Alaska Energy Authority
Regulation Resource Study
Technology Recommendation and Cost Estimates

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Summary of Changes

Revision	Revision Date	Revision Description
0	August 6, 2012	Initial Rough Draft
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Executive Summary

The intent of this phase of the study is to provide a recommendation on the technology and develop a budgetary cost estimate of regulation technology for the Railbelt. The selected regulation resource should enable the electrical system to accept more renewable energy by alleviating the gas constraints on utility generation that are currently prohibiting its development and secondarily provide contingency reserves for loss of generation or transmission resources in the Railbelt.

The study evaluated the impact of the single transmission line from the Kenai and the changing generation characteristics of the Railbelt. These factors were included in the selection and sizing of the regulation resources evaluated in the study.

Due to both gas and electrical system constraints faced by the Railbelt utilities, the ability to regulate an intermittent resource such as wind generation is limited. In order to deal with these system constraints a regulation resource that could use energy storage to regulate an intermittent wind resource is required prior to developing a renewable energy portfolio for the Railbelt.

The changing generation technology of the Railbelt has a dramatic impact on the regulation capability of the Railbelt. As the Railbelt utilities move towards smaller, more efficient units that more closely matches their capacity requirements, the chances of having "excess" regulation capability on the system to respond to unexpected events decreases dramatically. Even if sufficient gas supplies were available, operating capacity to respond to unexpected changes in non-dispatchable renewable energy or the loss of the Anchorage – Kenai Intertie will be minimal. Consequently, flexible regulation resources must be developed to allow additional renewables to be incorporated into the system, protect against sudden loss of generation or transmission resources, and to optimize the use of the new generation of high-efficiency gas generation.

This study evaluated three major technologies and their applicability in the Railbelt. These three technologies were: Battery Energy Storage Systems (BESS), Flywheel or rotating inertia technology, and Flexible Gas Storage (FGS). The selected technologies would augment the regulation capability of the Railbelt hydro resources and be used in conjunction with other regulation capabilities of the Railbelt.

The criteria used for the regulation evaluation were that no single event should result in the loss of load in the Railbelt and that the regulation system must work with any single regulation resource out of service or unavailable. For example, if the Kenai intertie was out service and hydro regulation was unavailable or if hydro was not scheduled for generation, the remaining regulation resources in the Southcentral Railbelt must be capable of providing the required regulation.

The driving force for determining the regulation requirement in the existing system is the loss of the single Anchorage – Kenai Intertie under maximum import conditions. Following the retirement of the large gas turbines, this contingency will be the largest resource loss for the Southcentral area.

The regulation requirements of the Railbelt are divided into short-term regulation requirements caused by variations in load and variable generation and long-term regulation required by sustained wind ramp events, loss of transmission interconnections, or the loss of a generation unit. The long-term regulation requirements exceed the capabilities of flywheel technology, consequently, this technology was dropped from consideration.

BESS and FGS technologies are ideally suited for the Railbelt and can be used in complimentary fashions to provide the optimum system performance. During normal operation, regulation would be provided by a combination of BESS, FGS and hydro resources. The system is capable of providing the required regulation following the loss of any one regulation resource. By utilizing complimentary regulation resources, the costs and sizes of each resource can be optimized to meet the Railbelt needs.

The BESS was sized to be the primary resource for short-term variable energy deviations from renewable projects such as wind or solar or from the instantaneous loss of generation. The goal for sizing the BESS was to provide regulation such that that the reliability of the Railbelt would be maintained at approximately its current levels following the addition of variable generation to the grid. The target is to provide enough regulation energy such that on average only twelve events which exceed the regulation capabilities of the BESS are expected during an average year.

The requirements for FGS were developed to enable the Southcentral utilities sufficient storage at gas generation plants to provide fuel for thermal regulation following the loss of the largest contingency (Anchorage-Kenai Intertie). The thermal regulation capacity must be capable of allowing the utilities to schedule gas from in-ground storage at the next scheduling interval, estimated at 6 hours.

Based on these criteria, we recommend the utilities use a BESS and on-site gas storage systems to provide the required regulation during both the short-term and long-term events. With the construction of the Beluga – Bernice tie, the BESS should be constructed with a capacity/energy rating of 25 MW/ 14 MWH and the FGS should be constructed to provide 1.91 MCF (262.5 MWh) to cover the small wind farm and the loss of one of the Kenai ties under maximum import conditions. Both the proposed BESS system and the FGS systems can be constructed in blocks either simultaneously or independently. However, construction of the facilities in blocks will increase the total costs over the duration of the project.

If the HVDC line is not constructed, the size of the BESS and FGS will increase significantly. The final size will be determined by the largest expected transfer of the single Kenai – Anchorage Intertie. To maintain reliability equivalent to the HVDC system, the BESS capacity would need to be increased to approximately 100 MW. It is unlikely that this BESS could be economically installed; therefore, lower import or lower reliability measures would need to be adopted. For the larger regulation requirement we recommend the FGS be located at two different locations with thermal generation. Two different locations are recommended to maximize the availability of on-line and off-line regulation resources.

The cost of the recommended alternative is as follows:

Description	Wind Farm Size	Capacity	Energy	Costs
BESS – HVDC	17 MW	25 MW	14 MWh	$26.7 M
FGS – HVDC	17 MW	NA	1.91 MCF (262.5 MWh)	$18.2 M

1 Introduction

The purpose of this report is to provide the results of a regulation resource technology evaluation and a preliminary cost estimate for the recommended alternative. EPS will recommend a regulation technology to provide the best-fit for the regulation application. EPS will then provide the life-cycle costs of different storage technologies based on their ability to meet the regulation needs.

The full breadth of the study includes the evaluation of BESS, FGS and Flywheel technologies in the South-central Railbelt area. Each of these technologies was evaluated independently and in combination with each other in order to provide the optimum solution for the Railbelt utilities.

The primary goal of the regulation resource is to provide the Railbelt utilities the ability provide regulation capability for renewable energy resources in the region that cannot be regulated by the current generation's fuel supply system.

In addition to providing regulation for renewable energy projects, the proposed system's secondary goal is to provide response to the loss of the Anchorage-Kenai intertie which will soon be the largest operating contingency in the Southcentral area. It is assumed that the Railbelt transmission planning study will recommend a second line connecting the Kenai Peninsula with the Southcentral transmission system (the Beluga – Bernice Lake HVDC Intertie). The regulation requirements were studied with and without this second transmission line to determine the impact on the regulation size and technology. However, due to the impact on transfer capability of the second transmission line between the Kenai and Anchorage, this study reduced the maximum import level into Anchorage from 125 MW to 75 MW.

The regulation resource must be capable of relieving the gas constraints placed on the Southcentral utilities by both gas transportation and gas producing entities in providing regulation for both non-dispatchable resources and system contingencies.

The system should be flexible in its response and implementation. No single failure of a regulation resource should result in the lack of regulation capability in the system. The regulation resource must also be designed to not place scheduling requirements on the Railbelt generation, it must be available if no hydro is scheduled to meet system load. The system should also be flexible in terms of its implementation and construction, allowing for modular implementation if budgetary constraints require it.

The regulation technologies to be evaluated are as follows:

- Battery Energy Storage System (BESS) – A BESS consists of large battery systems designed to provide both energy input to the system during generation shortfall and absorb energy during generation excess conditions
- Flexible Gas Storage (FGS) – FGS consists of compressed gas storage facilities located at or near thermal generation resources. FGS can provide stored gas to generation during energy shortfalls or absorb scheduled gas during excess energy production.
- Flywheel Technology – Flywheel technology consists of using the inertia of a rotating mass to provide or absorb energy stored in the rotating mass to the power system. Earlier flywheels were directly connected to the power system and their discharge or absorption was determined by frequency fluctuations of the power system. Modern inertia systems are connected by an inverter system, allowing the characteristics of the flywheel to be manipulated by the inverter controller.

2 Regulation Resources

As this study is highly sensitive to initial assumptions, it is important that the various project assumptions be understood when evaluating the results of the study. The following sections highlight the major assumptions used in the study, along with the expected impact of the assumptions. In order to determine the energy and power requirements provided by the proposed storage devices, the current and expected future regulation capabilities must be defined. EPS assumed the following regulation capabilities for the various Railbelt resources:

- 2015 Cases:
  - Natural Gas Turbines
    - Due to gas scheduling constraints, the Railbelt natural gas turbines will provide no regulation power or energy other than the requirements to meet the scheduled load ramp (absent the installation of flexible gas storage).
    - The gas turbines are set on a six-hour schedule that should not be revised except for emergency conditions. If the severe wind ramp events occur as infrequently as a couple of times per year, then the capability of changing the gas schedules at the hour will be analyzed as it pertains to the storage capabilities. However, excursions greater than one time per month (one average) must be compensated by other means.
  - Hydro Turbines
    - The hydro turbines at Cooper and Eklutna will provide no regulation power or energy during the hour.
    - The hydro resource schedules will be fully dispatchable at the hour from the maximum to minimum capabilities of the units. This will result in "ponding" water during those times when wind is available and hydro is scheduled, but is being displaced by wind energy.
    - The hydro resources may not be scheduled 24 hours/day for energy delivery to the utilities.
  - Wind Turbines
    - The study will assume no capability to forecast wind power output or ramps other than utilizing the same day patterns to predict the next few hours. This will provide a solution that will be capable of responding to the most likely, unconstrained wind changes.
    - Self-regulation by feathering the wind turbine blades will be evaluated as part of the storage solutions.
    - Both large and small wind farm sizes will be evaluated. EPS has projected wind power outputs for both wind farm sizes.
    - It is assumed that the northern Railbelt system will provide the regulation for the wind generation at Eva Creek. Additionally, since there is only one tie to the northern system, the two areas must be able to be operated so as to not impact the other, or in the extreme case, operated islanded from each other.
- 2025 Cases:

- Watana Hydro Addition
    - The proposed Watana hydro plant will not provide any sub-hour regulation power or energy during the hour due to downstream flow restrictions.
- Time Frames:
  - Since the utilities must account for all wind variations in order to maintain frequency stability, the required power and energy will be analyzed for several different time frames including 20, 30, and 60 minutes for electrical energy requirements and up to six hours for the flexible gas storage options.
  - Since the hydro resource schedules are able to change at the hour, the 60-minute time frame will take precedence over the other time frames, however, it is recognized that the majority of hydro resources are only available through a single contingency transmission line unless the Beluga-Bernice Lake HVDC line is constructed and that hydro resources are not typically scheduled 24-hours/day. In addition to the regulation requirements, the capacity and energy requirements for the loss of the largest intertie and largest unit will be evaluated.
  - The installation of a second Anchorage – Kenai transmission line will reduce the maximum capacity lost in the Anchorage area to 30 MW for the loss of the existing Anchorage – Kenai Intertie.
- Criteria
  - Due to the critical nature of the regulation requirements, the regulation system must be capable of operation during the loss of any single regulation source, i.e. loss of stored energy, loss of hydro, loss of gas storage. The system will not be required to operate during an N-2 condition.

3 Available Energy Storage Technologies

This section gives a basic summary of the battery and flywheel technologies that are currently available. The applicability for each technology for use as a regulation resource is determined. For each technology that is deemed applicable, an economic analysis will be performed to determine the lowest-cost option for the Railbelt regulation resource.

3.1 Lead-Acid

The lead-acid battery is the most mature battery technology with well over 100 years of service. Currently, there are three types of lead-acid batteries. The first of which is the flooded cell lead-acid battery. This technology is the most common form of the lead-acid battery. This technology uses lead/ lead alloy plates that will react with a sulfuric acid electrolyte to produce the movement of charge.

The flooded cell lead-acid battery has the advantage of being the lowest cost battery option with excellent shelf life, and good efficiency. The main problems with the flooded cell lead-acid battery are the numerous environmental concerns and the low cycle-life (only a couple hundred cycles for deep discharges). Since the regulation application will require thousands of cycles per year, the flooded cell lead-acid battery should not be considered for a regulation application.

The second type of lead-acid battery is the valve regulated lead-acid battery (VRLA). The VRLA battery was designed to reduce some of the maintenance concerns with the flooded cell lead-acid battery. Unfortunately, the changes required to reduce the maintenance needs further reduced the cycle-life of the battery, as such, should not be considered for a regulation application.

The third type of lead-acid battery is the advanced lead-acid. Due to continuing research into the lead-acid technology, some breakthroughs in the electrode materials have resulted in drastically improved battery cycle-life. With the cycle-life improvement, the advanced lead-acid batteries could be a potential solution for providing regulation services for the intermittent wind resource and should be further investigated, and included in the economic analysis. The two main competing companies using advanced lead-acid batteries are Axion Power and Xtreme Power. The Xtreme Power dynamic power resource (DPR) has been used in conjunction with several wind farm applications in Hawaii, and has recently been proposed as the battery technology to provide 36 MW, 24 MWh in conjunction with a large wind farm in Texas. This Texas installation represents one of the largest battery installations in the world, and is on the same scale as would be required for a Railbelt regulation resource. At a much smaller scale, Axion Power has recently connected to the PJM regulation market. This connection is significant in that it is also a regulation application that requires many charge/discharge cycles. The advanced lead-acid battery is recommended for further consideration as an option for the Railbelt regulation resource.

3.2 Nickel-Cadmium

The nickel-cadmium battery technology is the most common nickel-electrode battery in the utility industry. The nickel-cadmium battery is a favored alternative to the traditional lead-acid batteries due to the advantages of 1) greater depth of discharge, 2) greater tolerance of extreme temperature variation, 3) greater tolerance to over/under charging, and 4) lower maintenance requirements. This battery technology does have some setbacks that include 1) lower efficiency than lead-acid and, 2) environmental concerns due to the cadmium.

Although the nickel-cadmium battery is superior to the traditional lead-acid battery in performance, it does have a higher rate of self-discharge and requires continuous charge maintenance. The Railbelt system has experience with a nickel-cadmium battery system since the GVEA BESS uses the nickel-cadmium technology. The GVEA BESS was designed for VAr support, spinning reserve, and power system stabilization, but it was not designed for regulation. Due to the relatively limited cycle-life of nickel-cadmium batteries and the maturation of the nickel metal hydride battery, this technology should not be considered for a regulation application.

3.3 Nickel Metal Hydride

The Nickel Metal Hydride battery (NiMH) has basically displaced the nickel-cadmium battery since it has better energy density, better cycle-life, and no heavy metals (fewer environmental concerns). This battery technology was used in the early Toyota Prius Hybrid vehicles (the newest plug-in model uses lithium-ion). Due to the use in the plug-in hybrid vehicle market, these batteries are among the most field-tested solutions. The NiMH battery technology does not have the same discharge capabilities that a Ni-Cd battery has. Hence, NiMH batteries are used more often for low-current applications such as portable computers and cell phones, while the Ni-Cd batteries are used for high current applications such as portable power tools [2]. The Ni-MH batteries have slightly worse charge retention than their Ni-Cd counterparts and would require continuous charge maintenance.

Currently, there are no large format NiMH batteries. Large format NiMH cells would be better suited to a large-scale stationary battery system for utility use. The NiMH battery has largely been replaced by the lithium-ion technologies in consumer electronics, and does not have the same level of investment that it once had. Due to these factors, the Nickel Metal Hydride battery would not be a good selection for the Railbelt regulation application.

3.4 Lithium-Ion

The lithium-ion battery technology has rapidly taken over the consumer electronics industry due to its energy density advantage over the nickel metal hydride battery technology. This battery technology comes in several flavors based on the specific chemistry of the cathode. The different types include lithium-ion cobalt, lithium-ion manganese, lithium-ion phosphate, and lithium-ion titanate. The different chemistries offer differing specific power (charge/discharge rate), safety characteristics, and cycle-life [1].

The Chevrolet Volt and the newest Toyota Prius vehicles use lithium-ion battery packs. The selection of the lithium-ion technology for the transportation sector suggests that the regulation market might be an acceptable utility application for this technology since the frequent battery usage associated with a hybrid vehicle is similar usage that would be seen in utility regulation applications. Additionally, the new manufacturing capacity required by the electric vehicle industry will have a price reduction effect due to economies of scale.

The lithium-ion batteries have several desirable characteristics such as long-cycle lives, good energy density, and high power density. The lithium-ion batteries, however, are more expensive than many of the competing battery technologies, but due to their superior performance, particularly the excellent cycle-life, this battery technology should be considered for the regulation resource project.

3.5 Sodium-Sulfur

The sodium-sulfur battery is currently the most widely used utility-scale battery technology. It has been heavily used in Japan by TEPCO (Tokyo Electric Power Company) and is produced by NGK. There are several installations in the United States.

The sodium-sulfur battery must maintain high operating temperatures (> 250°C). As such, the batteries must be heavily insulated to maintain the temperature, and when the batteries are not providing power, must be heated via resistor banks. These batteries are primarily used for uninterruptible power supplies in Japan, but are beginning to see applications such as load shifting and wind smoothing here in the United States.

There was a sodium-sulfur battery fire on September 21, 2011 which has brought some scrutiny toward the battery safety. The cause has not been identified, and the production of these batteries has been put on hold until the safety concerns are resolved.

The sodium-sulfur batteries advantages are that the technology has a high round-trip efficiency. It has good energy density and cycle-life for large discharge depths (>5,000 at 90%), but poor cycle-life for smaller discharge depths (45,000 at 10%). The sodium-sulfur technology is not well-suited to frequent charge/discharge as would be expected with a regulation application. The sodium-sulfur battery technology should not be considered for the Railbelt regulation application.

3.6 Vanadium-Redox

The Vanadium-redox battery is a flow type battery. Flow batteries store their energy in liquid electrolytes, and pump the liquid to a fuel cell where the electro-chemical reactions occur. The vanadium-redox battery basically stores the energy in different ionic forms of vanadium. One of the advantages of this flow battery system is that the energy capacity (MWh) and the power capability (MW) can be sized separately based on the application. For example, if more energy is needed, simply adding electrolyte storage tanks will increase the battery energy. This is a desirable attribute for matching a vanadium-redox battery to an application that may require additional capacity at a later date.

The vanadium-redox battery technology is being developed by Prudent Energy. This battery technology is currently being tested at the University of Alaska Fairbanks. The vanadium-redox battery has decent AC-to-AC efficiency of 70% to 75%, good cycle-life, and good reliability. The vanadium-redox battery has some disadvantages such as have high cost, low energy density, and a limited number of installations in the field. The vanadium-redox battery technology is better suited to applications requiring several hours of stored energy such as peak shaving or energy arbitrage. Due to these disadvantages, the vanadium-redox battery is not recommended for the Railbelt regulation application.

3.7 Zinc-Bromine

The zinc-bromine battery is also a flow type battery. This technology has a significant promise, but has very limited field applications. During charging, metallic zinc is plated from the electrolyte onto the negative electrode and bromide is converted to bromine at the positive electrode. During discharge, the metallic zinc dissolves into the electrolyte.

The zinc-bromine technology has several advantages over the vanadium-redox battery. Zinc-bromine batteries have better energy density, lower cost, and fewer environmental concerns since zinc-bromine technology uses less toxic materials. However, the zinc-bromine batteries do not have independent sizing like the vanadium-redox battery. Also, the power capacity of the zinc-bromine battery is low which limits the charge/discharge rate.

The zinc-bromine battery technology is being developed and manufactured by ZBB Energy Corp. and Premium Power Corp. ZBB Energy has more utility scale projects online, but still has limited experience in the utility sector. Due to the poor power capability of this technology, a 50 MW system would require at least 150 MWh of storage. This would add to the cost of such a system compared to other technologies that could have a 50 MW / 50MWh configuration. Another disadvantage of this battery technology is that the battery maintenance requires “stripping”. Stripping is performed by discharging the battery cell down to zero volts. This will remove all zinc from the negative electrode. This process is performed to increase efficiency, and ensure consistent operation of all battery cells. Due to the poor power capability, the need for ‘stripping”, and the minimal field applications the zinc-bromine technology should not be considered for the regulation application.

3.8 Advanced Flywheels

Flywheels convert the electrical energy from the grid and convert it into rotating kinetic energy. The advanced flywheels spin at high speeds. In order to reduce the frictional losses, these flywheels operate with magnetic bearings in a vacuum. In order to maintain structural integrity at high rotational speeds, these flywheels are made of high-tech composite materials.

These advanced flywheels can charge and discharge without performance degradation which makes them ideally suited to regulation applications. Unfortunately, the advanced flywheel systems are quite expensive. The flywheel technology is primarily used in uninterruptible power supply applications. There are several flywheel manufacturers, but only Beacon Power is marketing towards utility applications. All the other companies are marketing toward uninterruptible power supplies. Beacon Power has a 20MW, 5 MWh flywheel system used for the New York regulation market. This project cost a reported $69 million. The Railbelt regulation application will need at least five times the storage, and that would make the flywheel option too expensive for the hour-long energy needs. Advanced flywheels are not recommended for the Railbelt regulation application.

3.9 Applicable Technologies for Railbelt Regulation Application

The need for near-constant charging and discharging characteristics of a regulation application removes several technologies from consideration based on limited cycle-lives (nickel-cadmium, sodium-sulfur, traditional lead-acid). Limited field experience and high costs also removes some technologies from consideration (vanadium-redox, advanced flywheels). The two technologies that should be further investigated are advanced lead-acid batteries, and lithium-ion battery technology.

4 Preliminary Wind Analysis

4.1 Regulation Resource Power Requirement

4.1.1 52 MW Wind Farm

With the assumption that the regulation resource must provide all the regulation within the hour, the wind data was analyzed to determine the power capacity needed to fully regulate a large wind farm with a capacity of 52 MW. The wind data was provided by Clarity Analytical in a one-minute time series showing wind farm power output. The maximum power required by the regulation resource was determined by the maximum inter-hour power change.

For each minute in the two years of analyzed wind data, the inter-hour maximum and minimum wind power output were found and compared. Using this method, the maximum inter-hour power change for the wind farm was approximately a net of 48.25 MW for the 52 MW wind Farm. Therefore, the estimated wind farm output can almost go from maximum power output to zero within one hour. In order for the regulation resource to prevent the rest of the Railbelt from seeing power fluctuations from the wind farm, the regulation resource, including the option of curtailment must compensate for the full net power of 48 MW. EPS recommends a regulation resource with at least 50 MW power capability in order to fully regulate the wind farm.

4.1.2 17 MW Wind Farm

With the assumption that the regulation resource must provide all the regulation within the hour, the wind data was analyzed to determine the power capacity needed to fully regulate a smaller wind farm with a capacity of 17 MW. The wind data was provided by Clarity Analytical in a one-minute time series showing wind farm power output. The maximum power required by the regulation resource was determined by the maximum inter-hour power change.

For each minute in the two years of analyzed wind data, the inter-hour maximum and minimum wind power outputs were found and compared. Using this method, the maximum inter-hour power change for the wind farm was approximately a net of 17 MW for the 17 MW wind Farm. Therefore, the estimated wind farm output can almost go from maximum power output to zero within one hour. In order for the regulation resource to prevent the rest of the Railbelt from seeing power fluctuations from the wind farm, the regulation resource, including the option of curtailment must compensate for the full net power of 17 MW. EPS recommends a regulation resource with at least 17 MW power capability in order to fully regulate the wind farm.

4.2 One Hour Regulation Resource Energy Requirement

4.2.1 52 MW Wind Farm

One way of determining the regulation energy requirement was based on the worst case one-hour need. This need is based on the upward regulation requirement to compensate for the wind output. The worst case scenario is the one-hour interval that represents the maximum amount of regulation energy that the utilities must provide for in the regulation scenario. Conditions where the wind turbines are operating near cut-out or are experiencing severe fluctuations are assumed to be curtailed by the operating utility.

The wind was analyzed for each year of data available. For each minute of wind data, the change in wind output was integrated over a one-hour time period to provide the necessary energy for that hour. The worst-case hour would require 36 MWh from the regulation resource. Sizing the regulation resource to provide for the worst case scenario would result in an expensive, over-sized regulation resource. A simple control method was developed in an attempt to minimize the battery energy sizing using two years' worth of wind data. This method and its results are described in the next few paragraphs.

First, the worst-case hourly regulation requirement based on the initial wind power was calculated from the two years' worth of wind data. This worst case regulation was calculated using a very simple method. The next hour wind schedule was set to the value of the wind plant at the beginning of the hour. Any downward movement in the wind would be balanced out by the regulation resource such that the net power out of the wind farm plus the regulation resource would stay flat for the entire hour. The worst case energy requirement was tabulated for each 2 MW range of wind starting power. The resulting energy need was calculated and put on a graph to visualize the results. The following two examples should provide some assistance in understanding the blue curve shown below in Figure 1. The blue curve represents the largest amount of regulation energy required to fully regulate the wind farm output based on the initial power output at the beginning of the hour.

- For a starting wind power output of 0 to 2 MW, the worst case energy needs for a wind down ramp is 1.86 MWh. This would occur if the wind started at 2 MW and quickly ramped down to 0 MW and stayed there for the rest of the hour.
- For a starting wind power output between 32 and 34 MW, the worst case energy needs for a wind down ramp is 27.1 MWh. Again, this would occur if the wind quickly ramps down from the starting value to near zero and stays there for the rest of the hour.

A linear characteristic was selected to represent the necessary battery regulation based on the starting wind power output. The slope of this line is approximately 0.83 MWh required per MW initial power output. The characteristic is shown in red in Figure 1. It is assumed that the battery power rating is such that the battery can provide a power output equal to the large wind farm plant output (50 MW). The red characteristic curve shows a desired regulation resource charge level. A control strategy should attempt to keep the regulation resource energy at the desired energy in real time. By controlling the regulation resource to the resource characteristic, two benefits are realized:

1. For lower wind power outputs (0 – 30 MW), the regulation resource would provide enough energy for all wind down ramps. In order to minimize the regulation resource energy requirement, the loss of a large amount of wind power will require grid regulation resources to survive. This can occur when the blue curve is above the red curve for large starting power outputs (30 – 50 MW). The regulation resource should be sized to keep the occurrences of this shortfall to fewer than once per month.

2. By maintaining a minimum charge level that will survive all wind down ramps, the regulation resource will have a maximum amount of room to absorb energy for wind up ramps. This will minimize the need to feather the wind turbine blades and maximize the amount of energy captured from the wind farm.

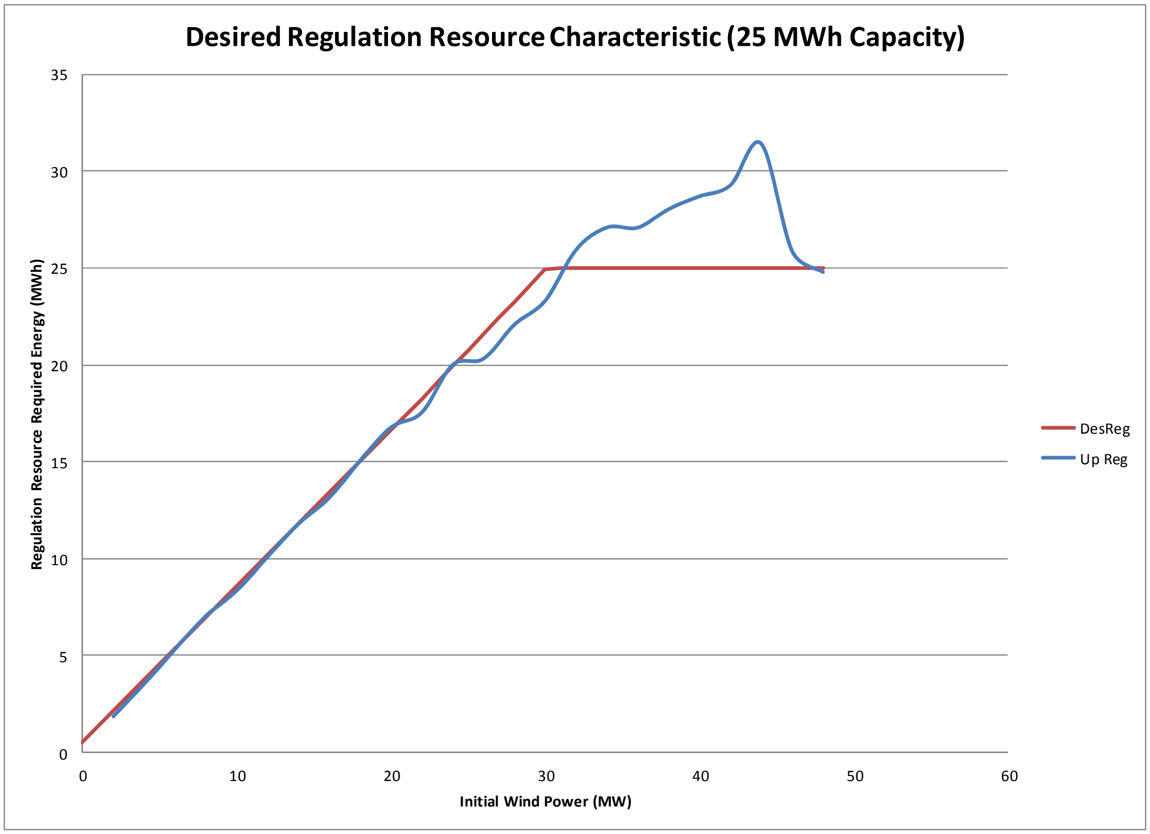


Figure 1: Desired Regulation Characteristic

Stated again, the characteristic shown in Figure 1 would represent the desired regulation from the regulation resource up to its energy limit (25MWh in this example). There will be instances, if the wind is near its maximum power output, when there can be a regulation resource shortfall. When the blue curve is above the red curve, it is possible to run into these shortfall conditions. The battery energy management system should try to keep the battery state of charge near the red regulation characteristic. It is not prudent to always keep the battery charged near its maximum output since this would mean that the battery could not absorb the positive changes in wind power. So in order to maximize the battery's usefulness, the battery should be kept near the desired regulation characteristic. This way the battery has the maximum ability to absorb the wind energy when its power increases while always maintaining enough energy to survive severe wind down ramps.

Due to the limitation of battery sizing, there will be times when the battery will have insufficient energy to fully regulate all wind down ramps. Additionally, there will be times when the battery does not have sufficient room to absorb the wind up ramps. The wind plant can be controlled to limit the up ramps to prevent battery overcharging, but results in unused wind energy. For the extreme wind down ramps, the grid will need to supply for the regulation shortfall. To determine the number of hours, and amount of shortfall and feathered energy, a simulation was run for the two years' worth of wind data. This simulation can determine the effect that battery sizing and control strategy have on the amount and frequency of regulation shortfall, and wind turbine feathering.

The following battery control strategy was implemented to keep the battery near the desired regulation characteristic using the following equation.

$$Wind_{schedule} = Average_{Xsamples} + \left(Energy_{Battery} - Energy_{Desired}\right) * Correction\ Factor$$

Equation 1: Basic Wind Scheduling Method

The Average term is equal to the average value of the wind power output for x number of samples before the hour schedule begins. The battery energy is the available energy in the battery at the start of the hour. The desired energy is the energy value taken from the characteristic from Figure 1 using the average power as a look-up value. The correction factor is a value used to determine how quickly the controls will adjust the battery to the desired energy level.

For example, let’s assume that the battery has an energy level of 20 MWh, and the wind has been steady at 20 MW. The desired energy is approximately 17 MWh. In order to maximize the ability of the battery to absorb energy if the wind increases, the battery charge should be reduced to the ideal value of 17 MWh. Therefore, the wind schedule will be adjusted for the next hour so that the battery will discharge its excess energy. Going through the calculation Wind schedule = 20 MW + (20 MWh – 17 MWh) * (1/5hours) = 20.6 MW. The wind schedule for the next hour would be 20.6 MW. Again, if the wind holds steady at 20 MW, the battery will discharge 0.6 MW for the entire hour to maintain the wind schedule of 20.6 MW. By providing this energy, the battery will be closer to the desired energy value for the next hour. A larger correction factor will move the battery charge level to the desired level more quickly. This control strategy was implemented for the two years’ worth of wind data using different battery energy ratings and correction factors. Table 1 shows the results of the analysis.

Table 1: Regulation Shortfall and Feathering Analysis Results

			Average	Energy (MWh)				Shortfall
Case	Battery Size	Correction Factor	Samples	Total Wind	Feathered	Shortfall	% Feathered	Hours
1	35	0.2	5	152666	233	0.4	0.2%	5
2	35	0.5	5	152666	625	0.0	0.4%	0
3	30	0.2	5	152666	870	5.5	0.6%	6
4	30	0.5	5	152666	2008	5.4	1.3%	2
5	25	0.2	5	152666	1830	21.1	1.2%	11
6	25	0.5	5	152666	3892	18.5	2.5%	5
7	20	0.2	5	152666	3100	82.8	2.0%	48
8	20	0.5	5	152666	6280	52.0	4.1%	16
1a	35	0.2	5	162228	369	1.2	0.2%	3
2a	35	0.5	5	162228	773	0.0	0.5%	0
3a	30	0.2	5	162228	1122	1.2	0.7%	3
4a	30	0.5	5	162228	2319	0.0	1.4%	0
5a	25	0.2	5	162228	2203	21.7	1.4%	19
6a	25	0.5	5	162228	4424	16.2	2.7%	9
7a	20	0.2	5	162228	3613	120.5	2.2%	70
8a	20	0.5	5	162228	7018	67.5	4.3%	25

Cases 1-8 show the results for the first year of wind data, whereas 1a – 8a represent the second year. Battery sizes were selected from 35 MWh to 20 MWh in increments of 5 MWh. Correction factors of 0.2 and 0.5 were used for each battery size using the 5 minute wind average to determine the wind scheduling. Case 1 resulted in 233 MWh of lost energy due to the need to feather the blades when the battery could not absorb the entire wind increase which corresponds to 0.2% of the annual wind energy. Case 1 resulted in shortfall of only 0.4 MWh that occurred over 5 separate hours throughout the year. The grid would need to supply this additional energy.

The general observations from the results shown in Table 1 are that as the battery energy level decreases, the amount and frequency of feathering and shortfalls increases. Also, the smaller correction factor results in less energy lost due to feathering, but more regulation shortfall. The recommended regulation resource should only rely on the grid for regulation for emergency conditions. For this reason, a 20 MWh battery that would rely on the grid to supply shortfall energy more than once per month should not be considered. The 25 MWh battery should be the smallest battery considered for further analysis for a 52 MW wind project since it would have between 5 and 19 shortfall hours per year. Economic analysis will determine the appropriate amount of battery storage as it compares to the value of the unused wind energy, and frequency of battery pack replacement.

4.2.2 17 MW Wind Farm

Similar to the 52 MW scenario, the wind output was analyzed for each year of data available. For each minute of wind data, the change in wind output was integrated over a one-hour time period to provide the necessary energy for that hour. The worst-case hour would require 13 MWh from the regulation resource. Sizing the regulation resource to provide for the worst case scenario would result in an expensive, over-sized regulation resource. The same control method used for the 52 MW wind farm was used for the 17 MW wind farm. The worst case energy requirement was tabulated for each 1 MW range of wind starting power. The resulting energy need was calculated and put on a graph to visualize the results. The following two examples should provide some assistance in understanding the blue curve shown below in Figure 2. The blue curve represents the largest amount of regulation energy required to fully regulate the wind farm output based on the initial power output at the beginning of the hour.

- For a starting wind power output of 0 to 1 MW, the worst case energy needs for a wind down ramp is 0.95 MWh. This would occur if the wind started at 1 MW and quickly ramped down to 0 MW and stayed there for the rest of the hour.
- For a starting wind power output between 14 and 15 MW, the worst case energy needs for a wind down ramp is 12.1 MWh. Again, this would occur if the wind quickly ramps down from the starting value to near zero and stays there for the rest of the hour.

A linear characteristic was selected to represent the necessary battery regulation based on the starting wind power output. The slope of this line is approximately 0.83 MWh required per MW initial power output. The characteristic is shown in red in Figure 2. It is assumed that the battery power rating is such that the battery can provide a power output equal to the wind farm plant output (17 MW). The red characteristic curve shows a desired regulation resource charge level. A control strategy should attempt to keep the regulation resource energy at the desired energy in real time. By controlling the regulation resource to the resource characteristic, two benefits are realized:

3. For lower wind power outputs (0 – 12 MW), the regulation resource would provide enough energy for all wind down ramps. In order to minimize the regulation resource energy requirement, the loss of a large amount of wind power will require grid regulation resources to survive. This can occur when the blue curve is above the red curve for large starting power outputs (12 – 17 MW). The regulation resource should be sized to keep the occurrences of this shortfall to fewer than once per month.
4. By maintaining a minimum charge level that will survive all wind down ramps, the regulation resource will have a maximum amount of room to absorb energy for wind up ramps. This will minimize the need to feather the wind turbine blades and maximize the amount of energy captured from the wind farm.

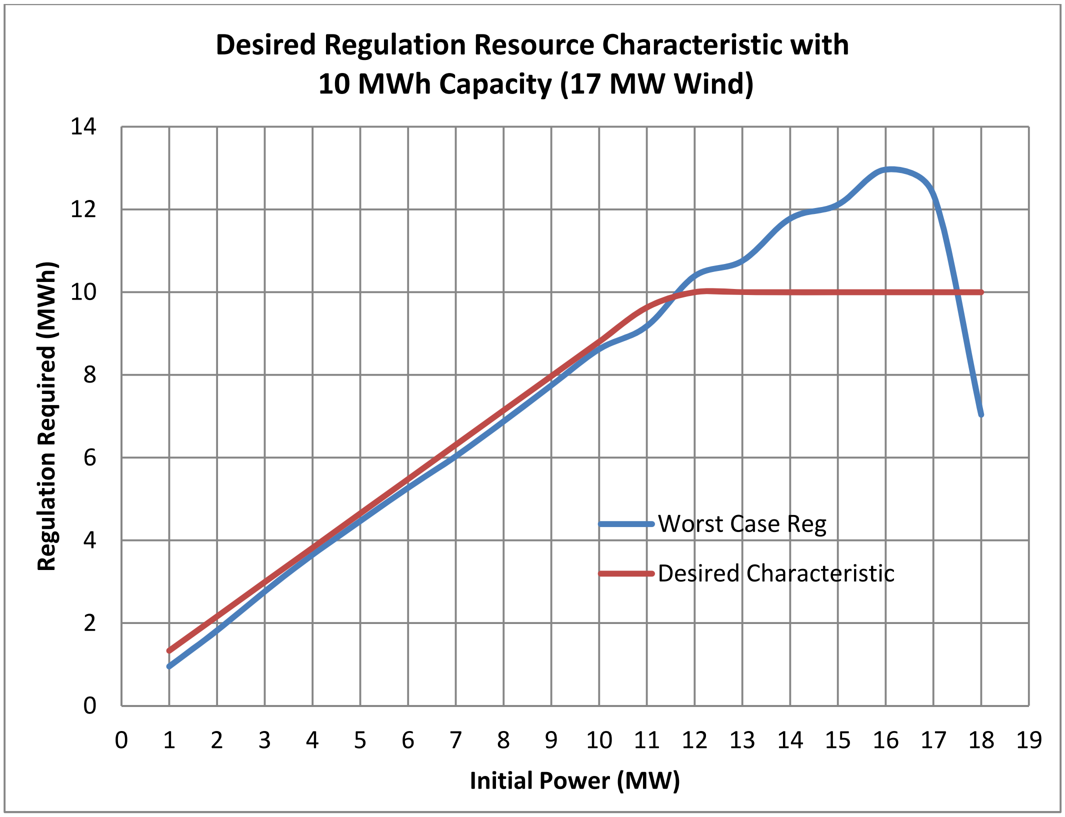


Figure 2: Desired Regulation Characteristic

Stated again, the characteristic shown in Figure 2 would represent the desired regulation from the regulation resource up to its energy limit (10 MWh in this example). There will be instances if the wind is near its maximum power output, when there can be a regulation resource shortfall. When the blue curve is above the red curve, it is possible to run into these shortfall conditions. The battery energy management system should try to keep the battery state of charge near the red regulation characteristic. It is not prudent to always keep the battery charged near its maximum output since this would mean that the battery could not absorb the positive changes in wind power. So in order to maximize the battery's usefulness, the battery should be kept near the desired regulation characteristic. This way the battery has the maximum ability to absorb the wind energy when its power increases while always maintaining enough energy to survive severe wind down ramps.

Due to the limitation of battery sizing, there will be times when the battery will have insufficient energy to fully regulate all wind down ramps. Additionally, there will be times when the battery does not have sufficient room to absorb the wind up ramps. The wind plant can be controlled to limit the up ramps to prevent battery overcharging, but results in unused wind energy. For the extreme wind down ramps, the grid will need to supply for the regulation shortfall. To determine the number of hours, and amount of shortfall and feathered energy, a simulation was run for the two years' worth of wind data. This simulation can determine the effect that battery sizing and control strategy have on the amount and frequency of regulation shortfall, and wind turbine feathering.

The following battery control strategy was implemented to keep the battery near the desired regulation characteristic using the following equation.

$$Wind_{schedule} = Average_{Xsamples} + (Energy_{Battery} - Energy_{Desired}) * Correction\ Factor$$

Equation 2: Basic Wind Scheduling Method

The Average term is equal to the average value of the wind power output for x number of samples before the hour schedule begins. The battery energy is the available energy in the battery at the start of the hour. The desired energy is the energy value taken from the characteristic from Figure 2 using the average power as a look-up value. The correction factor is a value used to determine how quickly the controls will adjust the battery to the desired energy level.

For example, let's assume that the battery has an energy level of 8 MWh, and the wind has been steady at 7 MW. The desired energy is approximately 7 MWh. In order to maximize the ability of the battery to absorb energy if the wind increases, the battery charge should be reduced to the ideal value of 7 MWh. Therefore, the wind schedule will be adjusted for the next hour so that the battery will discharge its excess energy. Going through the calculation Wind schedule = 7 MW + (8 MWh – 7 MWh) * (1/5hours) = 7.2 MW. The wind schedule for the next hour would be 7.2 MW. Again, if the wind holds steady at 7 MW, the battery will discharge 0.2 MW for the entire hour to maintain the wind schedule of 7.2 MW. By providing this energy, the battery will be closer to the desired energy value for the next hour. A larger correction factor will move the battery charge level to the desired level more quickly. This control strategy was implemented for the two years' worth of wind data using different battery energy ratings and correction factors. Figure 2 shows the results of the analysis.

Table 2: Regulation Shortfall and Feathering Analysis Results

			Average	Energy (MWh)				Shortfall
Case	Battery Size	Correction Factor	Samples	Total Wind	Feathered	Shortfall	% Feathered	Hours
1	8	0.2	5	56320	1035	13.75	1.8%	20
2	8	0.5	5	56320	1933	7.2	3.4%	9
3	10	0.2	5	56320	545	1.2	1.0%	5
4	10	0.5	5	56320	1053	0.5	1.9%	2
5	12	0.2	5	56320	176	0.2	0.3%	2
6	12	0.5	5	56320	402	0	0.7%	0
7	14	0.2	5	56320	15.1	0	0.0%	0
8	14	0.5	5	56320	402	0	0.7%	0
1a	8	0.2	5	59083	1101	13	1.9%	31
2a	8	0.5	5	59083	2097	5	3.5%	12
3a	10	0.2	5	59083	589	0.3	1.0%	4
4a	10	0.5	5	59083	1154	0	2.0%	0
5a	12	0.2	5	59083	198	0	0.3%	0
6a	12	0.5	5	59083	444	0	0.8%	0
7a	14	0.2	5	59083	3.7	0	0.0%	0
8a	14	0.5	5	59083	14.6	0	0.0%	0

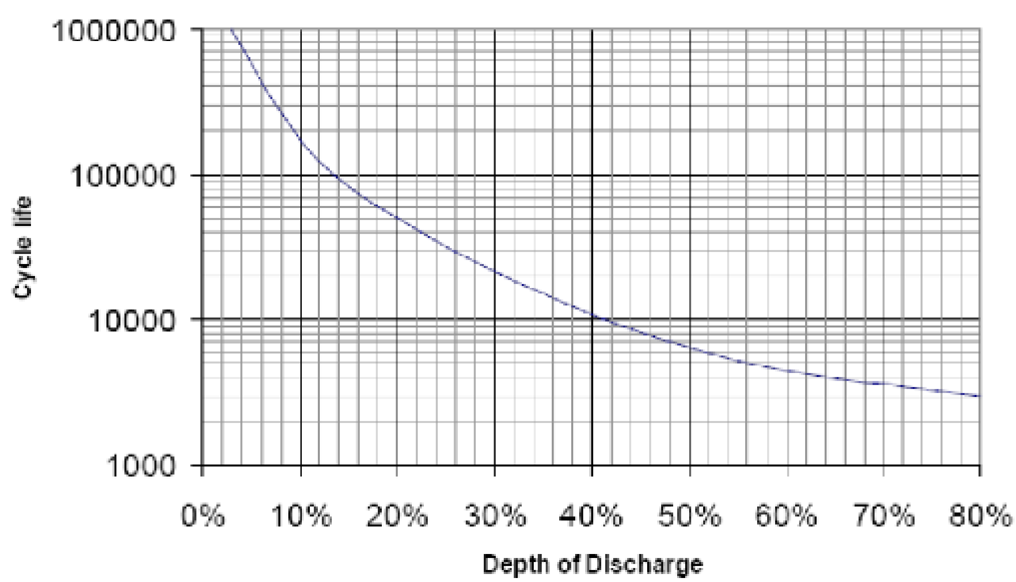
Cases 1-8 show the results for the first year of wind data, whereas 1a – 8a represent the second year. Battery sizes were selected from 8 MWh to 14 MWh in increments of 2 MWh. Correction factors of 0.2 and 0.5 were used for each battery size using the 5 minute wind average to determine the wind scheduling. Case 3 resulted in 545 MWh of lost energy due to the need to feather the blades when the battery could not absorb the entire wind increase which corresponds to 1.0% of the annual wind energy. Case 1 resulted in shortfall of only 1.2 MWh that occurred over 5 separate hours throughout the year. The grid would need to supply this additional energy.

The general observations from the results shown in Figure 2 are that as the battery energy level decreases, the amount and frequency of feathering and shortfalls increases. Also, the smaller correction factor results in less energy lost due to feathering, but more regulation shortfall. The recommended regulation resource should only rely on the grid for regulation for emergency conditions. For this reason, a 8 MWh battery that would rely on the grid to supply shortfall energy more than once per month should not be considered. The 10 MWh battery should be the smallest battery considered for further analysis for a 17 MW wind project since it would have between 0 and 5 shortfall hours per year. Economic analysis will determine the appropriate amount of battery storage as it compares to the value of the unused wind energy, and frequency of battery pack replacement.

4.3 Battery Life Evaluation

It is well understood that as batteries go through charge and discharge cycles, their effective life is reduced. Additionally, large charge/discharge cycles degrade the battery life more quickly than the small cycles. Many battery manufacturers provide curves that show the expected number of charge/discharge cycles based on the depth of discharge. The newer battery technologies can have a million or more cycles at low discharge depths, but approximately 3,000 cycles at 80% depth of discharge. A curve showing a SAFT Li-ion battery characteristic is shown in Figure 3.

- The chart below shows cycle life for medium-power discharges (typically 30 to 60 minutes)



Saft Li-ion battery cycle life

Figure 3: Battery Cycle-Life vs. Depth of Discharge

In order to determine the length of battery life, the wind data was analyzed to give a count of the different depths of discharge. Figure 4 is shown to explain the method behind the cycle counting. The blue trace shows a fictional wind power output over the course of 5 hours. The red trace represents the wind schedule. The area between the two curves would be where the battery would either charge or discharge to keep the total wind plus battery output equal to the schedule.

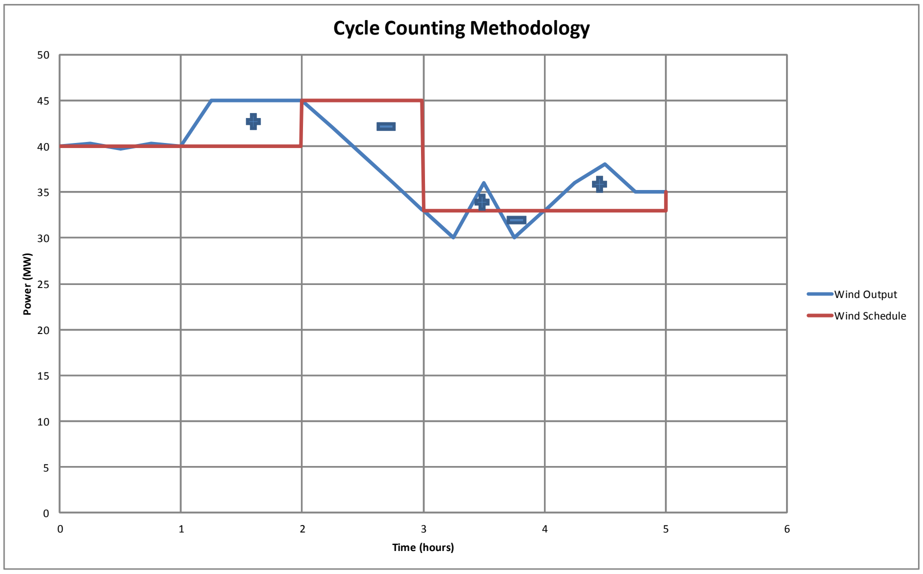


Figure 4: Cycle Counting Method

In the first hour, there are several very small wind fluctuations. The analysis assumed that deviations less than 500kW away from the schedule would not cause the battery to charge or discharge. As such, the first hour has no charge/discharge cycles. The second hour, the wind increases, therefore the battery would charge. The total energy absorbed by the battery (the area between the curves represents the energy). During the third hour, the wind decreases, and the battery would discharge. At the beginning of the fourth hour, the wind is still decreasing. However, since the battery did not switch from charging to discharging, the beginning of the fourth hour counts as a continuation of the third hour discharge. This five hour example results in two large charge/discharge cycles followed by three smaller cycles.

Analysis was performed using the described cycle counting method and the simulated wind data for a large wind farm. The charge/discharge cycles were tabulated for the entire year and resulted in approximately 21,000 cycles. The majority of the cycles occur at small discharge depths of less than 10%. Using an Excel curve fit equation to describe the battery cycle-life characteristic shown in Figure 3, the expected battery life was calculated at 8.7 years. An example of the calculation is shown below:

$$\sum_{n=0\%,2\%\ldots}^{100\%} \frac{Actual\ cycles\ at\ n\%\ DOD}{Rated\ cycles\ at\ n\%\ DOD} \qquad \text{for n = 6\%} \qquad \frac{572}{400000} = 0.143\% \text{ of total battery life}$$

There were 572 charge/discharge cycles between 4 and 6 percent for the 35 MWh battery control strategy shown in Table 1 as case 1. At 6% depth of discharge, the SAFT Li-Ion battery could withstand 400,000 cycles. Therefore, the 4-6% discharges account for 0.1% yearly battery life degradation. This was added to all the other depth of discharge ranges, and resulted in an annual battery degradation of 11.5%, or a battery life of 8.7 years for the first year's data set, and 8 years for the second year's data set. Using the same controls, a battery with a 25 MWh size would last for 6.3 years and 5.7 years respectively. When combined with the expected need for feathering and regulation shortfall the economic impact of battery size can be determined. This analysis was performed for both the 17 MW wind farm and the 52 MW wind farm options.

5 Technology Recommendation

When combined with the mature technology and lowest installation price, the recent breakthroughs in the lead-acid battery technology make the advanced lead-acid battery technology a front-runner for the stationary utility application market. The Sandia report further reinforces the market trend toward lead-acid batteries with carbon enhanced electrodes such as those provided by Xtreme Power, and Axion Power.

However, with lithium-ion's dominance in the consumer electronics industry and its move into the hybrid electric vehicle market, the lithium-ion battery technology should be considered. The lithium-ion battery technology does provide superior performance when compared to the advanced lead-acid battery technology. The high initial price of lithium-ion systems could be offset by its superior cycle-life which would mean fewer replacement battery packs. Therefore, it is important to study the impact of battery pack replacement costs when determining the best-fit battery technology.

5.1 Financial Considerations

The Sandia National Laboratories recently updated an Energy Storage Systems Cost report [2,3]. This report compared the different storage technologies and application types. The energy storage types studied included lead-acid batteries, sodium-sulfur (Na/S), zinc-bromine (Zn/Br), vanadium-redox (V-redox), Lithium-ion, compressed air (CAES), Pumped Hydro, High-speed flywheels, and super capacitors. The analysis studied the 10-year ownership of the storage device using the following factors:

- Efficiency
- Cycle-life
- Initial Capital Costs
- Operations and Maintenance
- Storage-device Replacement

Of course, the storage system cycle-life, and replacement costs are dependent on the application. The Railbelt regulation application is most closely represented in the Sandia report [3] by frequent, short-duration discharges. Table 3 which was taken from the Sandia report shows the costs in $/kW of the different technologies and applications. The most applicable data set is the row inside the gold box. The results of this study give an idea of the cheapest technological selection. The flywheel and super-capacitors are not suited for the Railbelt regulation application due to their limited storage capacities. The cheapest choices are the Carbon-enhanced electrode Lead-acid batteries, and the zinc-bromine batteries. While the cost analysis used for the Sandia report did not have the level of detail that will be used to determine the battery cycle-life for the Railbelt application, but it does provide a good baseline.

Table 3: Energy Storage Systems Cost Update

Technology/Use	Advanced Lead-acid Battery	Na/S (7.2 hr)	Zn/Br	V-redox	Lead-acid Battery with Carbon-enhanced Electrodes	Li-ion	CAES (8 hrs)	Pumped Hydro (8 hrs)	High-speed Flywheel (15 min)	Supercap (1 min)
Long-duration storage, frequent discharge	2839.26	2527.97	2518.03	3279.34	2017.87	2899.41	1470.10	2399.90		
Long-duration storage, infrequent discharge	1620.37	2438.97	1817.82	2701.41	1559.57	2442.79				
Short-duration storage, frequent discharge	1299.70		905.53	1459.85	669.85	1409.99			965.73	834.62
Short-duration storage, infrequent discharge	704.18		697.78	999.78	625.57	960.48			922.87	793.02

The battery technologies that should be evaluated in greater depth for the Railbelt regulation application are the advanced lead-acid battery technology and the lithium-ion technology. By combining the battery sizing, expected regulation shortfall, expected wind feathering, battery efficiency, and battery pack replacement frequency, the battery lifetime costs can be estimated. The battery size and replacement frequency are closely related. If a large battery is purchased, it will have a large initial capital cost. Since the battery is large, the same charge/discharge cycles would result in a lower depth of discharge. Both the advanced lead-acid and the lithium-ion battery technologies can withstand orders of magnitude more charge/discharge cycles at low discharge depths. The result is that a larger battery will last longer and may need fewer battery pack replacements during the battery system design life as was shown in the Battery Life Evaluation section.

5.2 Economic Analysis – Advanced Lead-Acid vs. Lithium-Ion

A preliminary economic analysis was performed to compare the advanced lead-acid technology against the lithium-ion technology. For the 52 MW and 17 MW wind farms' various battery energy capacities, the economic analysis took into account the following costs for assuming a project life of 20 years and a discount rate of 5%:

- Initial battery cost
- Cost of battery losses (lithium-Ion batteries have better round-trip efficiency)
- Battery pack replacement(s)

The battery life was calculated using the method discussed in the Battery Life Evaluation section. The analysis determined the expected time between battery pack replacements. The results of this analysis are shown below in Table 4.

Table 4: Battery Life Based on Battery Capacity

17 MW Wind Farm			
Battery Size (MWh)	Xtreme Power	Saft Li-Ion	Altair Nano Li-Tritanate
10	6.2	6.6	26.5
12	8.3	8	30.4
14	11.2	9.8	34.8

52 MW Wind Farm			
Battery Size (MWh)	Xtreme Power	Saft Li-Ion	Altair Nano Li-Tritanate
25	5.2	6.3	22.4
30	6.4	7.4	24.7
35	8	8.7	27
42	11.4	11.3	31.3

The following assumptions were made for the economic analysis:

- A 5% discount rate was used
- Cost for energy lost due to battery inefficiency is assumed to be 100 $/MWh
- Interconnection costs including a building to house the battery, the step-up transformer, and circuit breakers will cost a total of $2.25M. The same interconnection costs will be used for all energy storage capabilities, even though a smaller battery will need a smaller building.
- The Xtreme Power Battery costs that are based on a smaller-scale battery quote are:
  - $500,000 per MW of power conditioning system
  - $850,000 per MWh of initial battery pack installation
  - $300,000 per MWh of replacement battery packs
- The Saft Li-Ion battery costs that are based on smaller-scale battery quote are:
  - $500,000 per MW of power conditioning system
  - $2,500,000 per MWh of initial battery pack installation
  - $1,250,000 per MWh of replacement battery packs (No quote received, assumed ½ initial cost)
- The Altair Nanotechnolgies Li-Titanate battery costs that are based on smaller-scale battery quote are:
  - $1,500,000 per MW of power conditioning system
  - $2,417,000 per MWh of initial battery pack installation
  - $1,208,500 per MWh of replacement battery packs (No quote received, assumed ½ initial cost)

The results of the basic net present cost economic analysis are shown below in Table 5.

Table 5: Battery Initial Installation Cost and 20 Year Project Cost

17 MW Wind Farm						
Case	Xtreme Power		Saft Li-Ion		Altair Nano Li-Titanate	
(MWh)	Initial $	20-year $	Initial $	20-year $	Initial $	20-year $
Case 10	$ 19.25	$ 26.41	$ 35.75	$ 58.84	$ 51.92	$ 53.53
Case 12	$ 20.95	$ 27.04	$ 40.75	$ 59.38	$ 56.75	$ 58.36
Case 14	$ 22.65	$ 27.11	$ 45.75	$ 65.91	$ 61.59	$ 63.19

52 MW Wind Farm						
Case	Xtreme Power		Saft Li-Ion		Altair Nano Li-Titanate	
(MWh)	Initial $	20-year $	Initial $	20-year $	Initial $	20-year $
Case 25	$ 48.50	$ 66.95	$ 89.75	$ 133.96	$ 137.68	$ 141.16
Case 30	$ 52.75	$ 72.40	$ 102.25	$ 152.66	$ 149.76	$ 153.25
Case 35	$ 57.00	$ 73.28	$ 114.75	$ 166.94	$ 161.85	$ 165.33
Case 42	$ 62.95	$ 74.68	$ 132.25	$ 166.44	$ 178.76	$ 182.25

The economic results show that the initial cost is the dominant term of the 20-year project cost. Also, the high cost of the lithium-ion battery technologies is not offset by its superior cycle-life. This basic analysis shows that the lithium-ion technology is not as cost effective as the Xtreme Power even though the Case 25 Xtreme Power battery packs needed three sets of replacement battery packs over the 20-year project life. Due to the large price differential, additional factors that would have slightly improve the lithium economics such as: smaller building and lower shipping costs due to better energy density, lower maintenance costs, and a better environmental image would likely not make up for the significant price differential. EPS recommends the advanced lead-acid technology be used as the regulation resource.

When selecting a battery energy storage size, the frequency of shortfall hours should be considered. Shortfall hours are the hours that the battery runs out of energy during the hour, and the grid must supply for the shortfall. If a 25 MWh battery is selected to regulate the 52 MW wind farm, the number of shortfall hours would be between 5 and 19 hours per year. It would be up to the utilities to determine the best mix of battery size and frequency of shortfall. The 42 MWh case has been included since it is a combination of 25 and 16.67 MWh. This battery size would mimic the control characteristics of the 25 MWh, but would leave 16.67 MWh as a reserve for transient response to the loss of a generation unit, or the Kenai tie. The shortfall hours would be eliminated since the 16.67 reserve capacity could be used for severe wind ramp events, but during typical wind conditions, the 16.67 MWh would be reserved for a trip event. The 42 MWh battery system would be more expensive, but would require fewer replacement battery packs, and would provide the additional system benefit of transient event response to the loss of a unit or Kenai tie.

6 Six Hour Energy Needs

6.1 Wind Regulation

The one hour analysis assumes the ability to change the unit schedules each hour. The single contingency outage of the Kenai tie can island the Cooper Lake, and Bradley Lake regulation resources. There are also many hours during a typical day when hydro resources are not scheduled to meet the utility's energy demands. The loss of these regulation resources severely limits the Anchorage area utilities' ability to deal with the intermittent wind resource. This is due, in part, to the current gas delivery contracts which are scheduled every six hours. So, when either the Kenai tie is not energized or hydro is not scheduled, additional storage is necessary to regulate the wind farm output or the wind farm must be curtailed. Due to the amount of energy required for a six hour window (up to 300 MWh for a 52 MW wind farm), the battery and flywheel technologies will not be economical at this scale. Therefore, the addition of flexible fuel storage will be investigated as a means to regulate the intermittent wind resource while the Kenai regulation resources are not available. Even with a second transmission line connecting the Southcentral transmission system to the Kenai Peninsula, the loss of either transmission line can reduce the transfer capacity by approximately 30 MW. Flexible fuel storage would be needed to make up this shortfall until new gas schedules can be implemented.

Again, a power and energy requirement must be determined before any economic analysis can be performed. The six-hour energy requirement for wind regulation will be determined in much the same way that the one hour requirement was evaluated. The wind data was analyzed and the largest wind down ramps were sorted by the initial wind power output were plotted in blue on Figure 5. As an example, let's assume the wind starts out at 25 MW. The worst possible case would be an immediate ramp down to zero followed by six hours at 0 MW. This would result in an energy need of 150 MWh (25 MW* 6 hours). However, in the field, the wind never ramps down immediately, so the curve actually shows the worst case at 25 MW initial wind power to be 145 MWh. A linear curve was created to represent the six-hour energy needs against the wind starting power, and is shown in red.

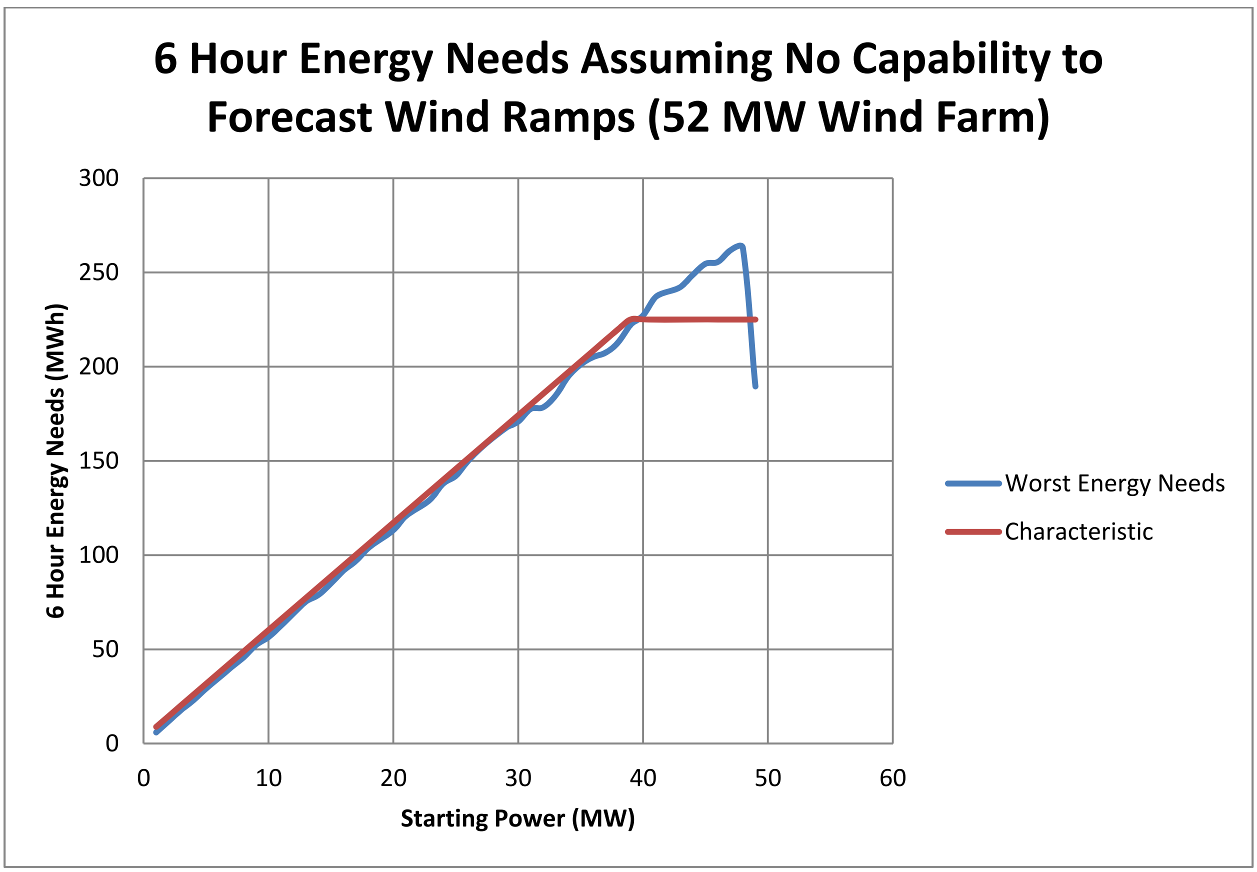


Figure 5: Six Hour Energy Needs Based on Wind Schedule

The years of wind data were analyzed by setting up a six-hour scheduling method. This assumes that the Kenai intertie is out of service which isolates the hourly regulation resources on the Kenai. Several different methods for creating a six-hour wind schedule were tested. Each method that was tested assumed there is no ability to forecast wind production. Each of these schedules was set and maintained for the entire six-hour time frame. For example, if the wind schedule is 25 MW, and the wind stops at the beginning of the first hour, the rest of the six hour scheduling period, the 25 MW wind schedule will be provided by the regulation resource.

The first method of setting a wind schedule uses the average wind output from the last 5 minutes of the previous hour as the basis for a wind schedule for the next six hours. This method simply averages the 5 minutes before the hour begins and uses the average as the schedule. The basic assumption made by the first method is “whatever the wind is doing now, it will continue in the future.”

Second, the average wind power output of the previous six hours was used to create the schedule for the next six hours. Again, the assumption is that the wind will continue what it did in the previous six hours, but by using a longer time-frame, will not be influenced by short-term wind fluctuations.

Third, the six-hour time frame from the previous day was used. This method assumes that the wind will follow a daily cycle, and the six hours from the previous day are a good indication of what will occur today.

Finally, a six-hour weighted average wind power was used. The weighting was assigned as (hour-1)*0.5 + (hour-2)*0.2 + (hour-3)*0.1 + (hour-4)*0.1 + (hour-5)*0.05 + (hour-6)*0.05. This method puts extra weight on the most recent hour, but would help remove some of the shorter term volatility from the wind scheduling.

A simulation was run for a 17 MW and a 52 MW wind farm with each of the scheduling methods discussed above. During this simulation, the wind data was used to determine the impact of different scheduling philosophies on the amount of wind spilled, and the amount of regulation shortfall. Based on the wind schedule, the regulation resource would either supply or absorb power to maintain the wind schedule using the same formula used for the one hour regulation analysis shown as Equation 1. The energy provided by the regulation resource during the six hour schedule was calculated. For the six hour periods where more energy to regulate a downward wind ramp is required than was available at the beginning of the six-hour schedule, the time frame is listed as a shortfall. For the six-hour periods where more energy to regulate an upward wind ramp is required than was available at the beginning of the six-hour schedule, the time frame is listed as feathered, and the energy difference would be “spilled”. The first few days of data is shown in Figure 6 and Table 6 below.

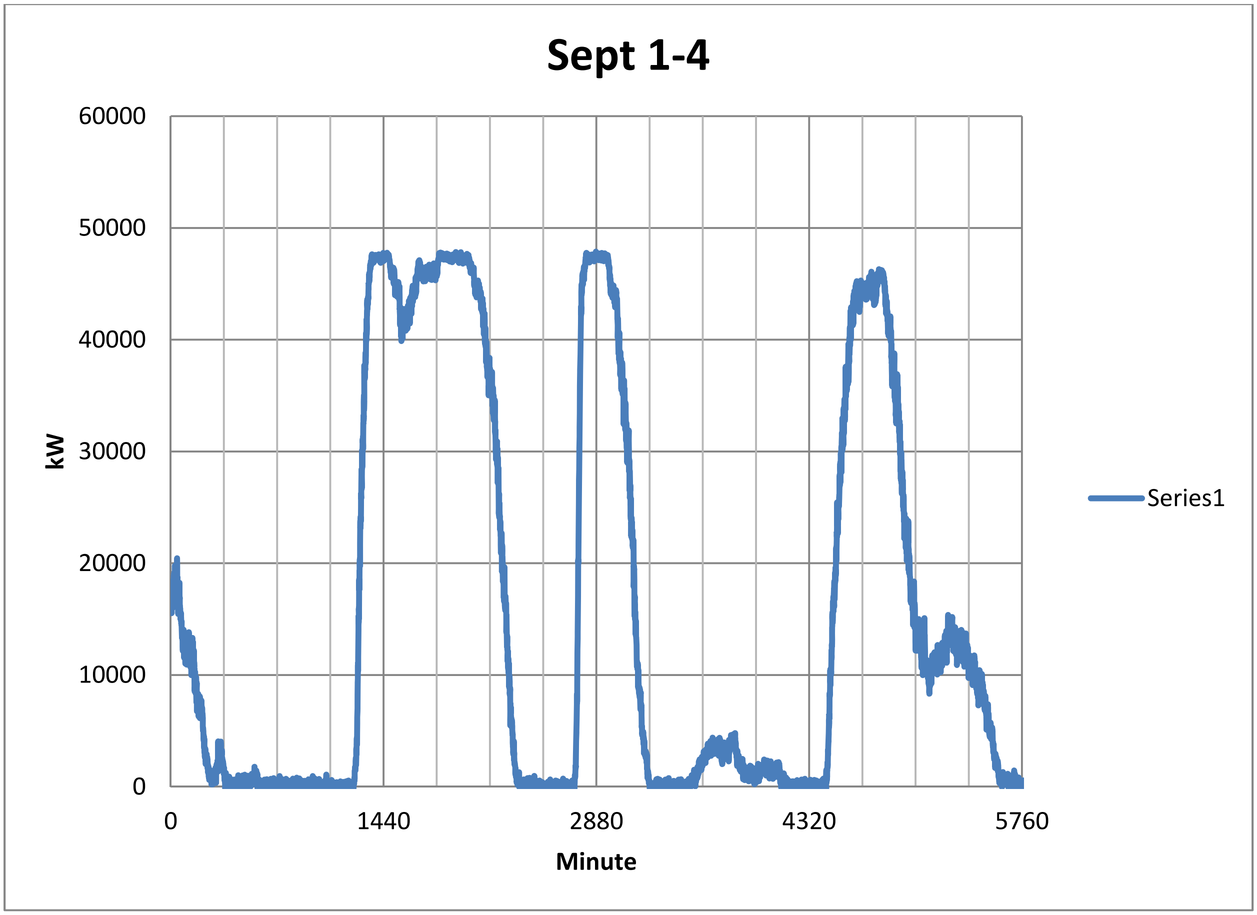


Figure 6: Wind Power for First Provided Days

Table 6: 52 MW Wind Schedules for September 1 through September 2

Hour	Schedule Type	Initial Storage	Schedule	Energy Used	Schedule Type	Initial Storage	Schedule	Energy Used
0	5 Min Avg	123 MWh	18.4	58.8	6 Hr Avg	123 MWh	18.4	58.8
6	5 Min Avg	64.2MWh	8.4	48.6	6 Hr Avg	64.2 MWh	10.1	58.5
12	5 Min Avg	15.7 MWh	1.5	8.9	6 Hr Avg	5.8 MWh	0.3	1.4
18	5 Min Avg	6.8MWh	0.3	-115.8	6 Hr Avg	4.4 MWh	0.0	-117.5
24	5 Min Avg	122.6 MWh	27.2	-107.0	6 Hr Avg	121.9 MWh	20.4	-147.5
30	5 Min Avg	229.5 MWh	41.1	-26.7	6 Hr Avg	269.5 MWh	46.2	3.5
36	5 Min Avg	256.2 MWh	42.5	197.5	6 Hr Avg	266.0 MWh	45.8	217.4
42	5 Min Avg	58.7 MWh	7.3	-49.5	6 Hr Avg	48.6 MWh	8.2	-43.8
0	Prev Day 6hr Avg	123 MWh	18.4	58.8	6hr Weighted	123 MWh	18.4	58.8
6	Prev Day 6hr Avg	64.2 MWh	10.1	58.5	6hr Weighted	64.2 MWh	9.1	52.8
12	Prev Day 6hr Avg	5.8 MWh	0.3	1.4	6hr Weighted	11.3 MWh	1.0	5.7
18	Prev Day 6hr Avg	4.4 MWh	0.0	-117.5	6hr Weighted	5.6 MWh	24.2	-116.6
24	Prev Day 6hr Avg	121.9 MWh	20.4	-147.5	6hr Weighted	123 MWh	43.3	-124.8
30	Prev Day 6hr Avg	269.5 MWh	37.4	-49.0	6hr Weighted	64.2 MWh	44.5	-13.8
36	Prev Day 6hr Avg	300 MWh	0.3	-55.8	6hr Weighted	123 MWh	7.0	209.5
42	Prev Day 6hr Avg	300 MWh	0.1	-92.9	6hr Weighted	64.2 MWh	20.9	-50.9

Figure 6 shows the first four days from the first year of wind power data with each vertical axis line representing a six-hour period. During these 4 days there are three spikes of full/near full wind power output. The first spike lasts for a full 12 hours. There are several ramps of the full wind output within the six-hour schedules. Again, without the ability to forecast the wind, these ramps must either be mitigated by the regulation resource, curtailing the wind, or a combination of the two. An improved forecasting system could reduce the energy needs for regulating the wind resources, and should be evaluated by the utilities. However, the impact of a state-of-the-art wind forecasting system was not evaluated as part of this study.

Table 6 shows the energy storage usage for the first two days based on the different scheduling methods described above. The top left quadrant shows the five minute averaging method. The top right quadrant shows the six-hour average method. The bottom left quadrant shows the results for the previous day six-hour average method. Finally, the bottom right quadrant shows the results for using a six-hour weighted average scheduling method. The initial storage column lists the amount of gas energy in storage at the beginning of each six-hour time frame. The schedule lists the wind schedule used for the next six-hour time frame. The energy used column lists the amount of gas storage energy that was used or saved during the six-hour time frame. The five-minute average scheduling method example is explained below:

At hour zero, the gas storage has 123 MWh of energy. And the wind power output over five minutes preceding the zero hour was 18.4 MW (schedule). During the next six hours, the wind output steadily drops. In order to make up for the shortfall from the schedule, the gas storage supplies the difference between the actual wind power, and the scheduled wind power. The total energy used to maintain the wind schedule was 58.8 MWh. At hour six, the initial storage is 123 MWh – 58.8 MWh = 64.2 MWh. The new schedule is 8.4 MW, and again, the wind power drops to zero over the next six hours, and the gas storage uses another 48.6 MWh. This process was repeated for the entire year.

This analysis clearly showed that the best method for creating a schedule in terms of minimizing feathered energy, minimizing shortfall energy, and minimizing total regulation usage was to use the first method of averaging the last five minutes of the previous hour to create a wind schedule. This means that the previous five minutes of wind data did the best job forecasting the next six hours of wind power. This result is not surprising since there is a weak correlation of wind power from day to day. This is easily observed by reviewing minutes 2880, and 4320 which are one day apart and vary by the full wind output.

Several year-long operational simulations using the five minute average wind scheduling method were run to determine the frequency of regulation shortfall and wind feathering based on the six-hour regulation resource and correction factor. Table 7 shows the results for a six-hour regulation resource designed for the regulation of wind farm output.

Table 7: Six-Hour Regulation Simulation Results for a 52 MW Wind Farm

Case	Energy MWh	Correction Factor	Total wind	Feathered MWh	Shortfall MWh	%feathered	6-hr Schedule Shortfall Count
1	300	0.8	152666	0.0	0.0	0.0%	0
2	300	0.5	152666	8.6	32.0	0.0%	3
3	250	0.8	152666	461.7	0.0	0.3%	0
4	250	0.5	152666	289.1	32.8	0.2%	3
5	225	0.8	152666	2361.0	0.0	1.5%	0
6	225	0.5	152666	1397.4	34.5	0.9%	3
7	200	0.8	152666	5767.0	45.5	3.8%	2
8	200	0.5	152666	3329.0	56.7	2.2%	4
1a	300	0.8	162228	0.0	12.0	0.0%	1
2a	300	0.5	162228	0.0	91.3	0.0%	4
3a	250	0.8	162228	592.0	12.0	0.4%	1
4a	250	0.5	162228	380.0	91.9	0.2%	4
5a	225	0.8	162228	2477.8	28.6	1.5%	3
6a	225	0.5	162228	1435.6	98.2	0.9%	4
7a	200	0.8	162228	5406.9	70.8	3.3%	3
8a	200	0.5	162228	3276.0	170.2	2.0%	6

The Energy MWh column lists the size of the gas storage facilities. The Feathered MWh lists the energy that the gas storage facility would not be able to store during the simulation year, and would force curtailment of the wind. The Shortfall MWh column lists the amount of energy that the gas storage facility is unable to supply during the simulation. The 6-hr Schedule Shortfall Count lists the number of six-hour schedules during which the gas storage is insufficient to cover a wind down ramp. Based on these results, a 300 MWh gas storage facility would be capable of providing the storage to fully regulate all wind up and down ramps for a year as shown in case 1. However, in order to minimize the project cost, a storage facility could regulate the large wind farm with as little as 200 MWh. It is recommended that the six-hour energy storage be at least 200 MWh for the purpose of regulating the wind farm output.

Table 8: Six-Hour Regulation Simulation Results 17 MW Wind Farm

Case	Energy MWh	Correction Factor	Total wind	Feathered MWh	Shortfall MWh	%feathered	6-hr Schedule Shortfall Count
1	100	0.8	56320	0.0	0.0	0.0%	0
2	100	0.5	56320	8.6	18.7	0.0%	3
3	85	0.8	56320	556.0	0.0	1.0%	0
4	85	0.5	56320	351.0	6.0	0.6%	4
5	75	0.8	56320	1694.6	2.0	3.0%	2
6	75	0.5	56320	1085.6	6.7	1.9%	5
7	65	0.8	56320	3229.0	55.0	5.7%	10
8	65	0.5	56320	2124.3	51.2	3.8%	13
1a	100	0.8	59083	0.0	0.1	0.0%	1
2a	100	0.5	59083	8.6	18.7	0.0%	3
3a	85	0.8	59083	589.9	0.5	1.0%	1
4a	85	0.5	59083	366.5	18.7	0.6%	3
5a	75	0.8	59083	1631.6	16.7	2.8%	4
6a	75	0.5	59083	1029.8	32.0	1.7%	6
7a	65	0.8	59083	3354.3	73.2	5.7%	12
8a	65	0.5	59083	2061.3	66.7	3.5%	13

The same analysis was performed to determine the regulation requirements for a 17 MW wind farm as opposed to a 52 MW wind farm. The results of this analysis are shown above in Table 8. The storage sizes were selected to be approximately one third of the sizes studied for the 52 MW wind farm. However, this analysis shows that the percentage of feathered energy is greater for the 17 MW wind farm for a storage facility of proportional size. This suggests that the 17 MW wind farm size could be more volatile and may require more storage as a percentage of the power than a larger wind farm. EPS would not recommend a gas storage facility smaller than 65 MWh for a 17 MW wind farm due to the frequency of energy shortfall, but anything 75 MWh or bigger would be acceptable. The costs of the feathered energy would need to be weighed against the cost of gas storage installation.

6.2 Loss of Kenai Tie

A secondary storage system sizing requirement is to compensate for the loss of the largest unit, or the Kenai tie. Since the largest unit on the system in 2015 is expected to be 61 MW, the largest single contingency in the existing transmission system will be the loss of the Kenai tie at its maximum import into the Anchorage area. The line's existing limit is 75 MW leaving Dave's Creek substation. When subtracting the loads along the line, this 75 MW import is less than 60 MW in the winter peak conditions, and as much as 68 MW in the summer valley condition. However the loss of the Quartz Creek – Daves line section results in a loss of generation of approximately 86 MW in the winter and 80 MW in the summer.

There are a few issues when considering energy storage for the loss of the Kenai tie. First, the ability to reschedule the hydro resources to compensate for the wind ramps is removed since these resources are islanded from the wind. Based on current gas scheduling contracts, the gas turbines are scheduled for six hours at a time. This could result in up to six hours of schedule mismatch. Second, the loss of the power import into the Anchorage area could result in load shedding for cases that have minimal spinning reserve in the Anchorage area. The recommended battery system for this secondary criterion could be used to supply for the lost import until the balancing authority has sufficient time to start a unit and prevent loadshedding following the loss of the tie.

Following the construction of the recommended HVDC Beluga-Bernice Lake transmission line, the outage of the existing Daves Creek – University line would result in a loss of approximately 30 MW of power during the maximum power transfer of 130 MW due to the 100 MW transfer limit of the HVDC Intertie. This could result in the need for 180 MWh (30 MW * 6 hours) of energy storage.

Prior to the construction of the new HVDC Intertie, or if the HVDC line is not constructed, the maximum import capability into Anchorage is assumed to be 75 MW.

In order to give the balancing authority sufficient time to start a unit, the battery must be sized to cover for the loss. PSS/E dynamics simulations were run with the Kenai tie importing 75 MW into the Anchorage area. The case was created with minimal spinning reserve. Setting the case up with minimal spinning reserve will give a worst-case simulation for any loss of generation or import into the Anchorage area. A 50 MW battery system was added to the Railbelt database. The battery was setup with a droop value that would force the battery to full output before the first stage of load shed. The Kenai tie was then tripped. The result of a PSS/E simulation is shown below in Figure 7.

It should be noted that the 75 MW import is not the worst case, single contingency event under this import condition. The loss of the Quartz Creek – Daves Creek Line section results in a loss of generation into the Anchorage area of 85-95 MW depending on the loads at Seward and along the University – Daves Creek transmission line. However, the loss of this line is extremely rare and it is unknown if the Railbelt utilities would limit the imports to cover the loss of this line or accept limited load shedding should it occur. For purposes of this study, we have assumed the utilities will accept limited load shedding for this contingency.

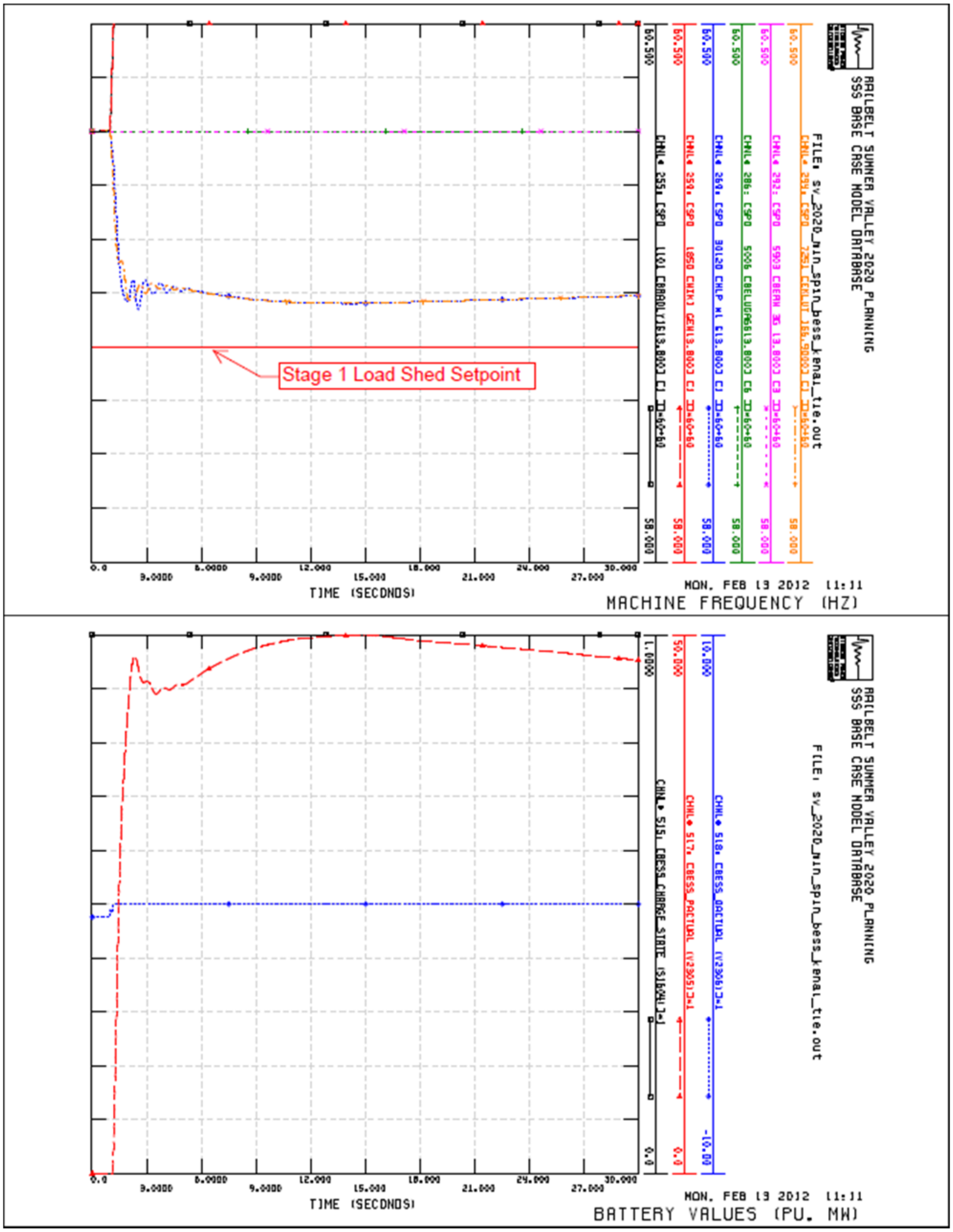


Figure 7: Summer Valley Loss of Kenai Tie at Maximum Flow

The top set of traces show the frequencies at various places in the Railbelt system. The bottom traces show the battery power outputs in red (MW) and blue (MVAR). The battery system prevented load shed by quickly ramping up to its maximum power output of 50 MW. This simulation resulted in the continued low frequency 30 seconds after the initial trip since there is no additional room on any of the units to restore the frequency to 60 Hz. Without operator intervention, the system would remain in this state until a unit could be started to restore frequency and off-load the battery. It is assumed that a unit could be started in 20 minutes after the loss of the Kenai tie. Therefore, a minimum of 16.67 MWh of battery storage is needed in order to supply 50 MW between the time when the tie is tripped, and a unit is started. The unit would then run using the gas storage system for the remainder of the six-hour schedule.

After starting a gas turbine using gas storage and restoring the load along the Anchorage – Kenai intertie, approximately 60 MW would be required from the gas turbine until the gas schedules can be changed. In order to provide this energy for six hours, the energy requirement would be approximately 60 MW for six hours or 360 MWh. This energy storage would be sufficient to prevent scheduling conflicts with the gas delivery companies for the worst case conditions of a) maximum import into the Anchorage area from the Kenai tie and, b) the loss of the tie immediately after the current gas schedule begins. The 360 MWh of energy storage would not be able to provide for any additional wind down ramps during the six-hour schedule. Therefore, in order to provide some margin, EPS recommends that the storage requirement be increased by 25% to 450 MWh to allow for additional gas storage to provide for some regulation for wind up or down ramps after the loss of the Kenai tie. While the 450 MWh of storage is not enough energy to deal with both the loss of the full wind output and the Kenai tie, it will be able to fully handle the loss of the Kenai tie along with a moderate wind down ramp. The loss of the full wind plant output coupled with the loss of the tie at its maximum import should be considered an N-2 contingency, and should not be part of the requirements of the storage system.

With the Kenai tie open, the utilities can change the gas schedules every six hours. With the 450 MWh of gas energy storage, the wind output could be fully regulated. In fact, the 52 MW wind could be regulated with at least 200 MWh of gas storage as was shown in case 1 in Table 7.

Assuming the second Anchorage – Kenai intertie is built, the loss of the existing intertie would result in the loss of 30 MW of capacity for the Anchorage utilities. In order to regulate the 17 MW wind farm, and provide for the 30 MW lost capacity 250 MWh (70 MWh + 180 MWh) would be needed. In order to regulate the 52 MW wind farm and provide for the 30 MW lost capacity, 380 MWh (200 MWh + 180 MWh) would be needed.

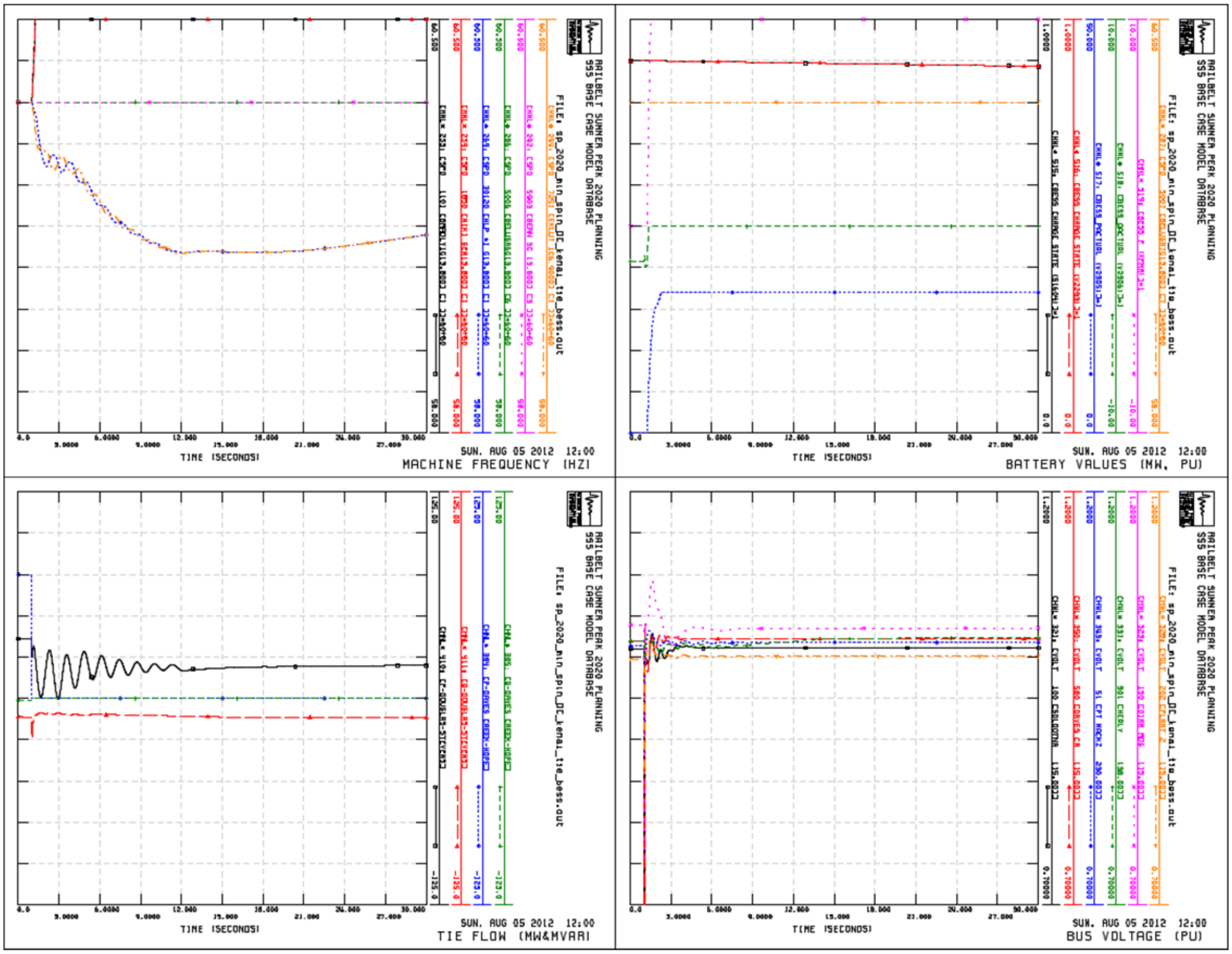


Figure 8: Loss of AC Anchorage - Kenai Intertie, 17 MW BESS, 30 MW Lost Import

Figure 8 shows the simulation result for the loss of the AC Anchorage – Kenai intertie with a 17 MW battery. It can be seen that the 17 MW battery can prevent the load shedding. The top left set of traces show the frequencies at various places in the Railbelt system. The top left traces show the battery signals such as power output (blue), per-unit energy (red), reactive power (green). The bottom left set of traces show the line flows in (MW). The bottom right traces show the bus voltages in per-unit at various places throughout the Railbelt system. This simulation resulted in the continued low frequency 30 seconds after the initial trip since there is no additional room on any of the units to restore the frequency to 60 Hz. Without operator intervention, the system would remain in this state until a unit could be started to restore frequency and off-load the battery. It is assumed that a unit could be started in 20 minutes after the loss of the AC Anchorage – Kenai tie.

In order to provide some margin for the condition where the wind is decreasing, and the AC Anchorage – Kenai Intertie is tripped, the recommended power and energy ratings are 25 MW and 14 MWh respectively. This would allow the capability of regulating a smaller wind ramp down coupled with the loss of the tie, but would not be able to respond to the full loss of the wind farm and the tie.

This study assumes that the recommended HVDC tie is being constructed. However, another option is to upgrade the existing line to allow a transfer capability of 125 MW. This case was not evaluated in this study. The minimum battery size and energy would be based on the trip of the upgraded transmission line and the loss of the 125 MW import into the Anchorage area. For this transmission configuration, the BESS should be sized as part of the overall transmission plan.

6.3 Gas Storage Description and Costs

In order to provide the energy required for longer term regulation of a six hour schedule, a battery system is not financially reasonable. Therefore, EPS recommends the use of a compressed natural gas storage system.

EPS recommends the use of containerized storage modules which store the natural gas at high pressure in trailer-sized transportable modules. For a design capacity of 360 MWh, eleven storage modules would be required. These storage modules would have approximately 25% of "emergency" capacity that could be used to supply regulation energy for extreme wind ramp events. Each storage module has 4 tanks that contain a total of 355,440 SCF of natural gas compressed to 3,600 psig. Eleven storage modules would results in a total storage capacity of 3,909,840 SCF. This storage could supply approximately 450 MWh of energy.

The gas storage facility would be placed immediately adjacent to an existing power plant. The storage facility consists of the gas storage modules, a compressor, and an electric driver motor, and associated piping etc. The compressor requires a 1250 hp motor and would take the gas from the pipeline which operates at 100 psig and compress it to 3,600 psig for storage.

The compressor and motor driver will be inside a pre-engineered metal building with concrete floor slab and foundation which will protect the compressor and driver motor from the elements and provide comfortable working conditions for maintenance. The storage modules will be located outdoors, anchored to concrete slabs. The compressor building will incorporate electric unit heaters for periods when the compressor is shut down for maintenance or repair. The building would also have a ventilation system capable of discharging the heat rejected from the motor and compressor. The ventilation system would also provide adequate air movement to prevent the buildup of flammable gas within the building.

The facility would tie in to the existing natural gas pipeline serving the power plant. The natural gas would be piped to the storage facility compressed and stored when the wind turbines are producing excess energy. When the wind turbines are providing less power than scheduled, the generators would ramp up and draw natural gas from the storage modules. During the storage discharge, a pressure regulating station will knock down the gas pressure from its storage pressure of 3,600 psig to the generator input pressure of 100 psig. The total cost for a 360 MWh gas storage facility would be approximately $22.8 million.

The cost analysis assumed a two gas storage facilities with associated compressors, buildings, site piping, storage modules, and labor expenses. A compressor building is included for the ML&P power plant facility. The cost analysis assumes that the Southcentral Power Plant has available room to house the natural gas compressor. One facility would have five gas storage modules while the other would have six. Two storage facilities would provide increased flexibility for maximizing the availability of on-line and off-line regulation resources.

Five different gas storage sizes were evaluated depending on the design criteria and the size of the wind farm.

- For a 17 MW Wind Farm
    - A 70 MWh gas storage facility with 25% "emergency" capacity (87.5 MWh)

- Gas storage located at one generation station
- Total system cost of $9.3 million

- For a 17 MW Wind Farm with capability to pick up 30 MW import reduction for 6 hours
  - A second Anchorage – Kenai intertie line is built, but the loss of the existing line would result in a 30 MW reduction in the Anchorage import capacity
  - A 250 MWh gas storage facility would be needed
  - Gas storage located at two generation stations
  - Total system cost of $18.2 million
- For a 52 MW wind Farm
  - A 210 MWh gas storage facility with 25% "emergency" capacity (262.5 MWh)
  - Gas storage located at two generation stations for improved availability
  - Total system cost of $18.2 million
- For a 52 MW Wind Farm with capability to pick up 30 MW import reduction for 6 hours
  - A second Anchorage – Kenai intertie line is built, but the loss of the existing line would result in a 30 MW reduction in the Anchorage import capacity
  - A 380 MWh gas storage facility would be needed
  - Gas storage located at two generation stations
  - Total system cost of $23.5 million
- For capacity restoration for loss of largest unit/Kenai Tie
  - No new Anchorage – Kenai Intertie
  - A 360 MWh gas storage facility with 25% "emergency" capacity (450 MWh)
  - Gas storage located at two generation stations for improved availability
  - Total system cost of $23.5 million

7 Conclusions and Recommendations

To provide Railbelt utilities with the ability to regulate both variable generation resources and the loss of the largest contingency in the Southcentral Railbelt, additional regulation resources are required in the Railbelt system. Regulation resources utilizing batteries, flywheels and compressed natural gas were evaluated in this study. Different battery and flywheel technologies were evaluated first by their suitability to a regulation application, and secondarily by their relative cost-effectiveness. Based on the long-term energy requirements, flywheel technology was considered infeasible for the Railbelt system. Based on the suitability and cost-effectiveness, EPS recommends the advanced lead-acid technology. The two main manufacturers of suitable lead-acid technology include Xtreme Power Inc., and Axion Power Inc. This report has focused on the Xtreme Power Inc. specific battery, but it is assumed that the Axion Power manufacturer would provide a system with similar capabilities and costs.

The regulation resource sizing has been evaluated using primary and secondary criteria. Primarily, the regulation resource should provide adequate regulation for the intermittent wind resource. Secondarily, the regulation resource could be able to provide adequate response to prevent load shedding in the Anchorage area for the loss of either a large unit, or the Kenai tie (with or without a HVDC intertie).

The power and energy requirements were evaluated separately. For a 17 MW wind farm configuration EPS recommends a power capability of at least 17 MW. For a 52 MW wind farm, EPS recommends a power capability of at least 50 MW. This power capability would be sufficient to regulate the full range of net power from the 52 MW wind farm. Additionally, the 50 MW is the minimum power capability to prevent load-shedding for the loss of the Kenai tie while operating at a maximum import into the Anchorage area.

For a 17 MW wind farm, to prevent an excessive number of hours during which the battery cannot account for wind down ramps, the minimum battery energy that should be considered is 10 MWh. The one-hour regulation resource energy capability was evaluated using economic analysis based on several factors including initial purchase price, battery pack replacement frequency, and losses due to battery inefficiency. The lowest installation cost was for a 17 MW, 10 MWh battery energy storage system.

For a 52 MW wind farm, to prevent an excessive number of hours during which the battery cannot account for wind down ramps, the minimum battery energy that should be considered is 25 MWh. The one-hour regulation resource energy capability was evaluated using economic analysis based on several factors including initial purchase price, battery pack replacement frequency, and losses due to battery inefficiency. The lowest installation cost was for a 50 MW, 25 MWh battery system.

However, a battery system with 42 MWh of energy capacity would be a reasonable alternative. It would increase the original purchase price by 30%, but would provide the additional system benefit of carrying enough storage capacity to provide 50 MW for 20 minutes. The reserve capacity would be enough to provide enough energy to survive the loss of the Kenai tie at 75 MW import in to the Anchorage area without load shedding, and provide enough time to start an additional gas turbine. The 42 MWh battery would only cost 11.5% more over the 20 year life of the project since the battery packs would need less frequent replacement. EPS recommends a battery energy capacity of 25 MWh solely for the regulation of the wind farm. However, with the additional system benefits of a 42 MWh battery, the larger battery energy capacity should be considered as an alternative in the final regulation resource decision process. Additionally, if the DC tie is not built and the utilities move forward with an upgrade of the AC tie, the battery MW/MWH capabilities should be determined as part of the coordinated transmission plan.

Similarly, for a 17 MW wind farm and the addition of a HVDC Beluga-Bernice Lake intertie, a BESS capacity of 25 MW and 14 MWH of energy is recommended to prevent load shedding in the Southcentral area following the largest contingency and to provide regulation of the wind resource.

In order to minimize costs, it could be possible to implement a battery system with a smaller power capability. An example would be to use the 25 MW battery system to regulate a 52 MW wind farm. During a system configuration with both minimal online reserves, and a risk of losing the full wind output, the wind farm could be curtailed prior to the loss of the total wind farm to prevent an energy shortfall. This would result in a slight reduction of renewable energy over the year, but would provide significant savings in the form of a smaller battery inverter system.

Due to the current gas contract schedule, the natural gas delivery amounts are set with six-hour schedules. With the loss of the Kenai tie and the associated hydro regulation resources, the Anchorage area utilities have very little capability to provide regulation for an intermittent resource. With the installation of gas storage facilities, the utilities will have the ability to regulate an intermittent resource such as wind. Again, the sizing of this resource was evaluated using the primary design criteria of providing wind regulation and the secondary criteria to cover the loss of the Kenai tie. In order to fully regulate the full wind output over a six hour schedule for a 17 MW or a 52 MW wind farm, approximately 100 MWh or 270 MWh of energy is needed, respectively. In order to minimize the costs, the gas storage capacity was reduced to a level that would minimize costs while still minimizing the frequency of storage energy shortfall.

The secondary criteria of covering the loss of the Kenai tie would need 360 MWh without a Beluga-Bernice HVDC tie or 180 MWH if the HVDC tie is constructed. In order to survive the worst case loss of the Kenai tie and provide minimal wind regulation, EPS recommends a 25% reserve margin of 90 MWh above the 360 MWh or 450 MWh for the no HVDC option and 45 MWH if the HVDC tie is constructed.

8 References

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