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Battery Energy Storage Systems Life Cycle Costs Case Studies

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Battery Energy Storage Systems Life Cycle Costs Case Studies*

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Abstract

This report presents a comparison of life cycle costs between battery energy storage systems and alternative mature technologies that could serve the same utility-scale applications. Two of the battery energy storage systems presented in this report are located on the supply side, providing spinning reserve and system stability benefits. These systems are compared with the alternative technologies of oil-fired combustion turbines and diesel generators. The other two battery energy storage systems are located on the demand side for use in power quality applications. These are compared with available uninterruptible power supply technologies.

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Acronyms

AGC	automatic generation control
BESS	battery energy storage system
DVR	dynamic voltage restorer
EMC	Electric Membership Cooperative
ESD	electronic selector device
GTO	gate-turn-off
LCC	life cycle cost
MP&L	Metlakatla Power and Light
O&M	operation and maintenance
p.a.	per annum
PCS	power conversion system
PREPA	Puerto Rico Electric Power Authority
SMES	superconducting magnetic energy storage
SOC	state of charge
T&D	transmission and distribution
UPS	uninterruptible power supply
VRLA	valve-regulated, lead-acid

Executive Summary

The life cycle costs (LCC) of four operating, full-scale battery energy storage systems (BESS), were determined and compared with the LCC of alternative mature technologies that could serve the same applications. Two of the BESSs are located on the supply side, providing spinning reserve and system stability benefits. The remaining two BESSs are located on the customer side ensuring that high quality, reliable power is available to critical loads during unplanned events that could cause power quality problems.

For the two supply-side applications, oil-fired combustion turbines and diesel generators are the alternative technologies. In both cases, the LCC analysis shows that the BESSs, at current capital costs, had a competitive advantage over the alternatives even though the capital cost for battery energy storage was substantially higher. At Puerto Rico Electric Power Authority (PREPA), the LCC of the BESS was $25.2 million (M) which was about $4M lower than the alternative, while at Metlakatla Power & Light (MP&L) the LCC of the BESS was $3.44M, approximately $1M lower than the commercially available alternative. There are special circumstances that enhance the value of battery energy storage for these two applications. These are:

1. Island utilities unable to economically interconnect with other utility grids.
2. Combustion turbines and diesel generators operating at partial loads (thus inefficiently) to provide spinning-reserve and load-following capabilities.
3. Fuel prices substantially higher than the national average.

The two applications studied thus represent high value-added niche markets for BESSs.

In customer-side applications, uninterruptible power supplies (UPS) are routinely used to protect specific equipment but are typically not sized to provide facility-level protection. This has opened opportunities for consumer installation of utility-scale BESSs for power quality applications. For one of the customer-side applications studied, Oglethorpe, the conventional alternative was to connect two commercial 200 kVA UPS units in parallel to provide up to 5 minutes of protection. The alternative technology for the other customer-side application, Vernon, was a small, conventional flywheel-based UPS system with a backup diesel generator. In both cases, the LCC for the BESS and for the alternative were very close. At Vernon, the LCC of the BESS and the alternative were both around $6.3M, while at Oglethorpe LCCs were around $1.65M for both systems. Thus, the BESSs were fully competitive with the commercially available alternatives for these types of applications.

BESSs considered in this report use different types of lead-acid batteries, a mature technology. Significant cost reductions for lead-acid batteries are not expected. However, the power conversion system (PCS) and integration of BESSs are candidates for optimization and cost reduction. In this analysis, a 15% capital cost reduction is assumed to be achievable for large, optimized, and mass-produced BESSs for installations such as PREPA, MP&L, and Vernon. This report assumes that BESSs for power quality applications of the type installed at Oglethorpe could be reduced in price by 20% as the system is optimized and produced in quantity. When these lower capital costs are introduced, the LCC of BESSs systems for all four applications favor the BESS option over the competition. The assumption, of course, is that comparable cost reductions for the conventional options do not occur to the same extent over the same time horizon.

In conclusion, this comparison of LCC for BESSs and the commercially available alternatives show that for two of those applications, the BESS is favored at today's prices. The LCC of the BESSs and that of the alternative technologies are very close for the two remaining applications. As capital cost reductions are realized for BESSs through improved PCS technologies, better systems integration, and volume production, the are expected to be economically advantageous for all four of the applications considered in this report.

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1. Introduction

Utility-scale battery energy storage systems (BESSs) are entering initial stages of acceptance in the marketplace. Four BESSs are currently in operation, serving a variety of needs. Two of the projects are on the electricity supply side installed by utilities to provide dynamic operating benefits. They are:

Puerto Rico Electric Power Authority (PREPA): The 20-MW/14-MWh BESS provides spinning reserve and frequency control. The system is located near San Juan, Puerto Rico.

Metlakatla Power and Light (MP&L): The 1-MW/1.4-MWh BESS serves repeated demand spikes and provides voltage, frequency, and system stability and control. The system is located in Metlakatla, Alaska, on the Annette Island Reserve in southeast Alaska.

The two other BESSs are installed on the customer side of the meter. These systems provide reliable high quality power to prevent customer financial losses due to power disturbances and unplanned outages of the electricity supply system. These projects are:

GNB Technologies' Vernon Lead Smelting Factory: The 5-MW peak/3.5-MWh BESS provides protection for the sensitive emissions control loads in the facility. The system provides power for up to one hour to allow for orderly shut-down of the plant during an unplanned power outage. The BESS can also be used for demand peak-shaving. The system is located in Vernon, California, about ten miles from downtown Los Angeles.

Oglethorpe Power's Lithograph Plant Customer: The 1-MW/10-second system has the capability to provide ride-through for up to 10 seconds during voltage sags and momentary outages. The system is capable of repeated discharges over a short period of time. The system is located in Homerville, Georgia.

This report provides a short historical overview and the rationale used to justify each of the four projects. The report also analyzes the life cycle costs (LCC) of the BESSs for the four projects and compares them with the LCC of competing technologies that were considered as alternatives to BESSs to meet the same application needs.

LCC methodology provides a basis by which products with different capital and operation and maintenance (O&M) costs can be compared equitably. The computation of LCC considers both the initial capital costs and all subsequent costs incurred over the life of the product.[1] Despite the uncertainties inherent in projections of costs 20 to 30 years into the future, LCC provides a fair basis of comparison for two products capable of serving the same needs of the consumer.

During this study, the owner-operators and designer-integrators of the four systems were contacted. Discussions were held to ascertain operational experience, costs incurred, and benefits from each energy storage system. The four projects have different levels of operational experience, and as a result, the data available from the different projects varied. The storage systems at MP&L and Oglethorpe became operational in 1996/97, while the Vernon BESS has been in operation since early 1996 and the PREPA BESS since late 1994. The lack of availability of some of the operational data and projected costs were due to their proprietary nature.

In order to compare the LCC of the four storage projects with those of competing technologies, vendors of alternative technologies were contacted. The estimated costs of the competing technologies were obtained from vendor quotations and discussions with system operators. Technical guides, input from experts, and operational experience from other energy storage systems were used to estimate cost parameters that were not available by other means.

The vendors who supplied data were given an opportunity to comment on the analysis and computations made to ensure that the information provided was used in the proper context.

1.1 Cost Categories Adopted for Computation of LCC

Life cycle costing is a method of calculating the total cost of ownership over the life span of an asset.[2] Initial cost and all subsequent expected costs of significance have to be included in the calculations. In addition, computation of the LCC includes disposal value and any other quantifiable benefits at the end of the equipment life.

Costs associated with acquiring, utilizing, and disposing of an asset can be classified into several cost categories, such as:[3]

Capital or First Cost—Cost of getting a project started and equipment operational. These costs for the four projects are known with a high degree of certainty because they have been incurred and were tracked while the projects were implemented. This report breaks down the capital cost into its constituent components as given by the Opportunities Analysis report.[4]

Operation and Maintenance (O&M) Costs—These costs are experienced continually over the useful life of the equipment and include O&M labor; fuel and power costs; O&M supplies, spares, and repair parts, costs of insurance and taxes; and associated overhead costs. The burden these costs will impose over the life of the equipment are, to a large extent, estimates. For the four projects studied, we were able to ascertain the costs directly attributable to the projects in the recent past and those projected for the next fiscal year. These costs were then extended to cover the life of the equipment. In most instances, they were assumed to be constant (in real dollars) over the life of the plant; however, under certain conditions they were escalated. The relevant assumptions are explained for each of the four LCC estimates.

Fixed and Variable Cost—Fixed costs are generally made up of such cost items as depreciation, maintenance, taxes, lease rentals, interest on invested capital, and administrative expenses. Variable costs may include fuel usage, electricity to recharge batteries, watering, etc. Costs ascertained for this analysis included many items in the variable category. At times, segregating O&M costs between fixed and variable costs becomes subjective. For example, the equipment maintenance and consumables were estimated to be ~$70K per annum (p.a). Since most of it was fixed and some variable, $50K p.a was allocated as fixed cost and the balance as variable cost (see Table 2.1 for another example).

Incremental or Marginal Cost—The relevant cost for establishing the LCC for maintaining a certain level of service is often incremental. For example, even though a diesel generator may operate most efficiently at continuous rated output, it might also be operated at a lower, suboptimal level to maintain spinning reserve capability. The incremental cost associated with inefficient operation of the engine for this purpose is properly allocated towards the cost of maintaining spinning reserve and should not be associated with energy generation.

Direct and Indirect Cost—Only direct costs associated with the O&M of the plant have been included in the analysis. Indirect costs associated with management, legal, payroll, and procurement services have not been considered.

Sunk or Past Cost—Because only future consequences of investment alternatives can be affected by current decisions, costs incurred in the past have to be disregarded. However, there is an instance in the analysis where terminating the use of an existing diesel generator and investing in a storage system were justified on the basis of greater cost associated with the O&M of the diesel engine. In that case, the capital cost incurred to purchase the diesel engine is relevant to comparing the LCC of the two options.

1.2 Methodology of Computation

Initial capital costs are incurred in Year 0, just before the plant became operational. Total O&M costs were segregated into fixed and variable O&M costs. Some costs, such as battery replacement, which depend both on usage pattern as well as age, do not clearly fall into one of the two categories. When cost categories were not clear, the method of allocation is explained. However, the total O&M cost considered all relevant costs experienced continually over the useful life of the plant.

With the exception of diesel fuel (inflated at 1%/year), inflation was considered to be zero and costs are thus in constant dollar terms. Costs were extrapolated for 20 years of operation since all plants were assumed to have a useful life of 20 years. End-of-life costs in decommissioning the equipment were not considered due to their uncertainty. Their inclusion would have a minimal effect on the LCC of the systems because of the significant discount factor at the 20-year point.

After developing the relevant costs for each of the four systems during the 20-year life, the out-year costs were discounted using a 10% discount factor to compute LCC.

1.3 Assumptions

1. A discount rate of 10% was used. The discount rate was selected to represent a value between the cost of borrowing and the return on capital for a company installing such systems.
2. A system life of 20 years and battery life of 10 years were assumed.
3. Battery replacement costs and O&M costs were assumed to remain the same in real terms throughout the 20-year life.
4. All costs are given in 1997 dollars.

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2. The PREPA Project

PREPA installed a 20-MW/14-MWh BESS at the Sabana Llana transmission substation located near San Juan, Puerto Rico. Ground breaking for the project occurred in July 1993 and the system became operational in November 1994. PREPA is an investor-owned utility responsible for generation, transmission, and distribution of electricity to the entire island of Puerto Rico. The self-contained PREPA grid serves approximately 3,500 square miles and a population of approximately 3.5 million. Generation is located in the southern part of the island, while demand is concentrated in the north, around the city of San Juan.

2.1 Project Rationale

The Puerto Rican grid is an isolated island system. To guard against unplanned generator outages and system disturbances, PREPA has to maintain its own spinning reserve and load-following generation units. The system at present has a peak load of approximately 2.7 GW.

Responding to rapid demand growth in the 1960s, PREPA installed about 2,500 MW of generation, essentially doubling its generation capacity. Most of these units were 400-MW, oil-fired combustion turbines. To minimize unplanned outages, spinning reserve on the order of 400 MW is maintained by operating some of the combustion turbines under partial load. During unplanned outages, frequency generally dropped to unacceptable levels and loads had to be shed to bring the system back to stable operation. The sluggish response of the combustion turbines during outages, the cost of operating these turbines to provide the spinning reserve, and public outcry during the frequent load shedding led PREPA to search for alternative ways of providing instantaneous spinning reserve capability.

2.2 Technology Options

PREPA required instantaneous reserves at power ratings of 10–100 MW for durations of approximately 15 minutes in the form of spinning reserve. This time buffer was adequate to have other generators take up the lost load. BESSs are well suited to meet these requirements.

An alternative technology that could be used to provide the same service is the oil-fired combustion turbine. However, in order for the combustion turbine to supply power instantaneously, the turbines must be kept operating suboptimally at 60% of full-load capacity for approximately 12 hours each day. A 36% plant factor (or capacity factor) and the inefficient mode of operation imposes substantial cost inefficiencies. An oil-fired combustion turbine exhibits a heat rate of 10,200 Btu/kWh[5] at full load but requires 13,300 Btu/kWh at 60% load. At a fuel cost of $5.67/MBtu, these inefficiencies translate into a substantial cost penalty. Thus, in comparing the two technology options, one must assess the higher initial investment of a BESS against the lower initial cost and inefficient operation of the oil-fired turbines. A LCC comparison of the two technology options does exactly that.

2.3 Project Description

A BESS for the provision of spinning reserve was authorized by the PREPA governing board in 1990, and the design work began in 1991 for a 20-MW/14.1-MWh system.[6] The facility construction was completed in October 1993. After a year of extensive testing and debugging, the system commenced commercial operation in November 1994. Figure 2.1 illustrates the single line diagram of Sabana Llana BESS.

The battery consists of 6,000 cells arranged in six strings containing 1,000 cells each. Three such strings were connected in parallel to a 2,000-VDC bus and then connected via a 10-MW PCS to a 13.8-kVAC bus. The 13.8-kVAC bus has two such systems connected to it, and the bus is then connected via a transformer to the 115-kV substation.

C&D Charter Power Systems supplied the 6,000 battery cells, racks, watering system, electrolyte agitation system, and other battery-related equipment. General Electric supplied the PCS. The software for the control algorithm was implemented by Max Control Systems, Inc. PREPA, with the help of United Engineers and Contractors, was the system integrator and managed the project.

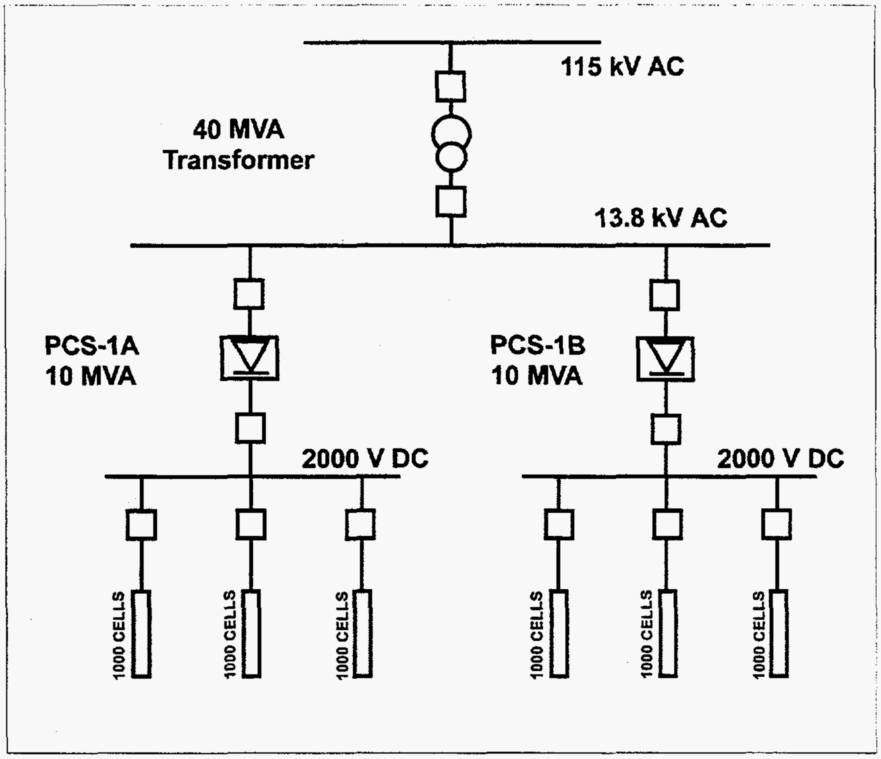

Figure 2-1. Single Line Diagram of Sabana Llana BESS.

A two-story, reinforced concrete building was constructed to house the equipment. The building has an external dimension of 172 feet × 95 feet, with the six battery strings occupying a total floor space of 24,700 square feet. The seismic activity in Puerto Rico and the weight of batteries required a reinforced concrete structure. A 100,000-gallon water tank is located just outside the building to be used in cases of accidents. The PCS, DC switchgear, and control room occupy close to 4,000 square feet of floor space, which is air-conditioned. A carbon dioxide storage tank is available to be used in this portion of the building in case of fire.

2.4 System Installation and Operation

The BESS has been in operation since November 1994. As of April 1997, the plant has operated 38 times providing instantaneous reserve. The system continuously provides frequency regulation and voltage stability. On average, close to 1 MWh of energy circulates through the plant every day when operating in the frequency regulation/voltage control mode.

The batteries are recharged to 100% state of charge (SOC) every three days. The recharging begins at midnight and follows a designated recharge algorithm. The recharging time varies depending on the SOC when the recharging begins. In addition, a constant trickle charge is applied when the SOC is between 70% and 90%, in order to try to maintain the SOC at 90%. Whenever, the SOC falls below 70%, a recharging cycle begins. All of these processes are automated.

In addition, the electrolyte agitation system operates for 15 minutes every six hours, and watering of the 6,000 cells is done every six months. Cell voltages and temperatures are monitored constantly with built-in alarms. When cell voltages and/or temperatures deviate beyond acceptable limits, an alarm signal appears in the control panel. Voltages are monitored in groups of four cells. If any given four-cell group exhibits a voltage variation of greater than 0.2 V (nominal group voltage equals 4 × 2 volts, or 8 volts) from the average of the other 8-V groups of cells in the 2000-V string, an alarm is set off and that particular four-cell group is investigated. The plant is staffed eight hours a day/five days a week by a plant manager, an electrician, and unskilled general help. The plant manager is constantly on call, if required.

2.5 LCC Analysis

The LCC analysis of the BESS and the combustion turbine option for the PREPA application is shown in the appendix in Tables A2-1 and A2-2. The PREPA Plant Manager and the staff of the Generating Planning Division provided all the cost information. The BESS was designed to reduce the number of oil-fired turbines operating under suboptimal conditions. The BESS was not designed to supply all the spinning-reserve generation capacity, rather the BESS with its ability to supply 20 MW of power for 15 minutes, provides PREPA the opportunity to bring its gas turbines on-line. This analysis assumes that spinning reserve duty by the PREPA BESS equates to a 30% capacity credit for the purpose of calculating the LCC of the alternative (6 MW of the 20-MW-rated BESS). PREPA planners did not consider capacity credit for BESS in their initial analysis but now agree with the 30% estimate.

To assess an alternative technology to the BESS, this analysis evaluates a peaking, oil-fired combustion turbine. The plant data for the 83-MW, No. 2 oil-fired Asea Brown Boveri turbines, three of which began operation by PREPA in July 1997, are used for this comparison. The total capital cost of this 240-MW project was \$160M.[7] This is equivalent to \$666/kW. The three turbines are being operated at 60% of full load for ~12 hours/day, with a projected annual capacity factor of ~36%. This mode of operation imposes a substantial penalty in terms of inefficient heat rates. The plant exhibits a heat rate of 10,200 Btu/kWh at full load and 13,300 Btu/kWh at 60% load. At a fuel cost of \$5.67/MBtu, this inefficiency translates into a substantial cost penalty. Hence, the LCC of this alternative to the BESS is the avoided cost of operating oil turbines inefficiently and the BESS's ability to displace 6 MW of oil turbine capacity.

A detailed LCC comparison of the two options (Table A2-1 and A2-2) is located in the appendix. This information is summarized below in Table 2-1. The notes given below Tables A2-1 and A2-2 in the appendix explain the basis on which the numbers were derived and the costs included. All costs incurred over the 20-year life of the two systems have been discounted to Year 0 (1997\$).

Figure 2-2 presents the data in Table 2-1 graphically to highlight the capital intensive nature of battery energy storage compared to the combustion turbine. Investing up-front capital to achieve O&M savings over time clearly requires detailed technical and economic analysis before such investment decisions are made.

2.6 Discussion

PREPA is an island utility that must maintain its own spinning reserve. Unscheduled outages of baseload generating units result in a very rapid drop in frequency, which results in load shedding. Reserve units must come on-line almost immediately in order to avoid shedding load. Maintaining oil-fired gas turbines as reserve units that are capable of supplying power instantaneously is very expensive since the fuel cost of \$5.76/MBtu for oil in Puerto Rico is high.

The capital cost of the BESS is much higher than that of equivalent combustion turbines. However, the BESS has relatively low O&M costs. In contrast, the

Table 2-1. Comparison of Discounted LCC of the PREPA BESS and Combustion Turbine

Cost Category	BESS	Combustion Turbine
<u>CAPITAL COST (\$K)</u>		
Total initial cost	21,400	3,960
<u>O&M Cost (\$K)</u>		
Discounted fixed cost	2,445	84
Discounted variable cost	255	25,470
Discounted battery replacement cost	1,050	--
Total–Life Cycle Cost	\$25,200	\$29,500

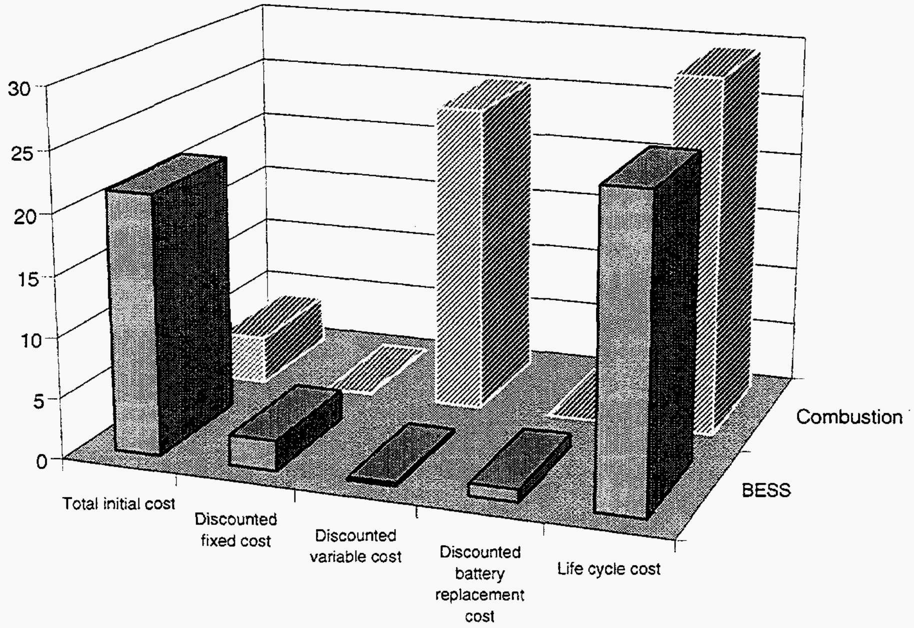

Figure 2-2. Components of Discounted LCC of the PREPA BESS & Combustion Turbine (in $M).

fuel costs for the combustion turbine are high, and as Table 2-1 and Figure 2-2 show, more than offset the high capital cost of the BESS plant. Clearly, lower fuel costs will make the combustion turbine option look more competitive with the BESS. The break-even point is when the fuel price is between $4.50/MBtu and $5.00/MBtu.

The average fuel price in the 48 contiguous states of the U.S. was approximately $3.16/MBtu in 1996.[8] which is lower than the break-even price of $4.50/MBtu to $5.00/MBtu. This underscores the fact that the BESS at PREPA addresses the needs of a market with higher-than-average fuel prices.

The batteries for the PREPA BESS carry a 10-year warranty, and the LCC analysis was therefore done assuming battery replacement every 10 years. The BESS will be less favorable from an LCC stand-point if batteries have to be replaced earlier and PREPA has to bear the cost of such replacement. This analysis finds that battery life must drop to 4.5 years in order for the LCC of battery energy storage to become equivalent to that of the combustion turbines.

The discount rate also plays a significant role in determining the LCC of the two systems. The results presented in Table 2-1 are at a 10% discount rate. At a 14% discount rate, the LCC of the BESS and combustion turbines drop to $24.3 million and $23.7 million, respectively, making the two options roughly competitive in this case. As expected in LCC analysis, higher discount rates have greater impact on systems with heavy front-end costs (the BESS), and lower discount rates have greater impact on systems with substantial out-year costs (the turbine). A discount rate of 10% was chosen as the average between the cost of borrowing and the return on capital expected by industrial customers in today's economy.

The BESS at PREPA has now been in operation for a little more than three years. To date, the O&M cost with the BESS has been on track with original PREPA projections. Major O&M deviations upward or downward could have negative or positive effects, respectively, on the BESS LCC.

3. The MP&L Project

Metlakatla is an island on the southern tip of the Alexander Archipelago in Southeast Alaska, adjoining the northwest corner of British Columbia. The Metlakatla Indian community has a population of approximately 1,500 and its electricity needs are served by a compact 12.5-kV network of hydroelectric and diesel generation. MP&L, the local utility, serves the Indian community, several relatively small commercial loads, and a large sawmill. The peak load of the system is about 3.5 MW, with approximately one-third of the total being associated with the sawmill. The system has an installed hydrogeneration capacity of 4.9 MVA and a large 5-MVA/3.3-MW diesel generator.

3.1 Project Rationale

The biggest load in the MP&L system is the sawmill. The chipper in the sawmill has a spiking load, with load swings of 600 kW and up to 900 kW at times. This caused substantial fluctuations in system voltage and frequency in the 3.5-MW grid system. Though the hydroelectric units have adequate capacity to satisfy the average active and reactive power needs, as well as the energy requirements of the system, they lack the speed of response required to follow the load fluctuations.

The utility purchased the 3.3-MW diesel generator in 1987 in order to meet the demand of the chipper, which comes on-line for 10 seconds every three minutes, 14 hours a day. The diesel was operated at 80% load, with the remainder of its capacity (700 kW) held in reserve to respond to load swings and short-term fluctuations in baseload. The generator had to be oversized and operated 14 hours a day in order to satisfy the response rate requirement, though the hydroelectric units had sufficient energy generation capability.[9]

The fuel and maintenance cost of operating the diesel unit to provide adequate capacity to meet the load swings was proving to be expensive, especially when sufficient energy and capacity was available from MP&L's hydroelectric units.[10] In 1992, the utility started exploring other technology options capable of responding to the large load swings.

3.2 Competing Technologies

The technologies required to perform the function of responding to the spiking load of the chipper had to have a quick response time, within 1/20th of a second, and had to be able to provide sufficient amount of energy at high power levels. Battery energy storage, superconducting magnetic energy storage (SMES), flywheels, and capacitors, coupled with high-response PCS are all theoretically able to provide the 1-MW 10-second (10-MJ) energy bursts required every three minutes. However, the ability to discharge the necessary amounts of energy every three minutes for 14 hours a day requires substantial amount of energy storage, which only battery energy storage has proven to provide.[11]

3.3 Project Description

The initial inquiry to explore the suitability of a storage system was made by MP&L with the Energy Storage Systems Program at Sandia National Laboratories in 1992. After considering different manufacturers, the utility approached GNB Industries and General Electric to conduct a techno-economic feasibility study that compared battery energy storage to other options using only the existing hydroelectric and diesel units. The study suggested that a 1-MW/1.4-MWh battery energy storage could provide the spinning reserve, frequency control, and power quality improvement that MP&L needed.[12] The project was estimated to cost $1.6M with a benefit: cost ratio of ~ 1.5:1.

After the competition of the final engineering cost estimates and environmental assessment, the turn-key project contract was signed in December 1995. The site construction began in May 1996, and checkout/energization was completed in November 1996. The commissioning tests started in December of 1996, and the plant has been in operation since February 1997.

The system consists of a PCS, an automatic generation control (AGC) system, batteries, racking and cables, and a butler-building-style shelter that houses all the equipment. The PCS, based on gate-turn-off (GTO) thyristors, allows bi-directional power flow between the AC system and the battery in less than a quarter cycle. The storage batteries consist of a string of 378 GNB Absolyte IIP, series-connected, valve-regulated, lead-acid (VRLA) cells. The BESS is capable of supporting a continuous load of 800 kVA and handles pulse loads up to 1200 kVA. A 900-kVA filter bank removes the harmonics and compensates the voltage of the electrical signal. The AGC ensures optimum integration of BESS response and hydroelectric operation. The steel butler building housing the equipment is 40 feet × 70 feet and sits on a concrete pad at the 12.47-kV substation for MP&L's main diesel generator. Figure 3-1 illustrates the simplified one-line diagram of the MP&L system.

3.4 System Installation and Operation

Since operation began in February 1997, improved efficiency in both the diesel and hydroelectric units has been achieved. A 60% increase in fuel-use efficiency has been noted. Within a month after operation, the BESS operated for 45 minutes when a 1-MW load was rejected and tripped one of the hydroelectric units. The only time the diesel operated in the month of February 1997 was to recharge the battery. The diesel unit will still be required to operate when the hydroelectric units undergo maintenance; however, the engine efficiency is high in this mode of operation. MP&L saved $39,100 in diesel fuel costs in March 1997.

Since the battery is a source of energy when the load jumps higher than average and acts as a sink for energy in the subsequent period, the net output for the hydroelectric plant is nearly constant, with the batteries requiring very little additional charging from the diesel. The BESS has demonstrated automatic, unattended operation, including charge, discharge, standby, ready, synchronization, disconnect, and black-start capability.

3.5 LCC Analysis

With the installation of the BESS, the 3.3-MW diesel unit has been relegated to a standby mode of operation. The diesel unit will not have to be operated when all the hydroelectric units are available with adequate water reserves to provide the energy requirements of the system load. Previously, the expensive diesel had to operate, despite the availability of the hydrogeneration capacity, in order to maintain system stability. The BESS now provides adequate system stability.

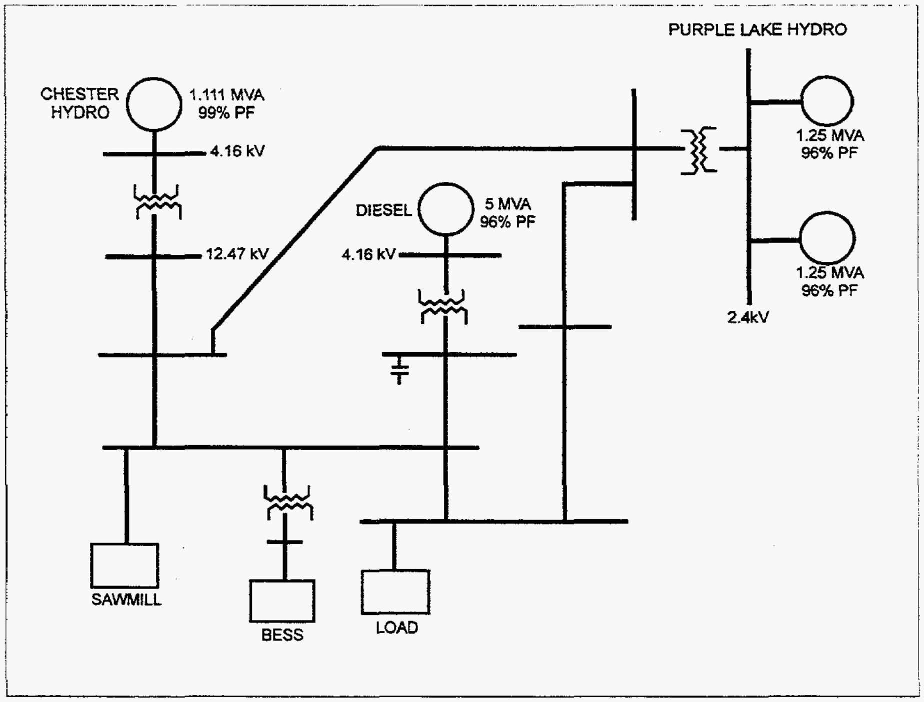

Figure 3-1. Simplified One-Line Diagram of the MP&L System.

With the operation of the BESS, an annual fuel savings of $350,000 is projected. The amount of fuel consumed in 1996, prior to the installation of the BESS, compared to the amount of fuel consumed in 1997 when the BESS was in operation is shown in Table 3-1. The table also shows the percent contribution of the diesel and the hydroelectric units in 1997. The contribution from diesel generation dropped from 24.4% in 1996 to 10.9% clearly demonstrating the value of the BESS.[13] As expected the contribution of hydroelectric generation increased from approximately 75% to 90%. Inadequate water reserves, combined with hydroelectric systems problems, led to a lower usage of hydroelectric generation than planned. Diesel generation had to be increased to account for the shortfall. Thus, the 10.9% contribution from diesel in 1997 represents a higher use of diesel than planned with the BESS in place.

The diesel overhauls, which have to be undertaken after every 20,000 and 40,000 hours of operation, at a cost of $230K and $370K, respectively, are significantly delayed by the operation of the BESS. The costs incurred during the 20-year life of the BESS, and the costs of supplying the same load-following capability with diesel generation are given in the appendix in Table A3-1 and Table A3-2, respectively. The notes given below each of the appendix tables explain the basis on which the numbers were derived and the costs included.

A LCC comparison summary is given in Table 3-2, which summarizes the data from Table A3-1 and Table A3-2. All costs incurred over the 20-year life of the two systems have been discounted to Year 0 (1997$).

Figure 3-2 graphically depicts the various discounted cost components of the two alternatives. The cost distribution is very similar to that of the PREPA case (Figure 2-2). The high initial capital cost of the BESS is compensated for by the extremely high fuel costs associated with the diesel generation system.

3.6 Discussion

A spiking load of ~600 kW is a considerable load swing for a 3.5-MW isolated electricity grid. MP&L must meet such power demands repeated to serve the sawmill. The hydrogeneration and water storage facilities provide adequate capacity to serve the island's year-round energy demand, but the hydroelectric plant's power capability and response time is not sufficient to meet the load spikes.

MP&L had two options—it could either install additional generation or interconnect with adjoining utilities. Interconnection was not practical since extensive over-water transmission would be required. Thus, in 1987, MP&L installed a diesel generating system. The diesel generator was used to provide load-following capability when the hydroelectric generation was in operation and to provide full back-up power for the island during the maintenance periods of the hydroelectric system.

Partial loading of the diesel generator was required when serving the load-following function. Operating a diesel generator at partial load is very inefficient. Furthermore, the delivered cost of diesel fuel to an isolated island in Alaska is as high as $5.70/Mbtu.[15] As Table 3-2 shows, the high initial capital cost of the BESS is more than offset by the high cost of diesel fuel combined with the inefficiency of the diesel generator operating at partial load. The break-even point in this case comes when annual diesel fuel costs drop to $250K.

Table 3-1. Comparison of Performance Data for MP&L 1996–1997[14]

Performance Measure	1996 without BESS	1997 with BESS
Diesel fuel consumption (gallons)	476,188	143,957
Diesel % of net generation	24.4	10.9
Hydroelectric % of net generation	75	90

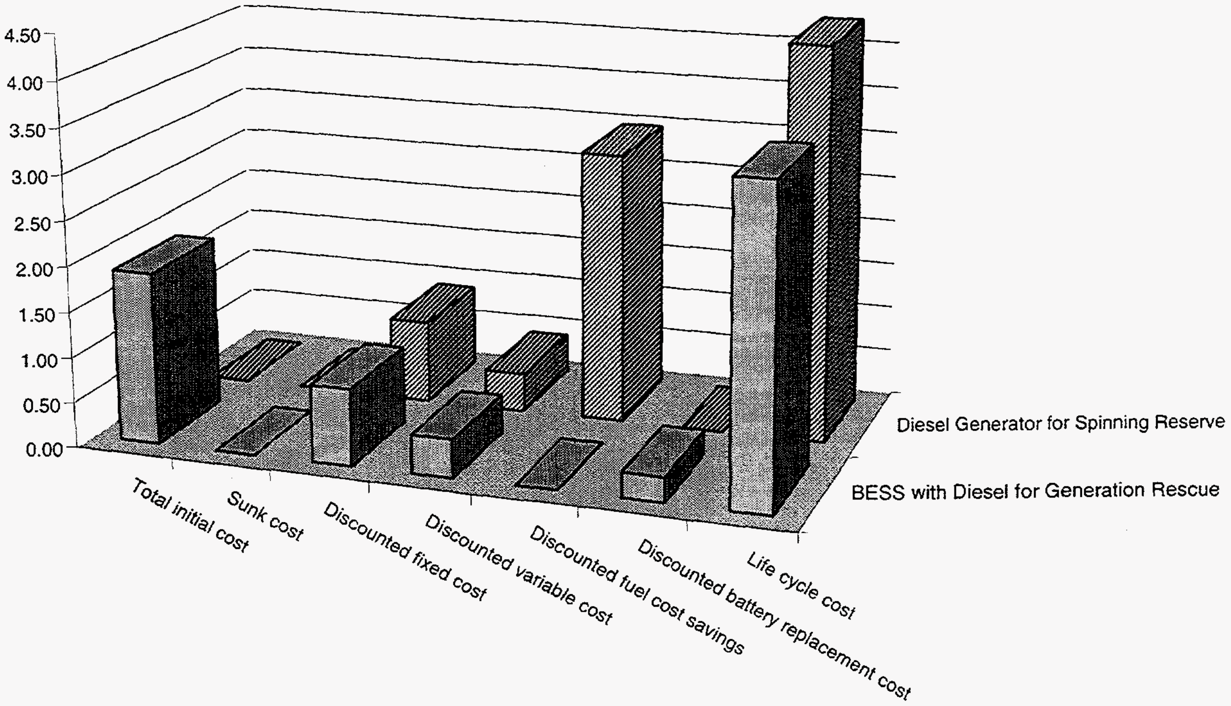

Figure 3-2. Components of Discounted LCC of the MP&L BESS and Diesel Generator (in $M).

Table 3-2. Comparison of Discounted LCC of the MP&L BESS and Diesel Generator

Cost Category	BESS with Diesel Generator	Diesel Generator Alone
CAPITAL COST ($K)		
Total initial cost	1,893	--
Sunk cost	--	0
O&M Cost ($K)		
Discounted fixed cost	849	907
Discounted variable cost	425	425
Discounted fuel cost savings	--	2,980
Discounted battery replacement cost	274	00
Total—Life Cycle Cost	$ 3,440	$4,300

A significant O&M cost associated with the diesel generator is regularly scheduled overhauls. As Table 3-2 shows, it amounts to $230K or $370K every three years. If the BESS eliminated the need for the diesel, this cost factor would also be eliminated. However, in reality, the diesel generator is still in service in a stand-by mode. When the hydroelectric units are not all available, the diesel generator must operate to provide the shortfall. The presence of the BESS, however, allows the diesel to be operated at full load instead of a partial load, and it is also operated for shorter periods. Thus, in the LCC analysis of the BESS, one cannot completely eliminate the diesel overhaul cost. However, the new combined system has not operated long enough to know how often such overhauls must be made to the diesel. If we make the conservative assumption that the overhaul cost will not change but the time between overhauls will be doubled, the LCC of the BESS/standby diesel and diesel-only options are $3.97M and $ 4.31M, respectively. In this case, the LCC of the BESS is still lower than the diesel option, although the BESS advantage is somewhat reduced.

Since its installation, the BESS has demonstrated benefits that were not realized during the project planning phase. Noise reduction has resulted from the infrequent use of the diesel generator, a benefit that is significant and greatly appreciated by the island residents. Moreover, the presence of the BESS has contributed to system stability and better management of the hydroelectric resources.

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4. GNB Technologies Vernon Lead Smelting Facility

A lead smelting and recycling center operated by GNB Technologies is located in Vernon, California, 10 miles southeast of downtown Los Angeles. The facility processes over 10M used-car batteries annually, reclaiming approximately 100,000 tons of lead. The plant power is fed from a 4.16-kV feeder from the local municipal utility and has a typical load of approximately 3.5 MVA.

4.1 Project Rationale

The BESS was installed at the smelting center to provide emergency power for critical loads, primarily those dealing with environmental controls. The BESS can provide protection for most of the factory's 3.5-MW load for up to one hour, which provides sufficient time for orderly shutdown of the plant if the power outage persists. Prior unplanned power outages caused unintended lead emissions which, in addition to health hazards, resulted in air quality violations and fines.

In addition, the system provides peak shaving of to 500 kW when the facility demand exceeds a preset threshold. Limiting the maximum power drawn from the grid will reduce the factory's annual electricity demand charges by approximately $50,000. The BESS, while maintaining high levels of power quality and reliability, also provides power factor correction by supplying reactive power.

4.2 Competing Technologies

GNB is a manufacturer of lead-acid batteries and has a strong interest in participating in the emerging market for BESS for electric utility applications. The Vernon plant provides GNB with an excellent opportunity to showcase the performance of their own BESS. Consequently, GNB did not consider competitive technology options in great detail as they selected the BESS.

A rotary, on-line power protection system coupled to a diesel generator was considered to be the competing technology in this assessment. This system continuously conditions utility power through a motor-generator pair. The motor-generator pair has enough inertia built into the system conventional (flywheel) to carry the load for 3–5 seconds during a power outage, which provides sufficient time for the stand-by diesel unit to come on line and supply the load. Due to the on-line protection capability of this motor-generator power protection system and the need to maintain the water jacket temperature of the diesel, the parasitic electricity consumption is about 7% of the system's 1.6-MVA rating. Two such systems in parallel will be required to displace the BESS at the smelting factory.

4.3 Project Description

The lead smelting facility at Vernon is required to adhere to the strict emission standards of the South Coast Air Quality Management District. The large fans used to recover the lead dust generated by the factory are susceptible to outages and may result in the factory releasing lead dust into the atmosphere.

In order to avoid further risk of lead emissions, GNB decided to install a UPS based on its own battery, with the PCS supplied by General Electric. The project was announced in November 1994, and construction began in January 1995. The construction and installation phase were completed in August 1995, and commissioning tests were completed in November 1995.

The BESS utilizes GNB ABSOLYTE IIP VRLA batteries and contains 2,268 cells (756 modules/3 cell per module) capable of supplying 3.5 MWh at the one-hour rating. The GTO-based General Electric BC2000 12-pulse PCS consists of three, 1.25-MVA units.

4.4 System Installation and Operation

The BESS has been in operation since early 1996. The system is designed to operate for 10 seconds at a maximum plant demand of 5 MVA immediately after takeover and has a continuous rating of 3.0 MVA. Upon sensing a loss of utility voltage:

- The incoming circuit breaker will open and the BESS will supply the entire load,

- The control system will shed all but the critical loads, and
- The BESS will carry the critical loads at 3.0 MVA for one hour.

In addition to the power quality protection function, the system has performed in a peak shaving mode for six hours daily, periodically since April 1996 to provide power cost savings. However, its main function still remains providing backup power.

4.5 LCC Analysis

The Vernon BESS is an off-line system with a start-up time of less than 1 second. The installed cost of the BESS was about $4.2M, which protects all the factory loads tied to the 4,160-V substation bus.

Two containerized rotary power quality systems, rated at 1.6 MVA each, cost approximately $2.5M. Given the output voltage of 480 V, the necessary step-up transformer to 4,160 V adds another $2M to the equipment cost. However, this $4.5M power quality system can provide continuous power conditioning and backup generation, while the interactive battery-based UPS can provide protection for only an hour. The rotary power quality system alternative has a parasitic load of about 7% of its rated output. The cost of this parasitic load, which is on the order of 200 kVA for the 3.2-MVA system, is about $100,000 per annum.

The detailed LCC analysis of two systems are given in the appendix in Tables A4-1 and A4-2. Table 4-1 compares the two systems on the basis of discounted costs. The notes given below the appendix tables explain the basis on which the numbers were derived and the costs included.

Figure 4-2 graphically represents the various components of the two technology options. The capital cost for the two technologies are comparable and the LCC for the two options are close enough that one could not be selected over the other, based on cost alone.

4.6 Discussion

The Vernon BESS protects environmentally sensitive critical loads in an urban area. The BESS and the commercially available alternative appear comparable in performance and cost. The diesel generator/flywheel storage system can carry the factory load beyond the one-hour capacity of the BESS, although there is no obvious need for such longer duration support for the critical loads of the plant.

The initial capital cost for the diesel generator/flywheel is slightly higher while the O&M cost for the BESS is slightly higher. As a result, the LCC of both systems are essentially equivalent. Battery replacement for this application is expected to be every eight years. If we assume a battery life of 10 years, the LCC cost for the BESS drops to $6M. Although it is now slightly smaller than the diesel/flywheel storage system, the difference is still not significant.

Table 4-1. Comparison of Discounted LCC of the Vernon BESS and Diesel Generator

Cost Category	BESS	Combustion Turbine
CAPITAL COST ($K)		
Total initial cost	4,245	4,500
O&M Cost ($K)		
Discounted fixed cost	852	1,703
Discounted variable cost	426	-
Discounted fuel cost	-	-
Discounted battery replacement cost	821	--
Total–Life Cycle Cost	$6,340	$6,200

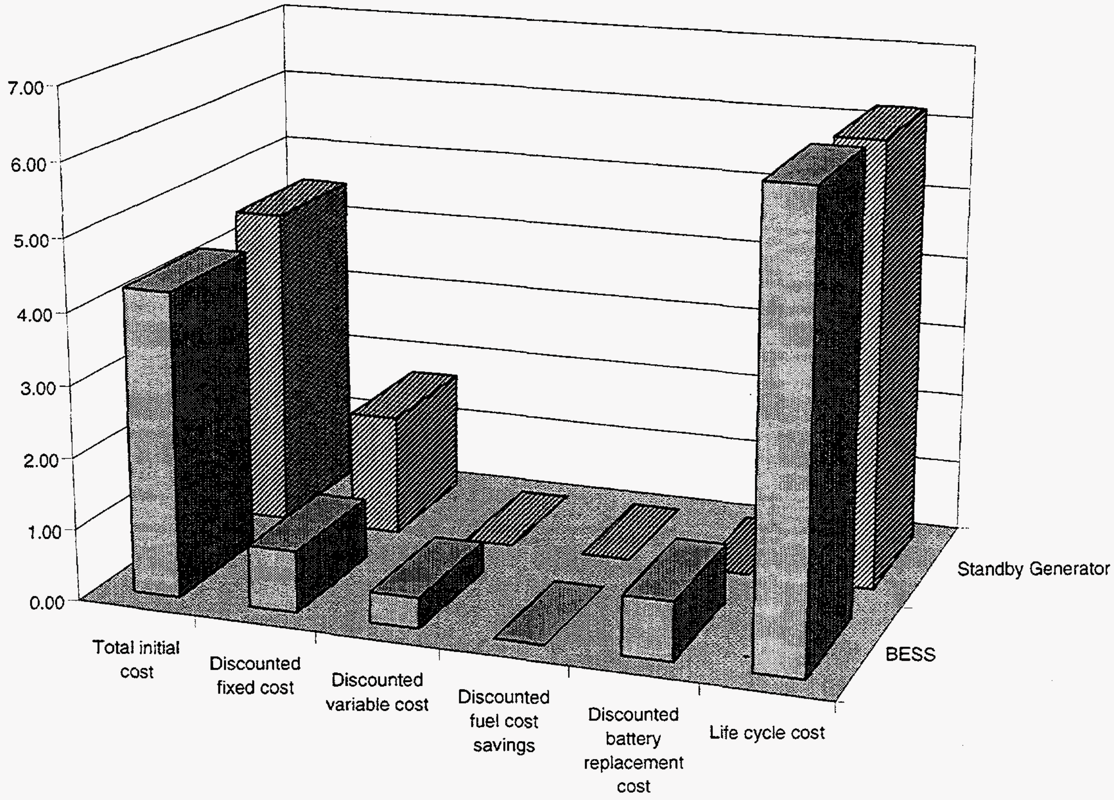

Figure 4-1. Components of Discounted LCC of the Vernon BESS and Diesel Generator (in $M).

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5. Oglethorpe's Power Quality System

A 1-MW/10-second battery-based power quality system is located at a lithograph plant in Homerville, Georgia. The plant is served by the Slash Pine Electric Membership Cooperative (EMC). Slash Pine EMC, headquartered in Homerville, has approximately 4,500 consumers/members, with the lithograph plant being the largest among them.

Oglethorpe Power Corporation was formed by 39 EMCs, including Slash Pine, in Georgia in 1974 to provide generation and transmission services, giving the local EMCs a measure of control over the source of electricity delivered to their customers through their own distribution system. Oglethorpe Power also provides services such as power quality assessments and solutions to their member EMCs. The 39 EMCs combined serve 72% of Georgia's territory and account for 23% of Georgia's peak load.

5.1 Project Rationale

Oglethorpe Power initiated examination of large power quality systems (in the 1–2 MW range) at the customer end when voltage sags were experienced by many of its EMC members and their customers. The typical sags were a maximum of 70 V and lasted 2 seconds.

There were multiple causes for such disturbances. Southern Georgia is a region with high incidences of lightning and occasional hurricanes, which can cause surges and short circuits in the lines. Line damage from trees and animals also contributes momentary supply disruptions. While momentary disturbances are not critical for most consumers, certain manufacturing facilities and commercial establishments could suffer serious financial losses.

The necessary customer-end protection against such occurrence was envisaged to have the following characteristics:

- At least 1 MW in capacity,
- Ride through of at least 5 seconds,
- Capability of many discharges over a short period of time,
- Fast transfer time,
- Compact footprint,
- Outdoor installation, and
- Economical and long life.

The system ultimately selected was AC Battery Corporation's PQ2000. The 2-MW system provides up to 10 seconds' worth of load protection. The system was designed for outdoor installation and has built-in heating and cooling systems. The system is scaleable in 250 kVA units up to the 2-MVA size. This system was selected because of the high power rating, the small parasitic load, and the capability of being configured to meet the required 2-MW size.

5.2 Competing Technologies

In its search for systems to meet the desired characteristics, Oglethorpe Power investigated various technologies including:

- Statcom,
- Dynamic Voltage Restorer (DVR),
- SMES,
- Active Power Line Conditioner,
- Statordyne, and
- Standard UPS.

A questionnaire covering a wide range of issues was sent to each manufacturer and the answers were analyzed. Questions dealt with:

- Projected commercial cost,
- Research and development needs,
- Installation needs,
- Footprint and system sizing,
- Input and output voltage,
- Switching time, and
- Fault current limitations.

The evaluation of the different products against the needs of customers was carried out by Oglethorpe, but the detailed analysis is not in the public domain. However, it is known that Westinghouse's Statcom and DVR provide protection for very short durations, in the range of a few cycles, and would not be sufficient for the specified requirements. Though Superconductivity, Inc., was at that time in the process of developing larger SMES magnets for longer duration protection, the magnets then available could provide protection only for 2–3 seconds for a 2-MW load.

The UPSs, which in most instances are battery-powered, are used in a wide range of industrial applications. They come in sizes ranging from the smaller 1–2 kW systems up to 100–200 kW and provide protection for durations of minutes to hours. However, of the UPS system manufacturers, (which included Best Power; Exide Electronics; GNB Technologies, Inc.; Liebert Corporation; Westinghouse Electric Corporation; Intermagnetics General Corporation; Superconductivity, Inc.; MGE UPS Systems; and Statordyne, Limited Liability Corporation) none of these companies had systems available in the MW range. Some of the UPS manufacturers were willing to supply MW-range systems by connecting their smaller units. One manufacturer said that nine 220-kVA units could be connected in parallel to achieve the 2-MW rating.

This multiple-parallel system is considered to be the alternate to the PQ2000 for this application. The product line offered by this manufacturer is able to provide protection for up to 5 minutes, longer than the 10 seconds offered by the PQ2000. Detailed equipment capital and operating cost data were obtained from this manufacturer and they were compared to that of the projected LCC of the system in place at the lithograph plant. Because the batteries in this competing system were oversized for the specifications, adjustments were made to take this into consideration. Detailed comparisons of the LCC of these two systems are analyzed in Section 5.5.

5.3 Project Description

The equipment for this project was supplied by AC Battery Corporation (Omnion Power Engineering) of East Troy, Wisconsin. PQ2000 is the trademark name of the company's 2-MW system providing protection to connected loads for up to 10 seconds.

The installation work began in May 1996 and consisted of laying conduit, pulling over 1 mile of cable, designing and pouring a foundation, installing a ground grid, and crimping approximately 250 lugs.[16] A redundant termination cabinet was installed to bypass the entire PQ2000 system, though such a bypass switch already exists within the PQ2000 system. The containerized equipment was delivered by truck in July 1996. It was lifted off the truck with a 60-ton crane and installed on the constructed concrete pad. The acceptance tests were completed, and the system has been in operation since December 1996. A simple line diagram of the system is provided in Figure 5-1.

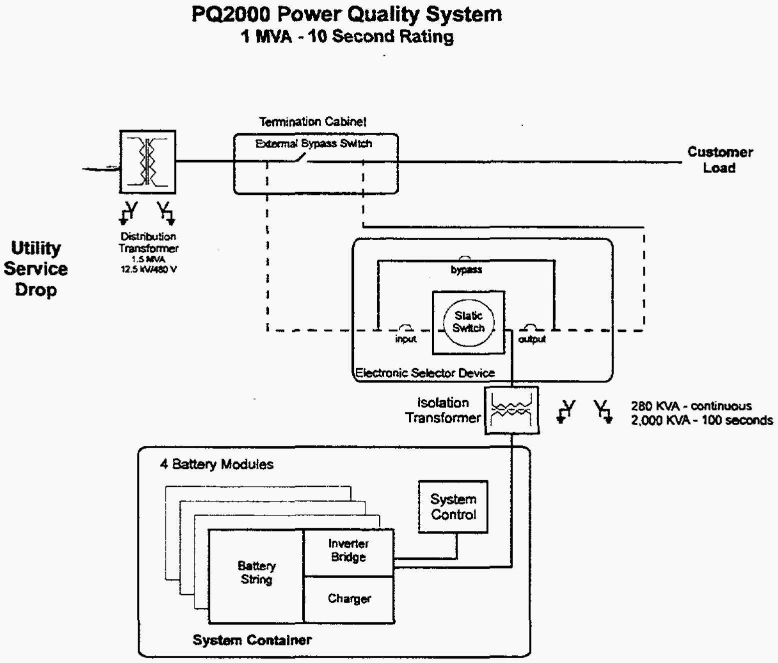

Figure 5-1. Line Diagram of PQ2000 Power Quality System.

The system consists of three pieces of equipment and a utility termination cabinet. The modular containerized equipment is suited for outdoor installation. The system container is capable of housing eight, 250-kVA modular battery strings and its charger and inverter bridge. The main container also houses the system controller. The system container at the Slash Pine site has four battery strings capable of carrying up to 1 MVA of critical load. The site at present has a load of approximately 650 kVA.

The battery modules and associated PCSs are connected to an electronic selector device (ESD) through an isolation transformer. The ESD continuously monitors the utility service and switches to battery power when it detects undesirable distortions in the supply waveform. The transfer occurs within ¼ to ½ Hertz, thus providing seemingly uninterruptible power to the connected loads.

5.4 System Installation and Operation

The system has been in operation since December 1996 and has protected the factory against supply disturbances more than 50 times as of July 1997.

The footprint of the three pieces of equipment combined is ~175 square feet.[17] Including equipment separation spaces, a total of only 400–500 square feet of outdoor space is required for installation. The compact design for the 2-MW/10-second system and the outdoor installation capability lowers the installation cost and provides siting flexibility.[18]

Many power quality systems use the on-line mode, which regenerates the incoming sine wave, to control power quality. In contrast, the PQ2000 uses a line-interactive concept for conditioning the raw utility power and switching to battery power only when the disturbance is acute. Since the PQ2000 system does not continuously regenerate the supply waveform, it does not protect against harmonic distortions. However, line-interactive systems have lower operating costs compared to on-line systems because of their smaller parasitic loads. This becomes a major cost-saving advantage for large systems. The ESD in the PQ2000 system, which continuously monitors the supply voltage, has a continuous loss of ~1% (a parasitic load of 20 kVA). Corresponding on-line systems typically have a continuous loss of ~4%.[19]

After analyzing numerous commercially available systems, a 1-MVA/5-minute, battery-based UPS system was chosen as the closest alternate to the PQ2000. It was assumed that two such systems would be connected in parallel to achieve the 2-MW power rating. When there was a deficiency in data for computing the LCC of this alternative system, relevant data obtained by the Energy Storage Association[20] from other equipment manufacturers were used.

It was found that the alternate system had a lower initial capital cost but had a higher operational and maintenance cost, mainly due to higher parasitic losses in the system. Overall, the LCC of both systems is about the same (when discounting the costs at 10%). Organizations with a lower cost of capital will favor the equipment with the higher capital cost and lower O&M cost: the PQ2000 system, in this case. Similarly, organizations with a higher cost of capital will favor the alternate system which had lower capital cost.

The detailed LCC analysis of the PQ2000 and the competing system are given in the appendix in Tables A5-1 and A5-2. Both LCCs are compared in a summary form in Table 5-1. The notes given below the appendix tables explain the basis on which the numbers were derived and the costs included.

It is apparent from the table that initial capital costs for the PQ2000 system are higher but are compensated by lower electricity costs and cell replacement cost. Overall, the LCC for the two systems are quite similar.

Figure 5-2 illustrates the various components of the discounted LCC of the two systems.

5.5 Discussion

The PQ2000 is an innovative product that received the coveted R&D Magazine's R&D 100 award in 1997. The innovative features include a large power rating, batteries optimized to provide short-duration protection, modularity, outdoor installation, and transportability. It is the first battery-based power quality system designed for providing facility-level protection. Conventional UPS systems tend to be used for equipment-specific power quality protection.

The PQ2000 is an off-line system that maintains line-interactivity through a static switch. The result is that

Table 5-1. Comparison of Discounted LCC Oglethorpe Power Quality Systems

Cost Category	PQ2000	Alternate PW System—UPS
Capital Cost ($K)		
Site Preparation and Installation	34	5
Interconnect Equipment	49	49
Equipment Cost	873	650
Taxes and Permits	67	46
Setup Cost	34	15
Total Initial Cost	1,057	765
O&M: Cost ($K)		
Maintenance Cost	348	341
Insurance and Taxes	73	56
Electricity Cost	127	358
Cell Replacement	50	182
Total O&M Cost Over 20 Years	598	937
Life Cycle Cost ($K)	$1,650	$1,700

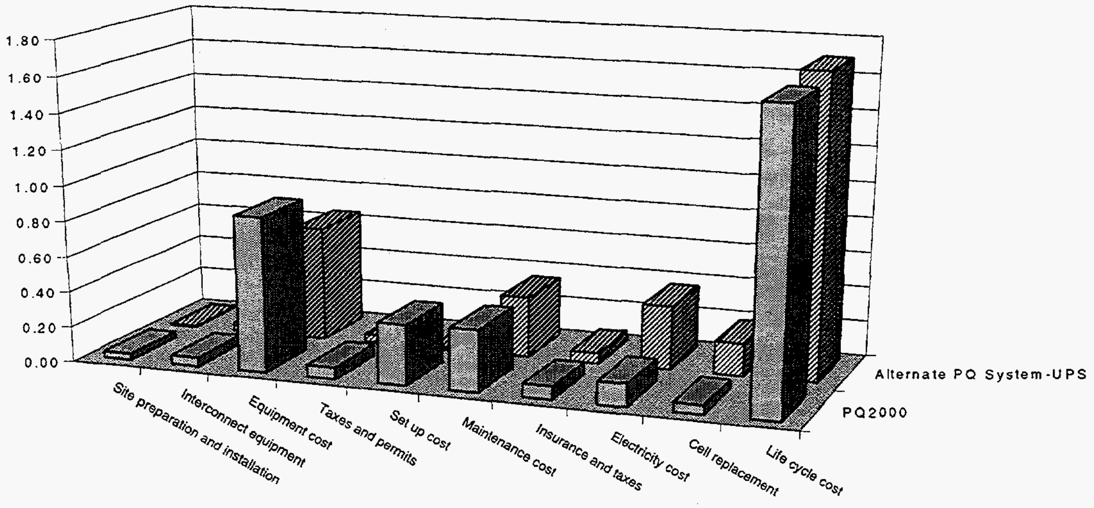

Figure 5-2. Components of Discounted LCC Oglethorpe Power Quality Systems (in $M).

parasitic losses with the PQ2000 are significantly smaller than those with a UPS. The battery replacement cost for the PQ2000 is substantially lower as well. The PQ2000 uses inexpensive lead-acid batteries that are mass-produced for vehicles starting/lighting/ignition applications. In contrast, the alternative UPS system in this study currently uses more expensive VRLA batteries. The set-up costs for the PQ2000 are greater than that of the UPS competition because the system requires a crane and a crew to unpack and mount the equipment. The set-up costs are less for the alternate UPS because the equipment comes in smaller containers and the cost of a crane and a crew to install the system is not incurred.

Battery life is assumed to be 5 years for both operations. However, this has not yet been demonstrated. Shorter battery life will have an adverse impact on the LCC of both systems, with the impact being more severe for the UPS system. A four-year battery life results in LCCs of $1.68M and $1.79M for the PQ2000 and the UPS alternative, respectively.

Omnion Power Engineering Corporation, the successor of AC Battery, reviewed a draft of this LCC analysis of the PQ2000 system. Comments suggest that both capital and operating costs have dropped significantly when compared to the Oglethorpe system. Such price decreases are to be expected in a new technology as the developer improves the efficiency of manufacturing. LCC of a similar system today is expected to be approximately $1.3M as opposed to about $1.65M shown in Table 5-1. The economic attractiveness of the PQ2000 unit clearly improves as its capital cost is decreased.

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6. Impact of Future Cost Reductions

A previous report[21] analyzed the capital cost of the four BESSs considered here. That analysis also surveyed the BESS vendors regarding the cost reduction potential on similar BESSs. Table 6-1 shows current and projected capital costs for the four BESSs. The table also shows the impact of achieving the projected cost reduction on the LCC.

As expected, capital cost reductions do have a favorable impact on the LCC of BESSs and enhances their competitive position. Table 6-1 assumes that no capital cost reduction will occur with the competitive technologies. This assumption is predicated on the fact that the competitive options are generally mature technologies and further cost reduction will be incremental and negligible. The lead-acid batteries in the BESS are a mature technology as well and further cost reductions will be modest. However, optimization of the PCSs in BESSs, as well as improving systems integration, will likely play an important role in the anticipated cost reduction of BESSs.

Table 6-1. Comparison of Current and Projected Costs for BESS Technologies and Competitive Options (in $M)

System	Current Capital Cost	Projected Capital Cost[22]	Current LCC	Projected LCC[23]	LCC of Competitive Option
PREPA	21.40	18.19	25.2	21.99	29.5
MP&L	1.89	1.61	3.44	3.16	4.30
Vernon	4.25	3.61	6.34	5.70	6.20
Oglethorpe	1.06	0.85	1.65	1.44	1.70

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7. Conclusions

The two BESS projects installed by PREPA and MP&L on the supply-side to improve dynamic operating benefits have unique attributes, namely:

1. Isolated, island utilities with high fuel oil prices, which are two to three times the national average.

2. Combustion turbines and diesel generators that are operated inefficiently under partial loads, thus increasing expensive fuel consumption.

There are other sites in the U.S. and elsewhere in the world that have the same characteristics. BESSs at current costs enjoy a competitive advantage for such applications. These applications represent a high value-added but a somewhat limited market. Utility-scale battery energy storage is an emerging technology and system vendors must rely on these high value-added niche markets to achieve system cost reductions that will enable them to supply cost-competitive systems to the potentially large markets throughout the electric utility industry.

The two other battery energy storage projects help customers solve power quality problems. The power quality issue has become increasingly important in recent years. Several estimates[24] indicate that productivity losses nationally due to power quality problems are enormous. This analysis shows that for the two applications considered, the BESSs are competitive with commercially available alternatives. The LCC estimates are based on current costs of BESSs. As BESS costs are reduced with time, its competitive position will improve.

Operational experiences with the four BESSs vary from several months to a few years. Projections of O&M costs based on such limited data are difficult. Vendor interviews have been used to obtain actual O&M costs. The cost data on the competing technologies considered for the two power quality applications were also developed on the basis of vendor estimates. Clearly the LCC estimates will change if the O&M costs deviate substantially from those considered here.

As expected, capital cost reductions do have a favorable impact on the LCC of BESSs and enhances their competitive position.

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8. Endnotes

1. Robert Brown and Rudolph Yanuck, *Life Cycle Costing: Practical Guide to Energy Managers.* The Fairmont Press, Atlanta, GA, 1980.
2. Fabrycky Wolter, *Life Cycle Cost and Economic Analysis.* Prentice Hall International Series, 1991.
3. Sydney Reiter, *The Financial Evaluation of Energy Costs and Projects.* Van Nostrand Reinhold Company, New York, 1985.
4. Paul Butler, *Battery Energy Storage for Utility Applications: Phase 1 - Opportunities Analysis.* Sandia National Laboratories, SAND 94-2605, UC-212, October 1994.
5. Information provided by discussions with PREPA Generating Planning Division.
6. W. Torres, Economic Benefits of the PREPA 20 MW Battery Energy Storage Facility in *Proceedings of the Fifth International Conference on Batteries for Utility Energy Storage.* San Juan, Puerto Rico, July 1995.
7. Due to the need for extensive piling at site, the original project cost of $130M was revised to $160M. Without the need for piling the per-unit cost would have been $540/kW. Piling, or shoring up the concrete pad, was necessary because the ground was unsteady and needed additional underground support.
8. Department of Energy/Energy Information Administration, *Cost and Quality of Fuels for Electric Utility Plants 1996.* DOE/EIA-0191(96), July 1997.
9. Nicolas Miller, et al., A VRLA Battery Energy Storage System for Metlakatla, Alaska, in *Proceedings of the Energy Storage Association November 1996 Meeting.* Amelia Island, FL, May 1997.
10. Demarest et al., Battery storage all but eliminates diesel generator. *Electrical World,* June 1997.
11. George Hunt, Battery Energy Storage Systems for Metlakatla, Alaska, in *Proceedings of the Energy Storage Association Spring 1997 Meeting.* Washington, D.C., May 1997.
12. George Hunt, Design and Commissioning of VRLA Battery Energy Storage Systems for Backing-up Critical Environmental Loads in *Proceedings of the Fifth European Battery Conference.* Barcelona, Spain, September 1996.
13. Information provided by MP&L.
14. Data provided by MP&L.
15. Information provided by MP&L.
16. Power quality workshop sponsored by Oglethorpe Power and Electric Power Research Institute, *Industry Power Quality Solutions: PQ2000 Demonstration and Field Test.* Amelia Island, FL, November 1996.
17. System container = 7 feet ×16 feet, ESD = 5 feet × 10 feet, Isolation transformer = 4 feet × 4 feet
18. The footprint is comparable to those designed by Liebert Corp., Best Power Technology Inc, and others. However, all of these systems are required to be housed indoors.
19. The comparison was made with UT3220, the 220-kVA on-line system manufactured by Best Power Technology Inc., Necedah, WI. This system has a on-line-mode efficiency of 96% and economy mode (line-interactive mode) efficiency of 97%.
20. Richard Schweinburg of Southern California Edison, Database on Large UPS Systems presentation, and Renewable Energy and Energy Storage: A Partnership That Makes Sense presentation in *Proceedings of Energy Storage Association Meeting,* Washington, D.C., April 30–May 1, 1997.
21. Abbas Akhil, Shiva Swaminathan, and Rajat K. Sen. *Cost Analysis of Energy Storage Systems for Electric Utility Applications.* Sandia National Laboratories, SAND 97-0443, UC-1350, February 1997.
22. Projected capital costs were based on the Cost Analysis of Energy Storage Systems for Electric Utility Applications, which determined that large BESSs would achieve cost reductions of 10–20%. Thus, in this analysis, a rate of 15% cost reduction was used for PREPA, MP&L, and Vernon. The same report projected that BESS power quality systems would achieve cost reductions of 20%. This formula was applied when determining the projected cost reductions for Oglethorpe.
23. The same method for determining projected capital costs was used for determining projected LCC, although O&M costs were assumed to remain constant with only capital costs being reduced by 15% or 20%. (See footnote 24).
24. Power quality workshop sponsored by Oglethorpe Power and Electric Power Research Institute, *Industry Power Quality Solutions: PQ2000 Demonstration and Field Test.* Amelia Island, FL, November 1996.
25. Power quality workshop sponsored by Oglethorpe Power and Electric Power Research Institute, *Industry Power Quality Solutions:*

PQ2000 Demonstration and Field Test. Amelia Island, FL, November 1996.

A

Detailed Life Cycle Costs

Tables

Table A2-1. Life Cycle Cost of the 20-MW/14.1-MWh Battery Energy Storage System at the Puerto Rico Electric Power Authority

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Equipment load interface	672																				
B. Power conversion system	5,713																				
C. Batteries & accessories	4,641																				
D. Monitors & controls	1,244																				
E. Facilities	4,748																				
F. Financing	1,000																				
G. Transportation																					
H. Taxes	891																				
I. Project management	1,877																				
J. Start-up & maintenance	614																				
TOTAL INITIAL COST	21,400																				
O&M COST ($K)																					
Fixed Costs																					
K. Salaries and wages		175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175
L. Transportation & allowance		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
M. Maintenance contracts		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
N. Consumables & supplies		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Variable Costs																					
O. Electricity & water use		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
P. Consumables & supplies		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Q. Battery replacement												3,000									
TOTAL O&M COST		317	317	317	317	317	317	317	317	317	317	3,317	317	317	317	317	317	317	317	317	317
TOTAL COST ($K)		317	317	317	317	317	317	317	317	317	317	3,317	317	317	317	317	317	317	317	317	317
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost ($K)	21,400	288	262	238	217	197	179	163	148	134	122	1,163	101	92	83	76	69	63	57	52	47
LIFE CYCLE COST ($K)	25,150																				

Table A2-1. Life Cycle Cost of the 20-MW/14/1-MWh Battery Energy Storage System at the Puerto Rico Electric Power Authority (Continued)

NOTES (information provided by PREPA Battery Energy Storage Plant Manager, Rafael Ruiz, and by William Monriog of the PREPA Generating Planning Division)

A. Includes transformer, protection gear, and other interconnect equipment.
B. Includes the rectifier/inverter bridge, AC and DC switchgear.
C. Installed cost of 6,000 cells, racks, watering system, electrolytic agitation system, temperature measurement, etc.
D. Facility monitoring computers, software, and associated equipment.
E. Cost of building and amenities, access road, landscaping.
F. Finance cost during construction.
G. Transportation cost included in individual equipment prices.
H. Taxes.
I. Project management expenses include design, specifications, bid evaluation, construction management, etc.
J. Costs associated with start-up.
K. Salaries and wages of four employees at location: plant manager, electrician, general help, and office assistant working one 8-hour shift, five days per week.
L. Site vehicle maintenance and travel allowances.
M. Includes as needed contracts with GE, C&D, and Max control systems. It also includes switchyard maintenance and waste disposal contracts.
N. Portions of the costs associated with consumable and supplies are variable. Includes replacement of failed cells, battery maintenance, PCS & switchyard maintenance, and office supplies.
O. During standby frequency regulation/voltage control mode of operation passes approximately 1 MWh through the BES daily. Assuming a round-trip efficiency of 70% and electricity cost of $60/MWh, annual cost is ~$7K. Considering 30 times a year plant operates, in rapid discharge mode, recharge electricity consumption and air conditioning loads, and other parasitic loads, the electricity consumption totals ~$10K annually. Battery cells are topped up with demineralized water every six months. Though demineralized water has a commercial value, the BES facility obtains it from PREPA's purchases, and it is not charged to the BES.
P. Portions of the costs associated with consumables and supplies are fixed. Includes replacement of failed cells, battery maintenance, PCS & switchyard maintenance, and office supplies.
Q. The 6,000 cells are warranted for 10 years and are expected to be replaced once in Year 11 at a cost of $500/cell.

Table A2-2. Life Cycle Cost of Oil-Fired Combustion Turbines for Spinning Reserve—Puerto Rico Electric Power Authority

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Capital Cost	3,960																				
TOTAL INITIAL COST	3,960																				
O&M COST ($K)																					
Fixed Costs																					
B. From production cost data		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
($30/MW-week) for 6MW																					
Variable Costs																					
C. Fuel cost		2,800	2,828	2,856	2,885	2,913	2,943	2,972	3,002	3,032	3,062	3,093	3,124	3,155	3,187	3,219	3,251	3,283	3,316	3,349	3,383
TOTAL O&M COST		2,810	2,838	2,866	2,895	2,924	2,953	2,982	3,012	3,042	3,072	3,103	3,134	3,165	3,197	3,229	3,261	3,293	3,326	3,359	3,393
TOTAL COST ($K)		2,810	2,838	2,866	2,895	2,924	2,953	2,982	3,012	3,042	3,072	3,103	3,134	3,165	3,197	3,229	3,261	3,293	3,326	3,359	3,393
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted total cost ($K)	3,960	2,555	2,345	2,153	1,977	1,815	1,667	1,530	1,405	1,290	1,185	1,088	999	917	842	773	710	652	598	549	504
LIFE CYCLE COST ($K)	29,514																				

NOTES (information provided by PREPA Battery Energy Storage Plant Manager, Rafael Ruiz, and by William Monriog of the PREPA Generating Planning Division)

A. Battery Energy Storage cannot continuously supply power indefinitely because of its limited energy supply capability. However, 20 MW of battery energy storage capacity is better able to provide 20 MW of spinning reserve capacity than 20 MW of combustion turbines due to the fast response of the BESS. Thus, the presence of the 20-MW BESS diminishes the need to build spinning reserve generation. Because the BESS cannot carry 20-MW loads indefinitely, a partial, 30%-capacity credit will be assigned to the BESS plant. A cost of approximately $3.9M may be avoided assuming 6 MW of $660/kW gas-turbine generation capacity can be eliminated with use of the BES.

B. Obtained from production costing model for the 83-MW turbine.

C. The 83-MW plant is expected to operate at 36% annual plant factor, generating 262 GWh of electricity a year. Operating at 60% of full load, the plant produces this energy at a heat rate of 13,300 Btu/kWh. If the plant were able to produce that energy with 10,200 Btu/kWh (full load heat rate), the annual cost saving is $4.6M. Prorating, (since the 60% of full load operation of the 83-MW plant is able to provide 33 MW of spinning reserve), the final cost saving with operation of the 20-MW battery is $2.8M. Assuming fuel costs increase by 1% per annum in real terms, the fuel cost saving discounted over 20 years is $25.5M.

Table A3-1. Life Cycle Cost of the Battery Energy Storage System at Metlakatla Power & Light

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Batteries & installation	570																				
B. Power conditioning system	361																				
C. System monitoring/control	209																				
D. Filters	171																				
E. Engineering services	323																				
F. Transportation & taxes	50																				
G. Facilities	209																				
TOTAL INITIAL COST	1,893																				
O&M COST ($K)																					
Fixed Costs																					
H. Salaries & consumables		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Variable Cost																					
I. Battery replacement cost									400								400				
J. Equip & software maint:		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
TOTAL O&M COST		150	150	150	150	150	150	150	550	150	150	150	150	150	150	150	550	150	150	150	150
TOTAL COST ($K)		150	150	150	150	150	150	150	550	150	150	150	150	150	150	150	550	150	150	150	150
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	1,893	136	124	113	102	93	85	77	257	64	58	53	48	43	39	36	120	30	27	25	22
LIFE CYCLE COST ($K)	3,444																				

NOTES (information provided by GNB Technologies, George Hunt)

A. Includes racking, fuses, etc.
B. Includes isolation transformers, fuses, CTs, PT, etc.
C. Station control, battery monitoring, outloop control, data acquisition, etc.
D. Filters and HV end of switchyard: capacitors, fuse contactors.
E. Project Management, systems study and design, site construction management.
F. Transportation of batteries to site. No taxes incurred.
G. Foundation, building, HVAC, lighting, auxiliary equipment.
H. Installation capable of remote operation. An annual cost of ~50K/year is estimated.
I. Batteries are expected to be replaced after 8 years.
J. Maintenance of the equipment, facility, and software.

Table A3-2. Life Cycle Cost of Operating Diesel Generators for Load Following at Metlakatla Power & Light

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Sunk Cost	-																				
TOTAL INITIAL COST	-																				
O&M COST ($K)																					
Fixed Costs																					
B. Overhauls–Spinning Mode		230	-	-	370	-	-	230	-	-	370	-	-	230	-	-	370	-	-	230	-
–Standby Mode																					
Variable Cost																					
C. Savings of diesel fuel cost		350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
D. Other O&M cost		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
TOTAL O&M COST		630	400	400	770	400	400	630	400	400	770	400	400	630	400	400	770	400	400	630	400
TOTAL COST ($K)	-	630	400	400	770	400	400	630	400	400	770	400	400	630	400	400	770	400	400	630	400
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	-	573	331	301	526	248	226	323	187	170	297	140	127	182	105	96	168	79	72	103	59
LIFE CYCLE COST ($K)	4,312																				

NOTES (information provided by MP&L, Dutch Achenbach)

A. The 3-MW diesel is already in place and operating.

B. The diesel units require minor overhauls every 20,000 hours of operation and major overhauls every 40,000 hours. Major and minor overhauls cost ~$370K and ~$230K, respectively.

C. It is estimated that @$0.78/gallon, 450,000 gallons of diesel fuel could be saved.

D. It is estimated that all other O&M cost savings associated with the operation of the diesel is ~$50K p.a.

Table A4-1. Life Cycle Cost of the Battery Energy Storage System at the GNB Technologies Vernon Lead Smelting Facility

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Batteries & accessories	1,375																				
B. Power conversion/controls	825																				
C. Balance of Plant	1,500																				
D. Transportation & packing	195																				
E. Taxes	350																				
TOTAL INITIAL COST	4,245																				
O&M COST ($K)																					
Fixed Costs																					
F. Salaries & consumables		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Variable Cost																					
G. Battery replacement cost									1,200								1,200				
H. Equipment and facility maint:		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
TOTAL O&M COST		150	150	150	150	150	150	150	1,350	150	150	150	150	150	150	150	1,350	150	150	150	150
TOTAL COST ($K)		150	150	150	150	150	150	150	1,350	150	150	150	150	150	150	150	1,350	150	150	150	150
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	4,245	136	124	113	102	93	85	77	630	64	58	53	48	43	39	36	294	30	27	25	22
LIFE CYCLE COST ($K)	6,343																				

NOTES (information provided GNB Technologies, George Hunt)
A. Battery installation, racking, monitoring, etc.
B. Power conversion system and control systems.
C. Butler building, foundation, facility equipment, project management, etc.
D. Factory to site transport and packaging.
E. Taxes: state, municipal.
F. The BES facility is not staffed and requires only periodic maintenance, estimated to cost not more than ~50K per annum.
G. Battery expected to be replaced in Years 8 and 16.
H. Estimated equipment and facility maintenance cost.

Table A4-2. Life Cycle Cost of Diesel Standby Generator with Induction Coupling for Power Quality Applications for Vernon Lead Smelting Facility

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Equipment cost	2,500																				
B. Step-up transformer	2,000																				
TOTAL INITIAL COST	4,500																				
O&M COST ($K)																					
Fixed Costs																					
C. Parasitic electricity charges	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
D. Maintenance contracts	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Variable Cost																					
TOTAL O&M COST		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
TOTAL COST ($K)		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	4,500	182	165	150	137	124	113	103	93	85	77	70	64	58	53	48	44	40	36	33	30
LIFE CYCLE COST ($K)	6,203																				

NOTES (information provided by Holec Power Protection, Robert Hall)

A. Containerized equipment to cost $1.25M each for the 1.6 MVA units. Uncontainerized will cost ~$1M.

B. The step-up transformer to step up the voltage from 480 V to 4,160 V at the substation serving the facility.

C. Constant parasitic load of 200 kVA for a year at an electricity cost 5 cents/kWh is ~$100K p.a.

D. Maintenance contract to maintain two 1.6-MVA units is ~$100K p.a.

Table A5-1. Life Cycle Cost of Oglethorpe Power's PQ2000 Power Quality Battery Energy Storage System

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
<u>CAPITAL COST ($K)</u>																					
A. Site Preparation & Install:	34																				
B. Interconnect Equipment	49																				
C. Equipment Cost	873																				
D. Taxes & Permits	67																				
E. Set-up Cost	34																				
TOTAL INITIAL COST	1,057																				
<u>O&M COST ($K)</u>																					
<u>Fixed Costs</u>																					
F. Maintenance Cost		41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
G. Insurance & Taxes		10	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5
<u>Variable Cost</u>																					
H. Electricity Cost		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
I. Cell Replacement						38					38					38					
TOTAL O&M COST		66	66	66	66	104	66	66	66	66	104	61	61	61	61	99	61	61	61	61	61
TOTAL COST ($K)		66	66	66	66	104	66	66	66	66	104	61	61	61	61	99	61	61	61	61	61
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	1,057	60	55	50	45	65	37	34	31	28	40	21	19	18	16	24	13	12	11	10	9
LIFE CYCLE COST ($K)	1,655																				

Table AS-1. Life Cycle Cost of Oglethorpe Power's PQ2000 Power Quality Battery Energy Storage System (Continued)

NOTES (information provided by AC Battery, William Nerbun, and by Omnion, Brad Roberts)

A. Estimate made by AC Battery Corp. Includes cost associated with grounding grid, concrete pad, cable ways, and fencing.
B. Estimate made by AC Battery Corp. Includes cable, current and potential transformer, safety eyewash, shower, and monitor station.
C. Delivered cost of equipment, estimated by AC Battery Corp.
D. Estimated to be 7% of equipment and installation cost by AC Battery.
E. Estimated cost for crane and crew to unpack and mount equipment, training, and connection of equipment.
F. AC Battery estimates customers to incur $7K/year for in-house maintenance and a $34K/year extended warranty charge.
G. Estimated to be 1% of initial equipment cost for the first 10 years and 0.5% of equipment cost in the last 10 years.
H. Continuous power loss of 20 kVA in the electronic selector device @ 6 cents/kWh = $10.5K/year. Corresponding air-conditioning load $3K/year. HVAC cost additional $1.5K/year.
I. Battery replacement cost of $38K every five years.

Table A5-2. Life Cycle Cost of UPS Power Quality System for Oglethorpe

Year of Operation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CAPITAL COST ($K)																					
A. Site Preparation & Install:	5																				
B. Interconnect Equipment	49																				
C. Equipment Cost	650																				
D. Taxes & Permits	46																				
E. Set-up Cost	15																				
TOTAL INITIAL COST	765																				
O&M COST ($K)																					
Fixed Costs																					
F. Maintenance Cost		115	15	15	15	115	15	15	15	15	115	15	15	15	15	115	15	15	15	15	15
G. Insurance & Taxes		7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Variable Cost																					
H. Electricity Cost		42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
I. Cell Replacement						150					150					150					
TOTAL O&M COST		165	64	64	64	315	64	64	64	64	315	60	60	60	60	310	60	60	60	60	60
TOTAL COST ($K)		165	64	64	64	315	64	64	64	64	315	60	60	60	60	310	60	60	60	60	60
Discount Rate	10%																				
Discount Factor	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15
Discounted Total Cost	765	150	53	48	44	195	36	33	30	27	123	21	19	17	16	75	13	12	11	10	9
LIFE CYCLE COST ($K)	1,704																				

Table AS-2. Life Cycle Cost of UPS Power Quality System for Oglethorpe (Continued)

NOTES (information provided by Best Power, Chris Loeffler)

A. It is assumed that the power quality system will be installed indoors in an existing building. Thus, the cost in this category is minimal. The opportunity cost of the space occupied is considered under maintenance cost. It is estimated that additional wiring and grounding will cost $5K.

B. This estimate is identical to that made by AC Battery. Most of the power quality suppliers require local contractors to carry out installation.

C. Delivered cost of two 5-minute, 1-MVA systems was estimated to cost $300K. Paralleling equipment to cost ~50K.

D. Estimated to be 7% of equipment cost—identical to the AC Battery estimate.

E. Visit by a service person from equipment supplier for training & start-up. Because equipment comes in smaller containers, cost of crane and crew required for PQ2000 is not needed.

F. Preventive maintenance contract cost for a 220-kVA, 5-minute system was obtained. Nine such systems can be connected to achieve 2-MW capacity. The preventive maintenance contracts for a 220-kVA system is $16K (for 5 years) for the PCS, and $6.5K (for 5 years) for the batteries. Assuming a volume discount of 25% for the nine systems, the 5-year maintenance contract cost for the complete system is ~$145K. In-house maintenance cost is estimated to be ~$10K/year. In addition, the opportunity cost of occupying 500 square feet of indoor space is assumed to be $5K/year.

G. Estimated to be 1% of initial equipment cost for the first 10 years and 0.5% of equipment cost in the last 10 years.

H. A constant parasitic loss of 4% of equipment rating is experienced by on-line systems but is lowered to 3% under economy mode of operation (line- interactive). The parasitic loss of this system is assumed to be three times that of the PQ2000 system. This loss of 60 kVA at 6 cents/kWh h amounts to an cost of $31.5K/yr. The corresponding air-conditioning loads to cool equipment is $0K/year.

I. Battery replacement cost of $150K for a 2-MW, 5-minute battery. Battery expected to be replaced every 5 years.

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