an ESS performing spinning reserve capacity and ramp rate limiting on the diesel and run-of-river hydro generators. ESS performing spinning reserve capacity allowed for the 0.5MW capacity reserve of the run-of-river hydro generation to be used without switching on a diesel generation. The analysis identified the optimal energy storage dispatch for different storage configurations, and quantified the fuel savings for each scenario. Based on preliminary results, the range of energy storage configurations was limited to a 0.75-2.0 MW power rating and a 0.05-2.0 MWh energy rating. This range of power and energy ratings provided the greatest expected benefit to cost ratios. Data for the energy balance model such as load demand and generation production was provided by CEC for years 2011, 2012 and 2013. Due to time restrictions on the project and missing data from the other years, it was decided that the data from 2011 would be used for the production cost model.

After this initial analysis and the existing infrastructure only being adequate with no modification for a certain MW and MWh ESS, it was decided to perform more detailed energy balance simulations on an ESS no larger than 2 MW and 2 MWh. Saving results used in the benefit cost analysis from the simulations are shown below in Table 1 and Table 2.

Table 1 - 2011 annual diesel fuel reduction (% gallons) as a function of energy storage power (MW) and energy (MWh) rating

	0.05 MWh	0.10 MWh	0.25 MWh	0.50 MWh	0.75 MWh	1.00 MWh	1.50 MWh	2.00 MWh
0.75 MW	12.79%	14.03%	14.52%	14.65%				
1.00 MW	12.80%	15.26%	15.74%	15.84%	15.95%	16.00%	16.08%	16.15%
1.50 MW	12.77%	15.39%	15.86%	15.96%	16.14%	16.25%	16.35%	16.46%
2.00 MW						16.30%	16.50%	16.66%

Table 2 – 2011 annual diesel fuel reduction (% MWh) as a function of energy storage power (MW) and energy (MWh) rating

	0.05 MWh	0.10 MWh	0.25 MWh	0.50 MWh	0.75 MWh	1.00 MWh	1.50 MWh	2.00 MWh
0.75 MW	7.67%	8.59%	9.01%	9.12%				
1.00 MW	7.68%	9.58%	10.21%	10.30%	10.38%	10.42%	10.49%	10.56%
1.50 MW	7.67%	9.68%	10.29%	10.46%	10.61%	10.73%	10.91%	11.05%
2.00 MW							11.07%	11.24%

The tables above show that as the power (MW) and energy (MWh) rating of the energy storage system is increased, the absolute reduction in diesel continues to increase. It should be noted that the marginal reduction in annual diesel consumption decreases with increased energy and power rating. This is illustrated in Figure 1.

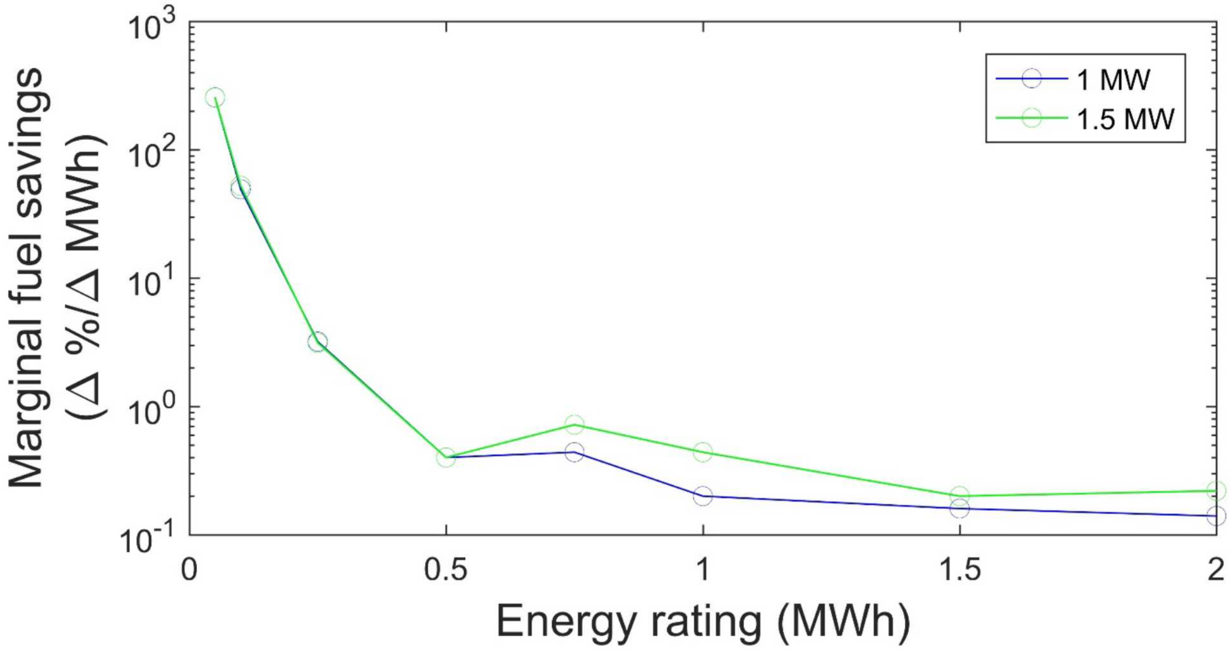

Figure 1 - Marginal fuel savings as a function of energy storage power (MW) and energy (MWh) ratings

The gray boxes in the tables represent energy storage configurations that were not analyzed. To determine which ESS rating provided the most benefit, yearly cost data from CEC was gathered for 2011 through 2016 and applied to the tables above. Assumption was made that the percent savings from year 2011 above would be the same each year from 2012 to 2016. Due to the sensitivity of cost data, only the results will be shown. The cumulative avoided costs for years 2011 through 2016 were calculated using the equation below.

$$AVC(MW,MWh) = \sum_{i=2011}^{2016} \frac{\left(G_i * G\%_{2011,MW,MWh}\right) * D_i + \left(R_i * R\%_{2011,MW,MWh}\right) * \left(\frac{OM_i}{R_i}\right)}{(1 + Rate_i)^{(2011-i+1)} * (1 + Inf_i)^{(2011-i+1)}}$$

Where:

AVC(MW,MWh)	Cumulative avoided cost from year 2011 to 2016 based on a certain ESS MW and MWh rating
i	Year in which cost data is used
G_i	Diesel fuel consumption for the i^{th} year with no ESS, (gallons)
$G\%_{2011,MW.MWh}$	Percent reduction for gallons for year 2011 using an ESS with a certain MW and MWh rating
D_i	Cost of diesel fuel for CEC for the i^{th} year, ($/gallon)
R_i	Energy produced by the diesel generators for year i^{th} with no ESS, (MWh)
$R\%_{2011,MW,MWh}$	Percent reduction for energy produced for year 2011 using an ESS with a certain MW and MWh rating
OM_i	Maintenance expense for running the generator for the i^{th} year, ($)
$Rate_i$	Discount rate based on i^{th} year [1]
Inf_i	Inflation rate based on past and future values [1] [2]

Table 3 shows the calculated avoided costs over the 6 years with a certain MW and MWh ESS rating. As the ESS MW and MWh rating is increased, the avoided cost is also increased.

Table 3 - Avoided cost savings over 6 years based on ESS MW and MWh ratings

	0.05 MWh	0.10 MWh	0.250 MWh	0.50 MWh	0.75 MWh	1.00 MWh	1.50 MWh	2.00 MWh
0.75 MW	$ 1.64	$ 1.81	$ 1.87	$ 1.89				
1.00 MW	$ 1.64	$ 1.97	$ 2.05	$ 2.06	$ 2.07	$ 2.08	$ 2.09	$ 2.10
1.50 MW	$ 1.64	$ 1.99	$ 2.06	$ 2.08	$ 2.10	$ 2.12	$ 2.14	$ 2.15
2.00 MW						$ 2.13	$ 2.16	$ 2.18
* *VALUES ARE IN $M*								

3. BENEFIT-TO-COST

The cost of an energy storage system varies based on the MW and MWh rating as well as the technology. Avoidance cost savings above are based on the ESS performing spinning reserve capacity which is a power technology application. Li ion systems are the most widely used technology for power applications. Energy storage installation costs vary by location. For this analysis, the installation costs are assumed to be: $250,000/MW and $817,500/MWh. The $/MW price was derived from working with multiple Li-Ion manufacturers for the installed cost of the power condition equipment for an energy storage system. The $/MWh price was derived from the Lazard report [3] using the cost from a Li-ion ESS installed within an island system. Typical lifecycle and warranty of an installed system is 12 years. The benefit-to-cost ratio analyzed in this report was based upon a 2011 installation. Avoidance cost saving presented in Table 3 are from 2011-2016. The next 6 years of projected cost avoidance savings were based on the average of the cost avoidance savings from 2011-2016. The table below shows the benefit-to-cost ratio for various configurations. The benefit is the avoided costs by installing an energy storage system and the cost is the purchase price of the system based on the power and energy rating.

Table 4 - Benefit-to-cost ratio for Li-ion ESS for 12 years using average avoided cost savings

	0.05 MWh	0.1 MWh	0.25 MWh	0.5 MWh	0.75 MWh	1.0 MWh	1.5 MWh	2.0 MWh
0.75 MW	12.03	11.22	8.00	5.31				
1.00 MW	9.45	9.95	7.54	5.23	4.02	3.26	2.37	1.87
1.50 MW	6.59	7.29	5.95	4.44	3.56	2.97	2.23	1.79
2.00 MW						2.70	2.09	1.71

In Table 4, when the value is greater than 1 the benefit provided over 12 years is greater than the initial cost of the system. The analysis assumes no discounting rate. The larger the benefit to cost ratio, the better the investment. It should be noted that there are other potential benefits that are not captured in this analysis that would improve the benefit-cost ratio for the larger energy ratings. These benefits are listed in Table 5 and discussed in more detail in the next section.

Figure 2 shows the 12 year benefit-to-cost ratio using the average avoidance cost savings for a 1 MW Li-Ion ESS with varying MWh ratings. The maximum and minimum savings were derived from the avoidance cost savings from years 2011-2016. If the maximum or minimum avoidance cost savings from 2011-2016 was used instead of the average avoidance cost which was used in Table 4, the results are shown in Figure 2 as the blue dashed lines.

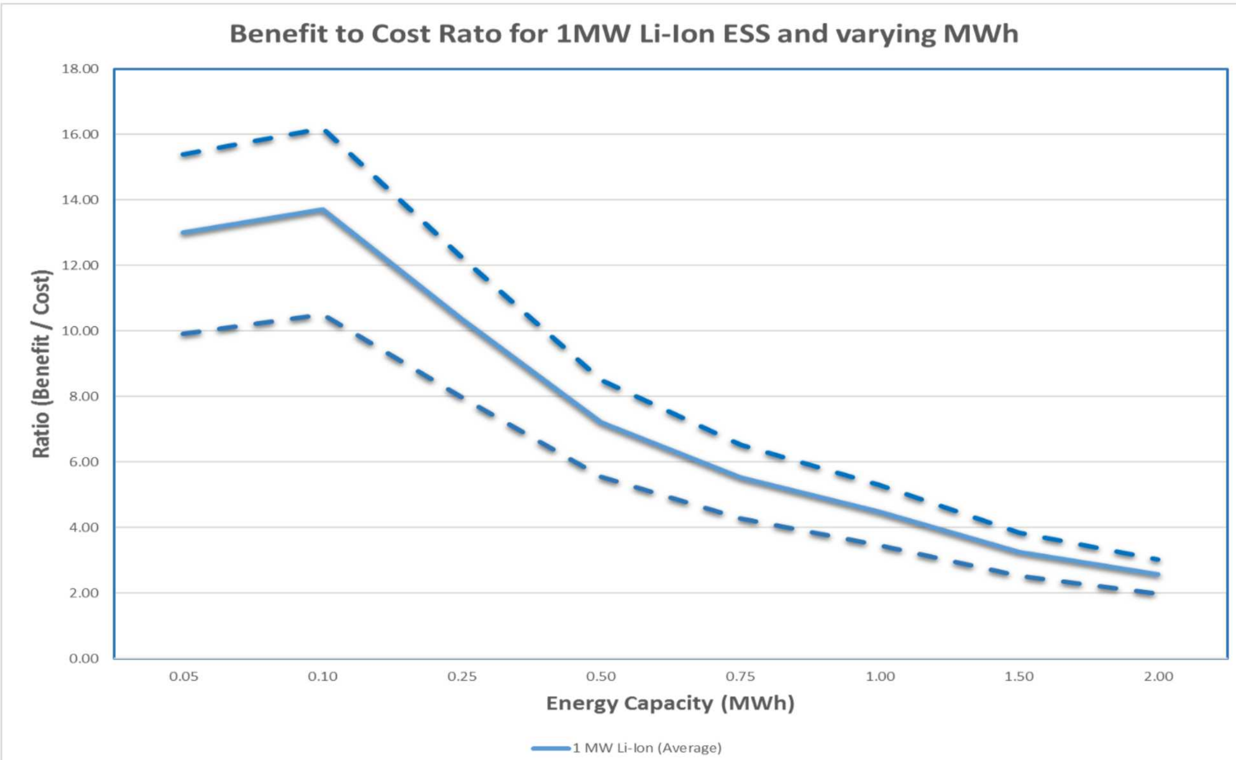

Figure 2 - Benefit-to-cost ratio for a 1 MW Li-Ion ESS increasing MWh rating

In Table 4 and Figure 3, the greatest benefit-to-ratio value typically occurs at 0.1 MWh. The only time this is not true is for the 0.75 MW ESS which has a steadily decreasing benefit-to-cost value as the MWh rating is increased. As the MWh rating of the ESS is increased (left to right in Table 4) the change in the benefit-to-cost ratio delta decreases. At 0.5 MWh, the benefit-to-cost ratio value is very similar for all the MW rated ESS. Overall, as the ESS MW and MWh rating is increased in Table 4 the benefit-to-cost ratio is decreased. Even through the smaller MW and MWh rated ESS has a larger benefit-to-cost ratio when applied as spinning reserve, purchasing a larger MW and MWh rated ESS allows for other applications to be applied. Also, the simulation from the previous report dispatched the smaller diesel generators within 30 seconds and the larger diesel generators in 2 min. Larger MWh rated ESSs allow for longer dispatch times giving the operator more flexibility to bring online diesel generators.

4. APPLICATIONS OF ESS IN THE CEC GRID

The application of the ESS providing spinning reserve in the CEC grid was evaluated in the previous study and presented in the sections above. There are other applications that can be used by the ESS which depends on the MW and MWh rating. ESS technologies are categorized into two groups which are power and energy systems. Power ESS are characterized as having a large MW rating providing a lot of MW for seconds to minutes. On the other side, energy ESS are characterized as having a large MWh rating providing MW for hours. A power ES may have a lower initial capital cost as completed to an energy ES, but an energy ES may have a lower cost per generated MWh given its increased capacity per charge. Also, the greater the energy capacity, the more applications an ESS can be used for. A list of the applications of an ESS (pertinent to CEC) is provided below. The applications are characterized by whether they are a power or energy application. Please note that in most cases an energy ES can perform power applications, but that a power ES may not be able to perform energy applications.

Table 5 - Application of ESS applicable for CEC

Application	Application Type	Description
Uninterruptible Power Supply	Power / Energy	ESS supplies voltage and power to a load during electrical disturbances on the grid within a predetermined time so the load never sees the disturbance. This application would be best fit for the a sensitive load such as the main Hospital.
Frequency Regulation	Power	ESS is charged or discharged in response to an increase or decrease of grid frequency and keeps it within pre-set limits eliminating the need to perform frequency regulation with the run-of-river generation.
Voltage Support	Power	ESS is charged or discharged in response to an increase or decrease of a voltage at which it is connected to and keeps it within pre-set limits. By supplying voltage support at the end of a line such as the airport, the diesel generators and run-of-river generators do not have to supply as much reactive power and low voltage conditions at the airport are avoided
Power Quality`	Power	ESS provides power maintaining a tight voltage and frequency window for sensitive loads. Power quality application can be applied at locations such as the hospital.
Ramp Rate Limiting	Power	ESS smooths the generators output by discharging and charging electrical power into the CEC grid based on a certain ramp rate (MW/min). Limiting the ramp rate eliminates rapid voltage and power swings on the CEC grid.
Distribution Deferral	Energy	Defer the upgrade of distribution electrical equipment due to congested feeders or increasing loads by placing an ESS at t

		he location where electrical power is needed. This application may be needed as the fishing industry increases.
Substation On-Site Power	Energy	ESS is connected to a substation such as Eyak or Orca and provides power to a certain feeder or feeders within that substation during power outages. The ESS can also be utilized to maintain electrical power to the substation control room.
Energy Time Shift	Energy	ESS stores electrical energy during low load to capture spilled hydro and provide this stored energy back to the CEC grid during peak load demands.
Load Leveling	Energy	ESS is charge during low load demands and discharged during high load demands keeping the load demand level.

In the section above discussing the benefit-to-cost ratio, these applications were not included as part of the benefits. If a cost avoidance or savings is provided for the applications in Table 5, the benefit-to-cost ratio will change. If an energy application benefit is included, the benefit-to-cost ratio values will increase as the MWh rating of the ESS is increased. The same will be true for the power applications and the MW rating of the ESS. To determine how much more an application would have to make over 12 years to equal the max benefit-to-cost ratio in Table 4 (16.56 for 0.75 MW / 0.05 MWh) the following equation was used.

$$K(MW,MWh)_i = \frac{B(MW,MWh)_{max} * C(MW,MWh)_i}{C(MW,MWh)_{max}} - B(MW,MWh)_i$$

Where:

$K(MW,MWh)_i$	Additional benefit needed from another ESS application to equal max benefit-to-cost ratio value for a certain ESS application based on the ESS MW and MWh rating
$B(MW,MWh)_{max}$	Max benefit using a certain application based on the ESS MW and MWh rating
$C(MW,MWh)_i$	Cost of ESS system based on MW and MWh rating performing a certain application
$C(MW,MWh)_{max}$	Cost of ESS based on MW and MWh for max benefit-to-cost ratio for a certain application
$B(MW,MWh)_i$	Benefit of ESS system based on MW and MWh rating performing a certain application
i	i^{th} ESS MW and MWh rating

In the analysis above using the ESS as a spinning reserve, the max benefit to cost ratio occurred at the rating of 0.75 MW and 0.05 MWh. Based on the cost and benefit values for the 0.75 MW / 0.05MWh ESS, the K value was calculated for all the other MW and MWh ratings and presented in Table 6.

Table 6 - Additional benefit needed from another ESS application to equal max benefit-to-cost ratio for the application of spinning reserve

	0.05 MWh	0.1 MWh	0.25 MWh	0.5 MWh	0.75 MWh	1.0 MWh	1.5 MWh	2.0 MWh
0.75 MW	0.00	0.22	1.58	4.01				
1.00 MW	0.75	0.69	2.04	4.48	6.91	9.36	14.25	19.15
1.50 MW	2.26	2.16	3.52	5.95	8.36	10.80	15.68	20.57
2.00 MW						12.28	17.15	22.03
* *VALUES ARE IN $M*								

Values presented in Table 6 are over 12 years. In order to determine the yearly benefit value, the numbers in the table have to be divided by 12. For instance, in order for a 1.5 MW / 1.5 MWh ESS to equal the same benefit-to-cost ratio for a 0.75MW / 0.05 MWh performing spinning reserve, the benefit value from another application would have to be approximately $1.31M per year ($15.68M / 12).

Since the smaller rated ESS has a significantly lower cost than the larger systems, the benefit-to-cost ratio will be higher. To determine the amount of benefit from an additional application that is needed to meet the system that has the highest earnings after 12 years, the table below is used which is the total avoided cost savings including inflation and discount rates and subtracting the initial capital cost of the ESS.

Table 7 - Total avoided cost savings over 12 years after paying off ESS

	0.05 MWh	0.1 MWh	0.25 MWh	0.5 MWh	0.75 MWh	1.0 MWh	1.5 MWh	2.0 MWh
0.75 MW	$2.52	$2.75	$2.74	$2.57				
1.00 MW	$2.46	$2.97	$2.97	$2.79	$2.61	$2.41	$2.03	$1.63
1.50 MW	$2.33	$2.87	$2.87	$2.70	$2.53	$2.35	$1.97	$1.59
2.00 MW						$2.24	$1.88	$1.51
* *VALUES ARE IN $M*								

In Table 7, the ESS that had the largest savings over 12 years was the 1 MW / 0.25 MWh. To determine how much benefit is needed from an additional application for a specific ESS rating to equal the earnings of the 1 MW / 0.25 MWh ESS the following equation was used.

$$APP(MW,MWh) = B(MW,MWh)_{max} - C(MW,MWh)_{max} - B(MW,MWh) + C(MW,MWh)$$

Where:

APP(MW,MWh)	Additional benefit needed from another ESS application to equal max earnings for a certain ESS application based on the ESS MW and MWh rating
$B(MW,MWh)_{max}$	Max benefit using a certain application based on the ESS MW and MWh rating (1 MW, 0.25 MWh)
C(MW,MWh)	Cost of ESS system based on MW and MWh rating performing a certain application
$C(MW,MWh)_{max}$	Cost of ESS based on MW and MWh for max benefit-to-cost ratio for a certain application (1MW, 0.25 MWh)
B(MW,MWh)	Benefit of ESS system based on MW and MWh rating performing a certain application

Results from the equation above are shown in Table 8. The smallest values or lowest annual additional cost needed to equal the max earnings within the table are in the range of 1 – 1.5 MW / 0.1 – 0.25 MWh. The table shows that if a 2 MW / 2 MWh had an additional average benefit value of approximately $121.40k or greater annually, the earning at the end of 12 years would be that of the 1 MW / 0.25 MWh or greater. If this additional benefit from another application can be realized, then after the 12th year the 2 MW / 2 MWh will begin to have a greater earnings than that of the 1 MW / 0.25 MWh.

Table 8 - Additional annual benefit needed from another application to equal max earnings

	0.05 MWh	0.1 MWh	0.25 MWh	0.5 MWh	0.75 MWh	1.0 MWh	1.5 MWh	2.0 MWh
0.75 MW	37.66	18.09	18.88	33.51				
1.00 MW	42.75	0.04	0.00	15.17	30.13	46.29	78.72	111.44
1.50 MW	53.61	8.04	8.29	22.90	36.59	51.47	83.05	114.81
2.00 MW						60.51	90.42	121.40
* ***VALUES ARE IN $k***								

5. CONCLUSION

The ESS provided a positive benefit-to-cost ratio when used as a spinning reserve. Since spinning reserve is a power application, the benefit-to-cost ratio values were greater when the MW rating was larger than the MWh rating. The highest value for the 12 year benefit-to-cost ratio for a Li-Ion ESS occurred at a power rating of 0.75 MW and 0.05 MWh. Benefits for other applications that the ESS could be used within the CEC grid were not included but should be considered. Looking at the avoided cost savings over the 12 year period and paying off the initial capital cost of the ESS, the 1 MW / 0.25 MWh had the largest earnings. Additional benefits required from another application annually to match the earnings from the 1 MW / 0.25 MWh system ranges from $40 - $121,400.

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