# Electricity Bill Reduction White Paper

David Watson
*Wind Energy Institute of Canada*
*21741 Route 12 North Cape, Prince Edward Island, Canada*
Tapabrata Chakraborty
*University of Regina-Electronic Systems Engineering*
*3737 Wascana Parkway Regina, Saskatchewan, Canada*
Marianne Rodgers
*Wind Energy Institute of Canada*
*21741 Route 12 North Cape, Prince Edward Island, Canada*

## Abstract

The Wind Energy Institute of Canada used its 1 MW/ 2 MWh storage system to reduce the electricity consumption of their 10 MW Wind R&D Park during periods of low wind. The storage system was charged during periods of high wind and that energy was released to the turbines and network when the wind power dropped below 0 kW. Despite December being historically one of the windiest months at North Cape, in 2014 there were three extended periods without significant wind power. This resulted in the battery reaching bottom state of charge and not being able to reduce the demand charge. The storage system was able to offset 8705 kWh, but this was insufficient to offset the net losses in the storage system for December 2014.

## 1. Introduction

The Wind Energy Institute of Canada (Institute), located in North Cape PEI, is a not-for-profit research institute which began as the Atlantic Wind Test Site. For over 35 years the Institute has been testing wind turbines and has been a leader in the integration of wind-diesel systems. Now the focus has changed as the Institute has installed a 10 MW Wind R&D Park with a 1 MW/2 MWh storage system to investigate wind integration techniques and increase understanding of the industry for energy storage. This project has received funding support from the federal government through Natural Resources Canada's Clean Energy Fund and from the provincial government through a loan, which is being repaid through the sale of the wind energy.

There are many possible uses for a storage system as outlined in Sandia National Laboratory's (Sandia) Electricity Storage Handbook(1) as well as in other papers on the subject of energy storage(2-4). The Institute's goal, along with their industrial and academic partners, is to test the storage system in various month long scenarios to understand the benefits and limitations of the storage system.

### *1.1 Wind R&D Park*

The Institute's Wind R&D Park has 5 DeWind D9.2 turbines, which each have a 2 MW rated output. These wind turbines have a synchronous generator that is connected to the variable speed shaft through a hydraulic Voith WinDrive. These turbines have a rotor diameter of 93 m which, along with the excellent wind resource in North Cape, have allowed the turbines to reach a monthly capacity factor of over 60% during strong wind months. The Wind R&D Park's storage system is comprised of S&C's Purewave inverter system, which interfaces GE's Durathon batteries to the substation. A back up diesel generator for substation power during extended outages on the transmission network has also been installed, but in December 2014 was not yet commissioned. The simplified one-line diagram of the Institute's Wind R&D Park is shown in Figure 1.

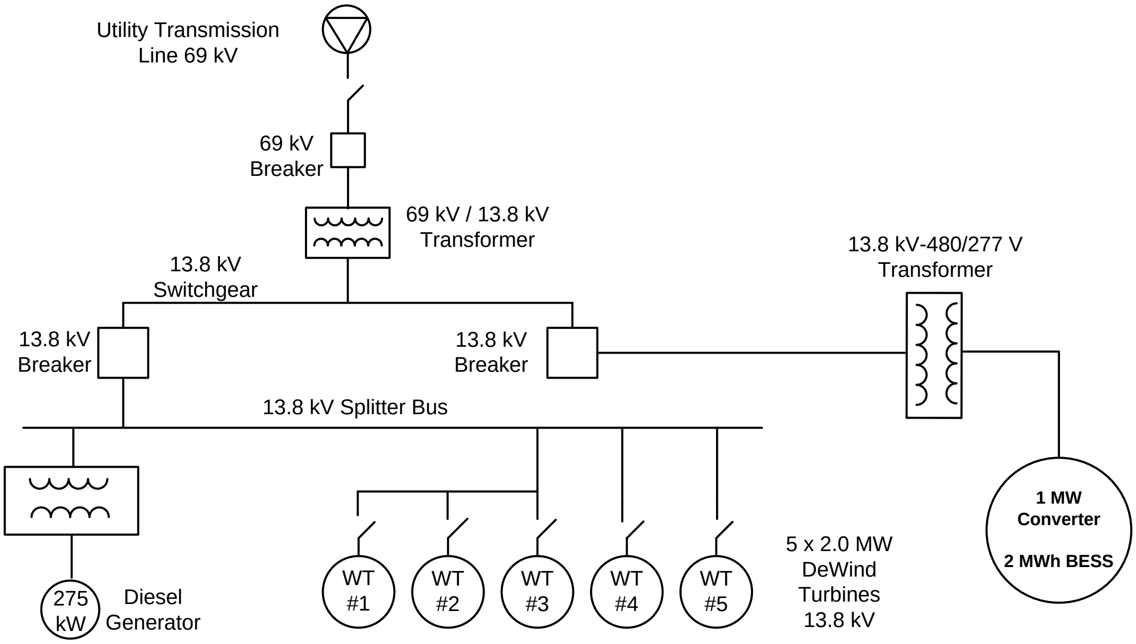

**Figure 1. Single line diagram of the Institute's Wind R&D Park**

### *1.2 Demand and Electricity Avoidance on a wind farm*

In the Institute's Wind R&D Park, electricity is needed during times of low wind to provide power to the substation as well as the turbines in order to run pumps, heaters, and yaw the turbines. This power is purchased from the local utility, Maritime Electric Company Ltd. (MECL) at the small industrial rate, which, in December 2014, had the following costs before tax:

- Energy Charge: $0.1566/kWh for the first block of energy, which is 100 times the demand charge and $0.0784/kWh for the remaining energy
- Demand Charge: $7.17/kW for the highest 15 minute monthly average

The sale of electricity from the wind farm is at a lower price than this electricity, especially the 1st block of electricity ($0.1566/kWh). This differential, along with the opportunity to avoid the demand charge, allows for a financial incentive for the Institute to operate the battery to provide power during times of low wind.

The cost of electricity between the Wind R&D Park's commissioning and the installation of the storage system is shown in Table 1. After the installation of the storage system, in February 2014, the energy and demand varied due to uncommon incidences when the storage system was charging during periods with insufficient wind power.

**Table 1. Energy and demand for the wind park between commissioning of wind park and installation of the storage system using December 2014 prices**

| Date | Energy (kWh) | Demand (kW) | Cost of Energy ($) | Cost of Demand ($) | Total Cost ($) |
|---|---|---|---|---|---|
| **Apr-13** | 15429 | 123.8 | 2157.32 | 923.55 | 3080.87 |
| **May-13** | 14163 | 116.2 | 2002.03 | 866.85 | 2868.88 |
| **Jun-13** | 16276 | 127.9 | 2252.86 | 954.13 | 3206.99 |
| **Jul-13** | 13771 | 162.5 | 2156.54 | 1212.25 | 3368.79 |
| **Aug-13** | 15538 | 126.4 | 2187.21 | 942.94 | 3130.15 |
| **Sep-13** | 6642 | 127.5 | 1040.14 | 951.15 | 1991.29 |
| **Oct-13** | 10347 | 122.5 | 1620.34 | 913.85 | 2534.19 |
| **Nov-13** | 8007 | 121.7 | 1253.90 | 907.88 | 2161.78 |
| **Dec-13** | 7764 | 141.8 | 1215.84 | 1057.83 | 2273.67 |
| **Jan-14** | 7942 | 143.3 | 1243.72 | 1069.02 | 2312.74 |
| **Average** | **11588** | **131.4** | **1712.99** | **979.95** | **2692.93** |

The Institute's Wind R&D Park produced 4496 MWh in December of 2013, giving a capacity factor of 54%. With this high capacity and the short amount of time the wind park has low production, December looked like a good month to reduce the electricity bill. As shown in Table 1, the turbines consumed only 7764 kWh over the month with a demand of 141.8 kW. The longest period between no wind power and 1500 kW for December 2013 was less than 15 hours.

## 2. Methodology

The logic was tested and implemented at the end of November 2014 with the month long test beginning the first of December 2014. During this period, a discharge of 120 kW was used whenever the net power dropped below 0 kW. The discharge was stopped when the net power was 350 kW, meaning the wind turbines were supplying 230 kW. The battery was charged at a rate of 500 kW whenever the wind power reached over 1500 kW and the charging was stopped when the net power dropped to 500 kW. The logic diagram is shown in Figure 2 and the conditions are explained in Table 2.

GE's Durathon battery has a self-discharge rate of approximately 0.5%/hour in order to keep the battery heated to its operational temperature of 280 °C. In order to avoid continuous charging near 100% state of charge (SoC), the battery does not charge, after reaching 100%, until the SoC drops to below 95%. During periods of high wind, this creates a charging every 7-10 hours as shown in Figure 3.

The Durathon battery requires a weekly maintenance cycle, which consists of a charge to 100% followed by a discharge to approximately 55% at a rate of around 200 kW and then a charge back to 100%[1]. This cycle takes approximately 11 hours if started from a high state of charge. The maintenance cycle reduces the SoC to 55%, which causes the length of time the battery is able to cover a low wind period to decrease from approximately 15 hours to 8 hours.

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[1] The maintenance cycle has been altered so that only a charge to 100% is required, and it is not required if normal operation has a similar characteristic to the formal maintenance cycle

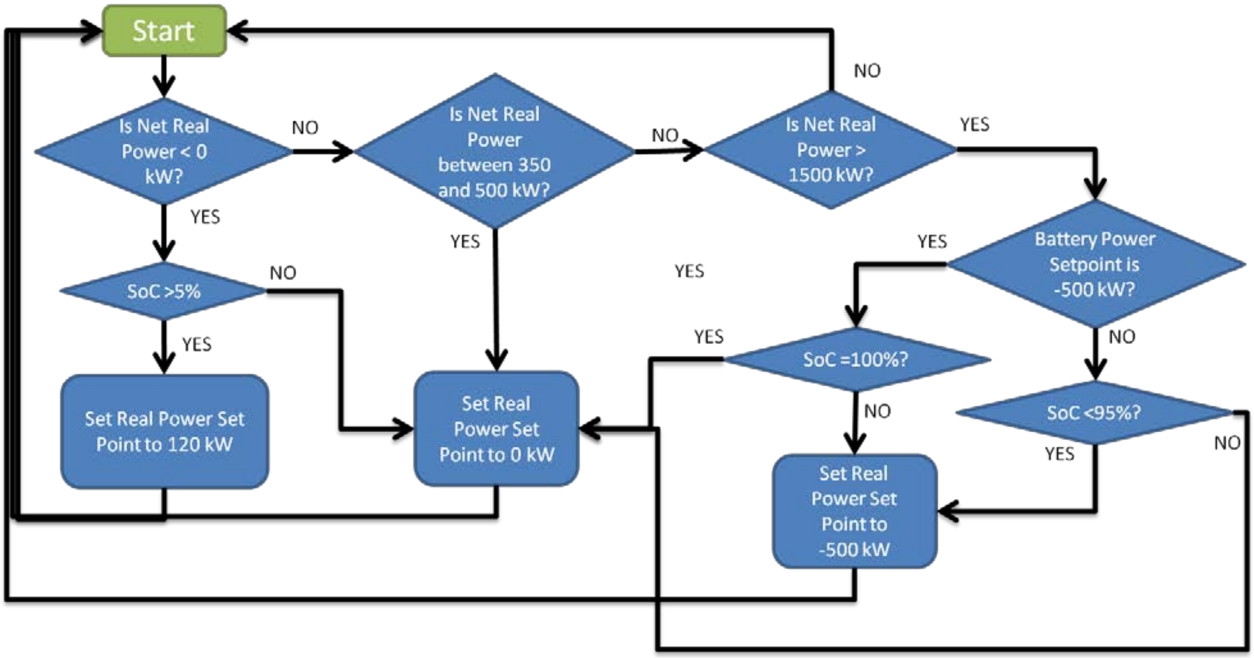

**Figure 2. Logic table for demand and energy avoidance**

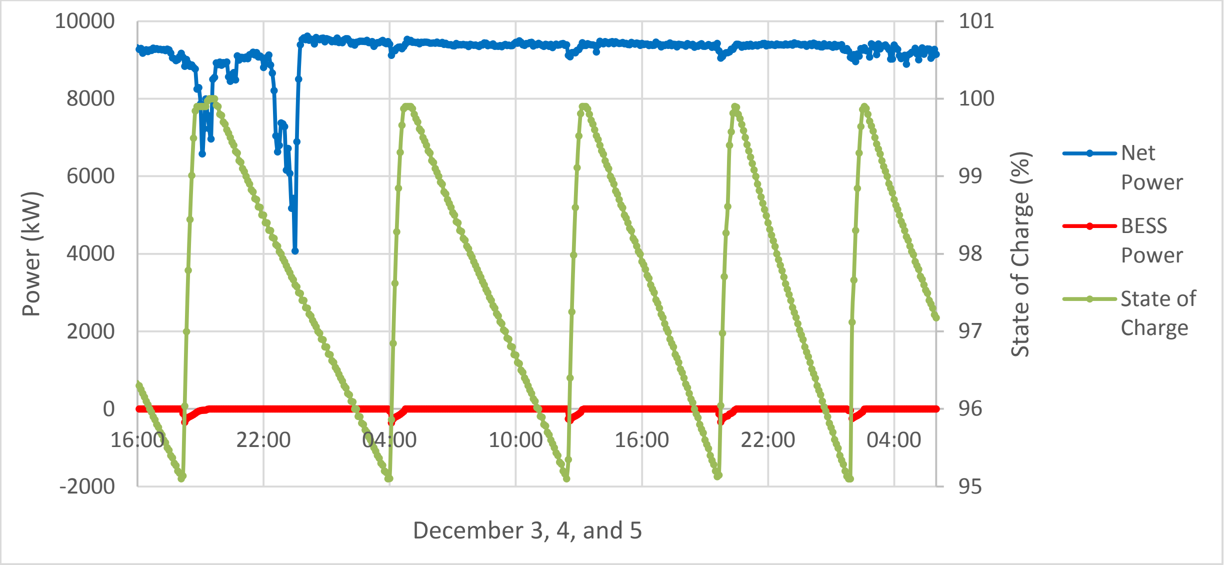

**Figure 3. Charging and self-discharge to keep BESS at operational temperature**

The logic implemented to control the maintenance cycle is shown in Figure 4. The logic ensures that the net power is above 5 MW and that the SoC is high to reduce the time needed in the maintenance cycle. The maintenance cycle is exited if it not needed (i.e. finished) or the net power falls below 500 kW as the battery will be required for the demand and energy avoidance. The battery operator can disable the maintenance cycle logic in order to avoid beginning the maintenance cycle if the forecast shows that an extended low wind period will happen just after the discharge period of the maintenance cycle.

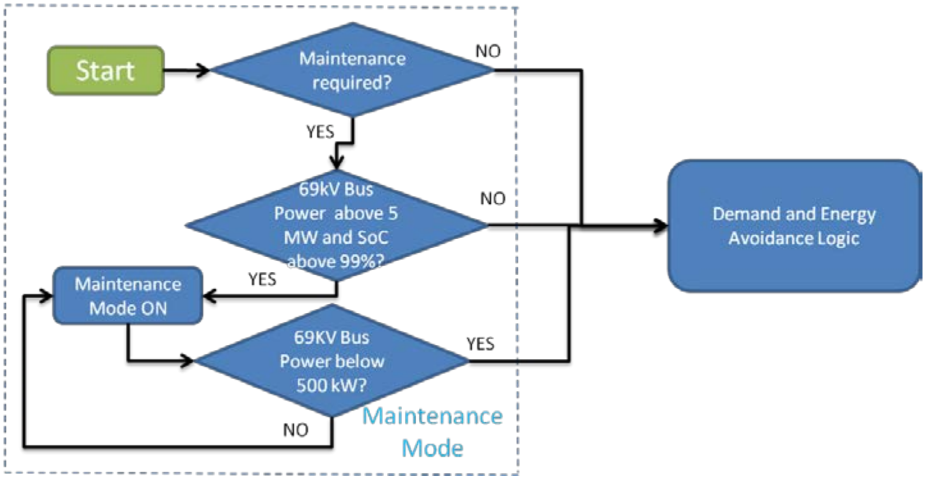

**Figure 4.** **Logic diagram for maintenance mode**

## 3. Results and Discussion

In December 2014 the electricity usage was reduced by 8705 kWh by discharging the BESS during periods of low wind. This resulted in a cost avoidance for the Institute of $867. The total battery efficiency for December was 56.4% with 29,806 kWh absorbed by the storage system and 16,580 kWh sent to the turbines and grid, mostly during periods of low wind. This results in a net loss of energy of 13,298 kWh which represents the opportunity cost of using the storage system.

### *3.1 Battery Performance*

The storage system discharging during low wind periods to ensure the wind park power remains around 0 kW is shown in Figure 5 along with the BESS power changing to idle mode and 500 kW charge mode.

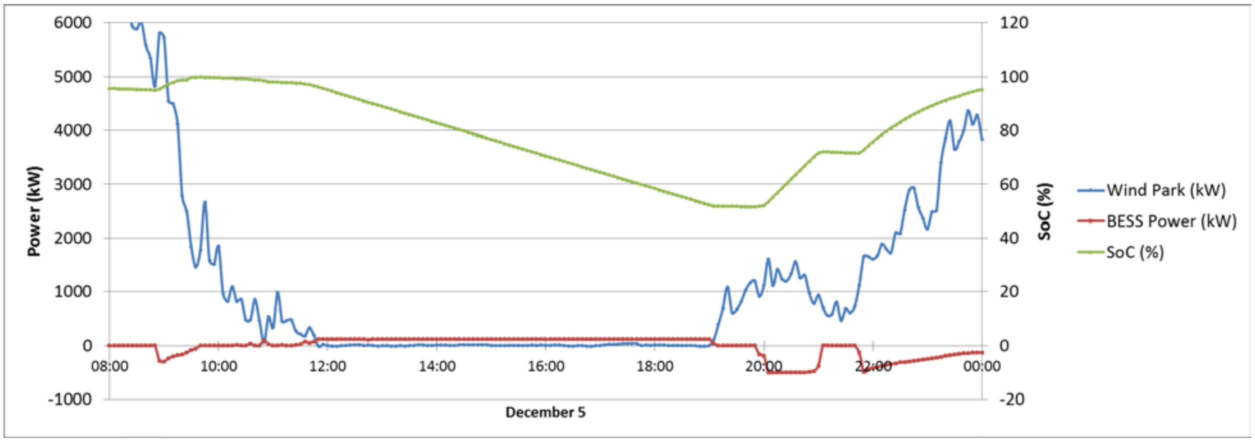

**Figure 5.** **Storage system working as expected to ensure net power stays near 0 kW**

During this month long scenario three maintenance cycles were accomplished (December 9th, 19th, and 26th). Additionally on December 6th the maintenance mode was attempted but stopped due to low wind and on December 7th the battery faulted due to a communication fault during the maintenance cycle. This fault occurred during a period of high wind so no demand or energy was absorbed from the grid. The fault happened at 1:50 on December 7th and was cleared at 12:10. The battery went through its heating and reconnecting cycle and came online at 19:15. The battery was therefore unavailable for 17 hours and 25 minutes. On December 18th a maintenance cycle also stopped due to a drop in wind power during its final charge cycle. The December 19th maintenance cycle is shown in Figure 6.

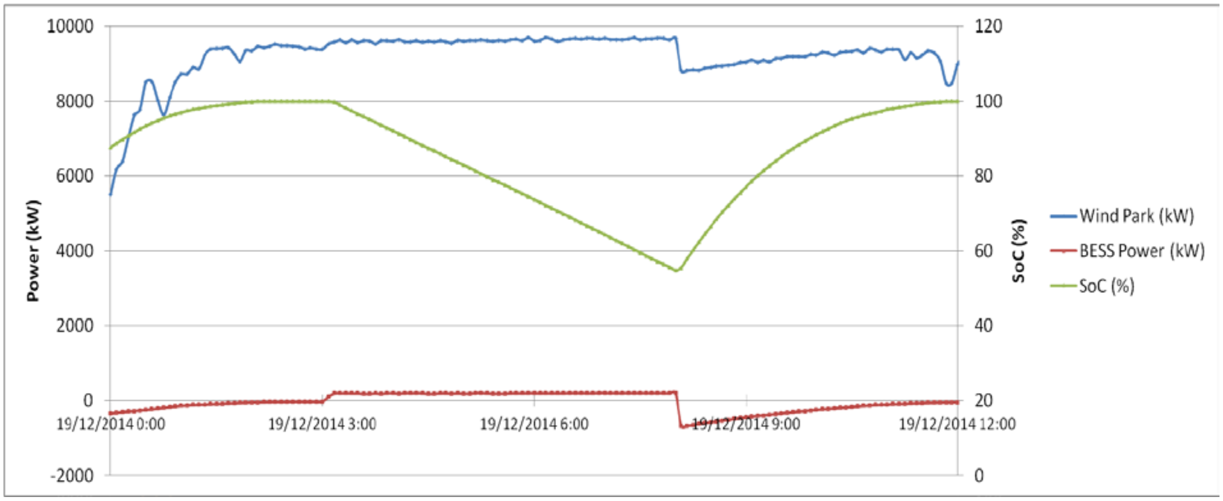

**Figure 6. Successful maintenance cycle on December 19th**

During periods of high wind the battery uses its own stored energy to keep the battery heated. This decreases the SoC and when 95% is reached the battery recharges to 100%. This cycle is repeated approximately every 8 hours, as shown for December 28th and 29th in Figure 7. Three cycles are repeated from December 28th at 18:00 to December 29th at 18:00.

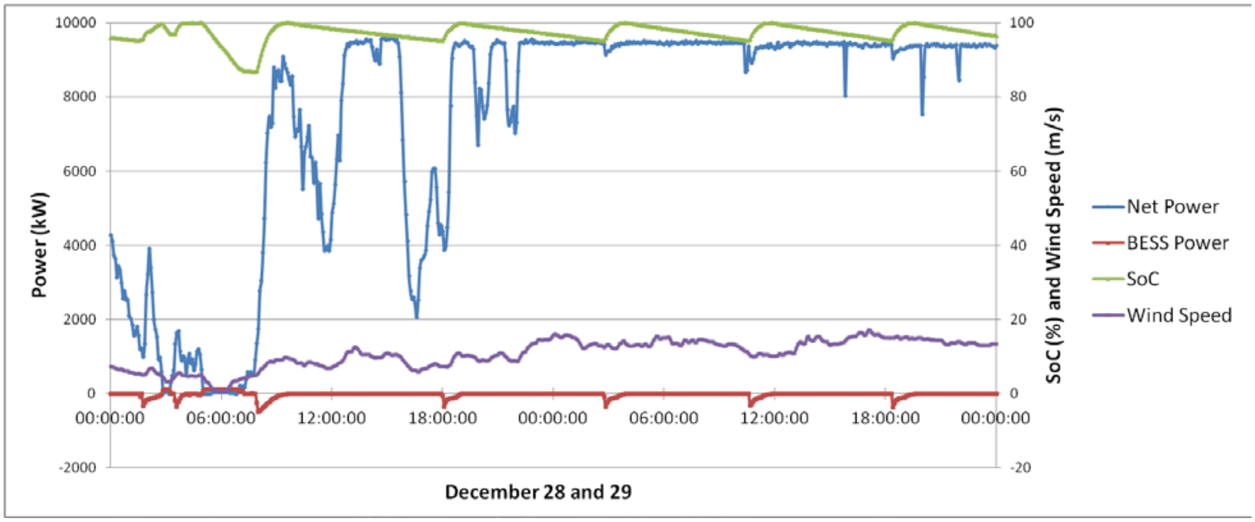

**Figure 7. Battery power and net wind park power during day of high wind**

On December 13th and 14th there was a low wind period of 30 hours during which the wind power did not reach 1500 kW to begin charging. The battery discharged at 120 kW for over 15 hours from 8:15 to 23:25 and then reached its lower threshold of 5% SoC. At this time the battery stopped discharging and slowly depleted to keep the batteries heated. It took 11 hours to reach 0% SoC where it remained for an additional 4 hours before the wind power rose to 1500 kW in order to begin the charging. Figure 8 shows the discharge and standby period and Figure 9 shows the recharge.

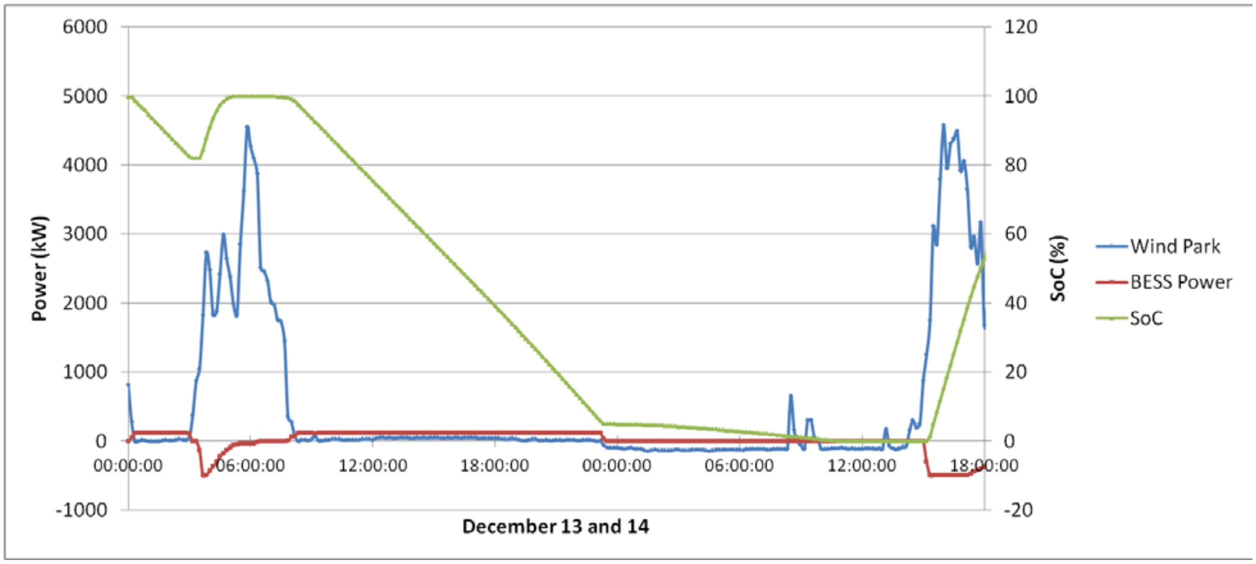

**Figure 8.** Battery power and SoC as well as net wind park power on a very calm day

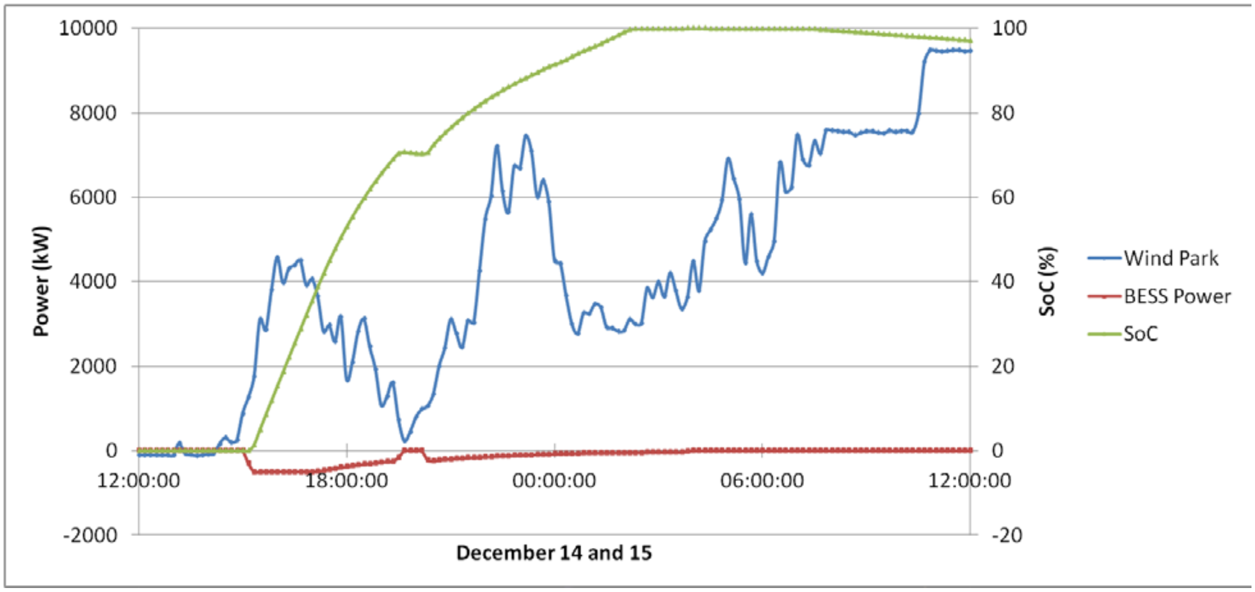

**Figure 9.** Charging after an extended period without wind

Note in Figure 9 that the SoC begins to increase well after the charging begins. This is because the 0% state of charge is slightly offset, not unlike the gasoline empty mark in most automobiles.

An extended period without wind power occurred again on December 16th and 17th with the wind remaining below the turbines cut-in wind speed for 37 consecutive hours as shown in Figure 10.

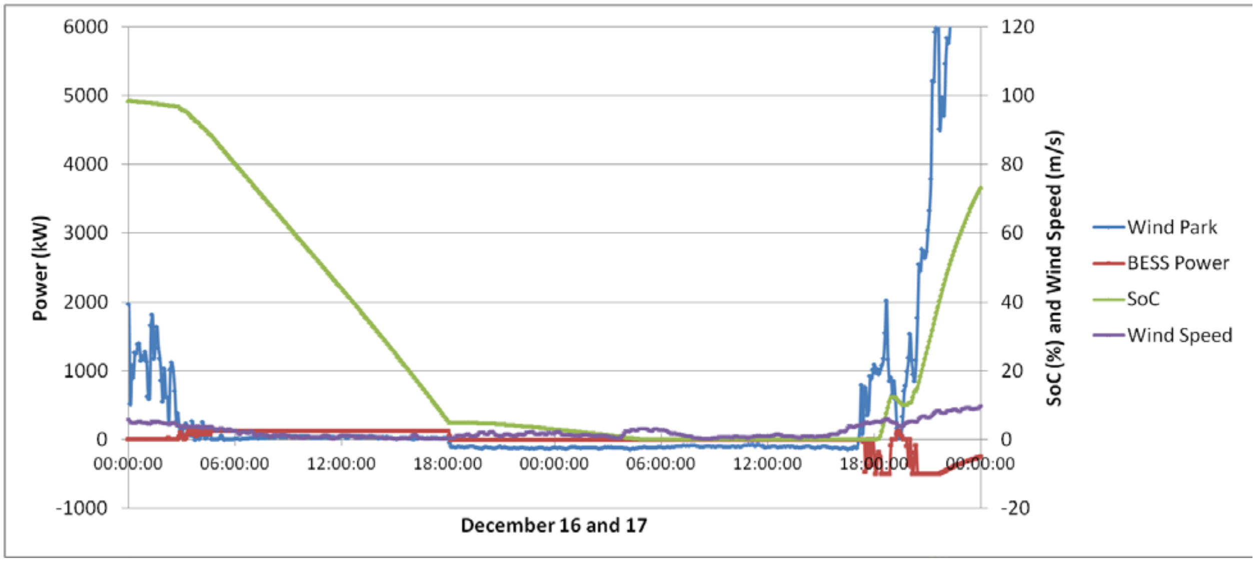

**Figure 10. Low wind on December 16th and 17th**

During both the low wind period of the 13th and 14th as well as the 16th and 17th the battery remained connected to the grid and, although the SoC remained at zero, there was still sufficient energy to keep the battery heated until wind power reached 1500 kW and charging commenced.

The battery operator looking at the long range forecast for December 21st to 24th and noted an extended period without sufficient wind power which was likely to cause the battery to fully self discharge to the point where it would disconnect from the network once the battery temperature reached 240 °C. To avoid this, the operator manually stopped the battery discharge at 6:40 on December 21st at 27.4%. This would allow for approximately 55 hours of self discharge. Despite this precaution the wind power did not reach the needed threshold until December 24th at 6:10, 84 hours from the beginning of the discharge, the longest time without wind power reaching 1500 kW since commissioning the wind park April 1st 2013. The time range of December 21st to the 24th is shown in Figure 11.

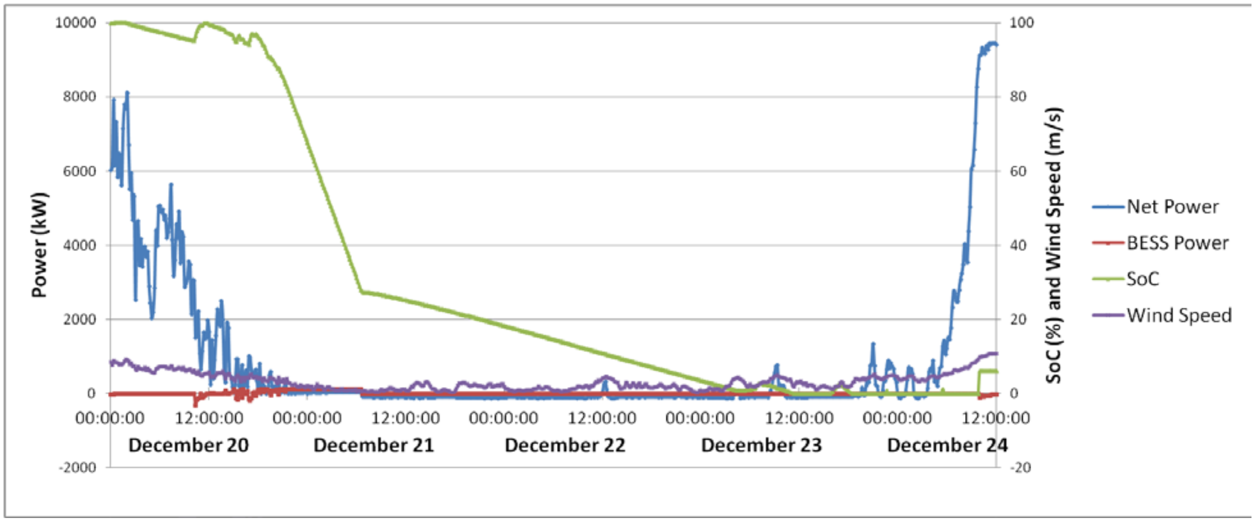

**Figure 11. Longest time range for the wind power to be below 1500 kW since commissioning**

Due to the battery fully depleting, the battery was reset remotely and entered its heating cycle at 10:10 on December 24th and, once its heating cycle was finished, it was returned to the demand/energy avoidance logic at 17:00, as shown in Figure 12. Note that the axes have been altered from the other graphs to show in detail the BESS power fluctuations during the heating cycle. The heating cycle consists of two parts; part 1 is the heating which draws around 100 kW at the beginning falling to 25 kW near the end of heating. Part 2 is where the 100 modules are connected to the busbar, this begins at the lowest voltage and increases the voltage by drawing power from the network (turbines in this case). This is the draw of around 600 kW. After this is complete, the heating cycle finished and the operator returned the battery to its normal logic program, which began the charging at 500 kW. The SoC of 6% is an offset value during the heating cycle, when the heating cycle finished the SoC was 3.6%.

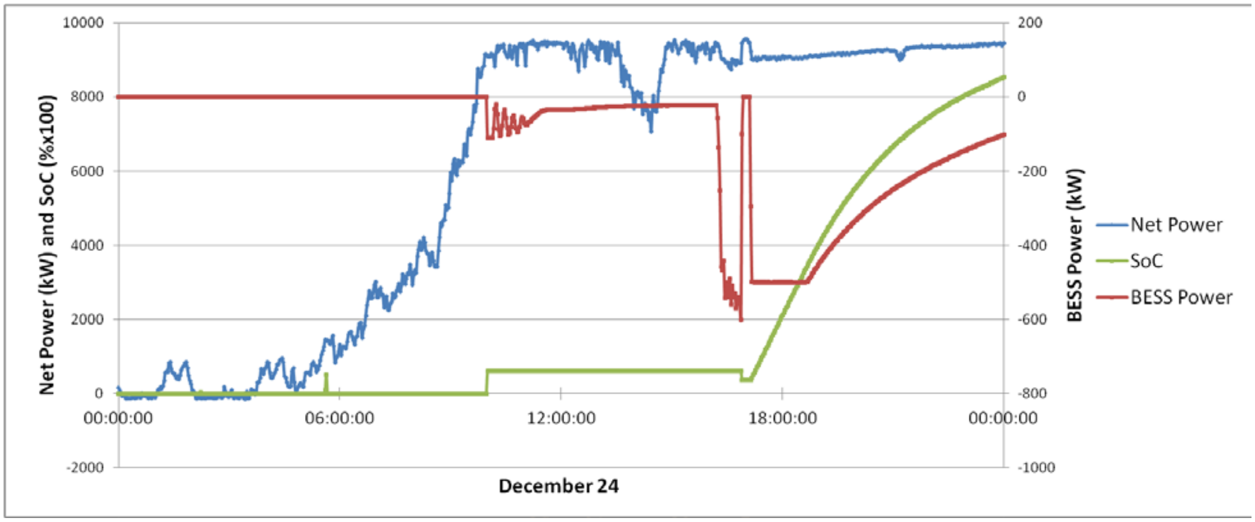

**Figure 12. Heating and charging after cooling due to extended low wind period**

### 3.2 *Efficiency and availability*

The auxiliary loads greatly influence the overall efficiency of a storage system when it is sparsely used. For GE’s Durathon battery, which operates at 280 °C the heating requirement during idle mode decreases the overall efficiency. For a discharge/charge cycle such as on December 5th (Figure 5) the efficiency over the 16.6 hours from SoC 100% to 51.5% and back to 100% was 72.7% with 909 kWhs being discharged. December’s overall efficiency was 56%.

The availability of the storage system in December 2014 is calculated as the total time the system is online, derating for modules offline. Two modules were offline for the entire month of December, additionally a fault on December 7th at 1:50 caused the storage system to be unavailable for 17 hours and 25 minutes. Table 2 shows the availability with and without the maintenance cycle time counted as available.

**Table 2. Availability of storage system in December 2014**

| | Availability (with maintenance cycle) | Availability (without maintenance cycle) | Total time (hours) | Maintenance cycles (hours) | BESS Fault (hours) | 2 modules offline (hours) |
|---|---|---|---|---|---|---|
| Dec-14 | 91.0% | 95.7% | 744.0 | 34.3 | 17.4 | 744.0 |

### 3.3 *Shortfalls of the demand and energy avoidance logic*

Using Acselerator RTAC data class in a program, a user can send variable power set points to the battery controller (S&C's SCADA). Controllable Analog Set Point (APC) is an IEC61131-3 standard data class that is used for this purpose and has 'SetMag' and 'Trigger' as two attributes or data elements in the APC data class hierarchy. In order to set the setpoint for the battery as shown in Figure 2, the 'SetMag' is sent from the RTAC to the S&C SCADA based on the readings from the ION meter which measures, amongst other things, the net real power send to and absorbed from the grid. In addition to the quantity which is requested, a 'Trigger' a Boolean variable needs to be sent to cause the value to change. The analog setpoint value in 'SetMag' is only sent when RTAC detects a rising-edge on this trigger (FALSE to TRUE). Table 3 shows the conditions used for this scenario.

**Table 3. Conditions for the demand/energy avoidance**

| | Start | End | Conditions |
|---|---|---|---|
| Discharge 120 kW | Net power <0 kW | Net Power > 350 kW | SoC >5% |
| Charge 500 kW | Net power > 1500 kW | Net power <500 | SoC <100%, when 100% is reached will not charge again until 95% is reached |
| The BESS power is always 0 between 350-500 kW and will be 0 from 350 to 0 kW if the battery is not discharging and from 500-1500 if the battery is not charging. Additionally if 100% has been reached it will not charge until 95% is reached. | | | |

When the net power is between 0 and 350 kW as well as between 500 and 1500 kW the trigger is set to false so that as the wind power increases and decreases the trigger is reset to false before being needed to send a new setpoint. As the wind power is updated every second, this ensures that even in fast changing wind speeds (and therefore power) the trigger will be set to false.

On December 10th at 15:00 the turbines began to go offline due to high winds causing vibration faults and power output oscillation faults. At 18:50 the last turbine went offline with the net power dropping from 1847 kW to -117 kW in five seconds. During this time the power dropped from 390 kW where the trigger was set to TRUE to below 0 kW, which caused the trigger to remain TRUE throughout the transition and therefore not update the setpoint to discharge at 120 kW. The battery operator noticed this condition at 19:40 and toggled the trigger value to FALSE, then back to TRUE in order to update the setpoint.

**Table 4. Wind Park power during a high wind event causing all turbines to go offline due to vibration faults and power output oscillation faults**

| **Time** | **Wind Park Power (kW)** | **TRIGGER** |
|---|---|---|
| Dec 10 18:50:25 | 1847 | TRUE |
| Dec 10 18:50:26 | 1430 | FALSE |
| Dec 10 18:50:27 | 1429 | FALSE |
| Dec 10 18:50:27 | 392 | TRUE |
| Dec 10 18:50:29 | 390 | TRUE |
| Dec 10 18:50:30 | -117 | TRUE |
| Dec 10 18:50:31 | -119 | TRUE |

One option to prevent this from happening is for a feedback loop to read whether the trigger is TRUE prior to setting the setpoint and transition the trigger to FALSE. This piece of code was added for the 120 kW discharge to avoid the situation on December 10th from happening again. No other changes were made to the system in December except a manual stop on December 21st at 27.4% to try to prevent the batteries from going offline due to losing all power during the longest period without significant wind power since the commissioning of the wind park.

## 4. Conclusions and next steps

December 2013 and December 2014 had dramatically different wind profiles. In 2013 the proposed energy and demand charge algorithm would have been able to avoid the turbines consuming electricity from the network, except after the high voltage line outage (December 4, 2013), which would have caused the battery to cool down and not be available when the turbines started up after the high voltage line was returned to service. For December 2013 an estimated 330 kWh would have been drawn from the grid, after the outage, with the remainder (7434 kWh) supplied by the battery. This would result in $1182.67 of savings, as high cost energy would be displaced, but the demand charge would not have been reduced.

December 2014 saw three extended periods without wind, December 13th and 14th had a period of 31 hours, December 16th and 17th a period of 39 hours and finally the 20th-24th where the wind power stayed below 1500 kW for 84 consecutive hours. These extended periods without wind is unusual in the winter in North Cape, although periods of 20-40 hours is fairly common during summer months.

For electricity bill reduction, the highest cost savings is when both the energy and the demand charge is avoided. This would mean that both the energy and demand would be avoided for the month in question. The total potential savings was shown in Table 1, with an average potential of $2692. Table 5 shows the energy drawn and released from the battery and the net economic impact of $-403.85.

**Table 5. Flow of energy and money over December 2014 scenario**

| | Energy drawn from turbines | Energy drawn from MECL | Power drawn from MECL | Energy released to turbines | Energy released to MECL | Net |
|---|---|---|---|---|---|---|
| **Energy (kWh)** | 29,618 | 188 | 5 kW | 8705 | 7875 | -13,226 |
| **Price ($)** | -2345.15 | -29.91 | -37.3 | 1384.97 | 623.54 | -403.85 |

There are various opportunities to improve the algorithm. The first way is to have a feedback loop to discharge at the rate needed to hold the 69 kV bus power at a set level, for example 0 kW. This would ensure that no power from the battery is exported to the grid during times of low wind, lengthening the discharge time. Similarly the charge rate could change based on the actual wind power to allow for charging once the wind power becomes positive.

A second improvement would be to incorporate a wind forecast so that the discharge could be increased or decreased based on the amount of time that the wind power is expected to be below zero.

This would allow for the demand charge to be reduced even during extended periods without wind power.

Using the Institute’s storage system to reduce the electricity bill of the wind turbines is unlikely to cover the operational costs unless the demand charge can be reduced. Utilizing a forecast and a dynamic charge and discharge rate would increase the ability of the 2 MWh system to provide the power to the turbines during periods of low wind. For the month of December the efficiency of the storage system was 56% and provided 8705 kWh of power to the turbines during periods of low wind, reducing the electricity bill by $1317.76. This would have been larger had the demand charge been reduced. The Institute and their partners have learned from this monthly scenario and look forward to making improvements in order to show how a storage system can have positive economic impact for a wind farm.

## 5. References

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