Final Report - Award No. DE-FC26-08NT02874

Integrated, Automated Distributed Generation Technologies Demonstration

Kevin R. Jensen

ATK Launch Systems
P.O. Box 707 MS 552
Brigham City, UT 84302-0707
Phone 435-863-5379
E-Mail: KevinR.Jensen@ATK.com

Sept. 2014

Acknowledgement: This material is based upon work supported by the Department of Energy [National Energy Technology Laboratory] under Award No. DE-FC26-08NT02874.

Table of Contents

1. EXECUTIVE SUMMARY

The purpose of the NETL Project was to develop a diverse combination of distributed renewable generation technologies and controls and demonstrate how the renewable generation could help manage substation peak demand at the ATK Promontory plant site. The Promontory plant site is located in the northwestern Utah desert approximately 25 miles west of Brigham City, Utah. The plant encompasses 20,000 acres and has over 500 buildings. The ATK Promontory plant primarily manufactures solid propellant rocket motors for both commercial and government launch systems.

The original project objectives focused on distributed generation; a 100 kW (kilowatt) wind turbine, a 100 kW new technology waste heat generation unit, a 500 kW energy storage system, and an intelligent system-wide automation system to monitor and control the renewable energy devices then release the stored energy during the peak demand time. The original goal was to reduce peak demand from the electrical utility company, Rocky Mountain Power (RMP), by 3.4%.

For a period of time we also sought to integrate our energy storage requirements with a flywheel storage system (500 kW) proposed for the Promontory/RMP Substation. Ultimately the flywheel storage system could not meet our project timetable, so the storage requirement was switched to a battery storage system (300 kW.)

A secondary objective was to design/install a bi-directional customer/utility gateway application for real-time visibility and communications between RMP, and ATK. This objective was not achieved because of technical issues with RMP, ATK Information Technology Department’s stringent requirements based on being a rocket motor manufacturing facility, and budget constraints.

Of the original objectives, the following were achieved:

- Installation of a 100 kW wind turbine.
- Installation of a 300 kW battery storage system.
- Integrated control system installed to offset electrical demand by releasing stored energy from renewable sources during peak hours of the day. Control system also monitors the wind turbine and battery storage system health, power output, and issues critical alarms.

Of the original objectives, the following were not achieved:

- 100 kW new technology waste heat generation unit.
- Bi-directional customer/utility gateway for real time visibility and communications between RMP and ATK.
- 3.4% reduction in peak demand. 1.7% reduction in peak demand was realized instead.

2. WIND TURBINE

ATK originally contracted with J.P. Sayler and Associates for a 100 kW rebuilt wind turbine. They were paid $49,000 on receipt of PO for initial down payment. J.P. Sayler claims the wind turbine they were going to purchase from Broadwind was sold to someone else before they could purchase it. J.P. Sayler did not tell ATK of this development for three months. During this time period, J.P. Sayler tried to locate another wind turbine. When they finally found one, the cost increase was significant and ATK terminated the contract and demanded our down payment back. J.P. Sayler insisted the $49,000 was spent trying to find another unit and he was not able to reimburse ATK. This action has gone to the ATK legal department but their efforts to get the $49,000 have been in vain.

After this contract fell through, ATK contracted with Talk Inc. to install a remanufactured 95 kW wind turbine. The installation completed in November 2012. The wind turbine is situated on a hill that separates two large valleys and is an ideal wind location. This area of the plant sees a significant amount of wind. The wind generator is generating power about 60% of the time. The output of the generator depends on wind speed (See Figure 1). The wind turbine has been in operation for 18 months.

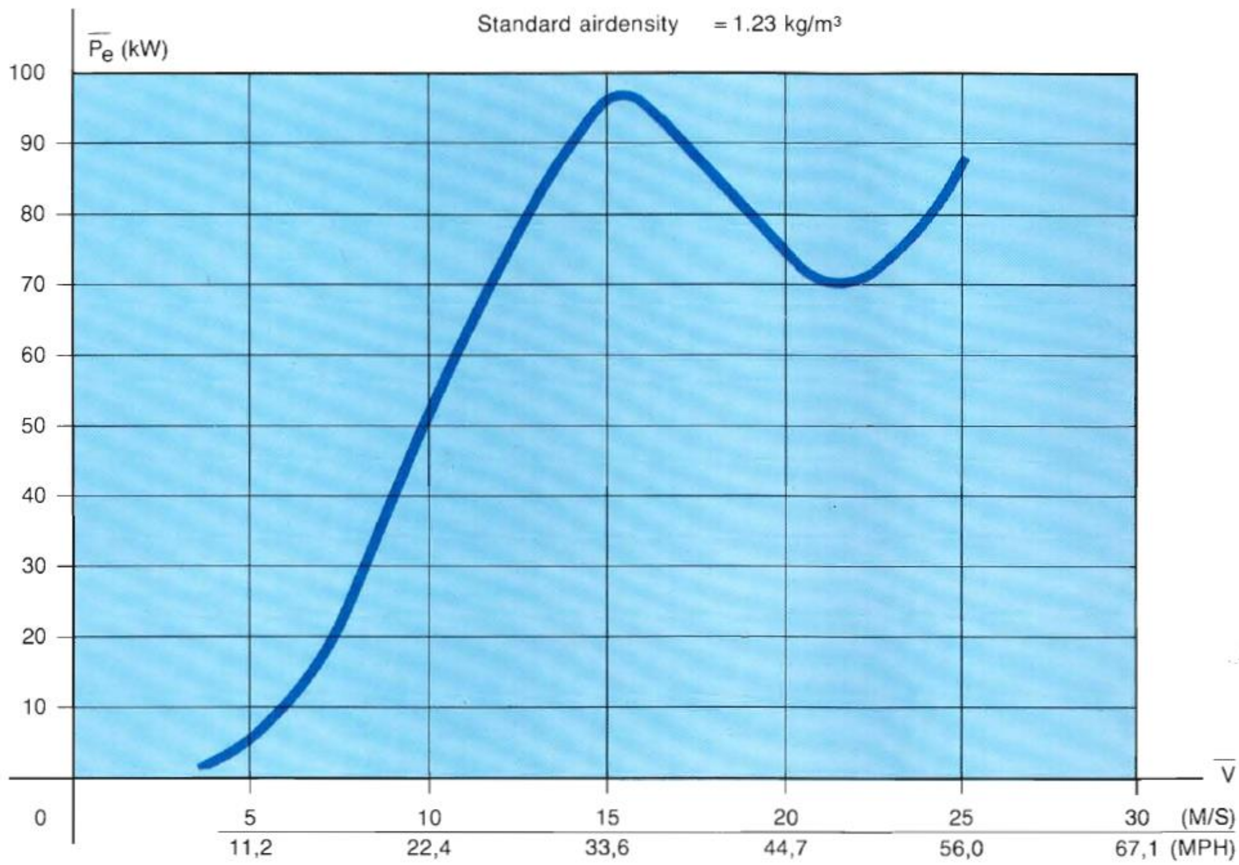

Figure 1 – Wind turbine: Wind speed versus power output curve

In one year, the wind generator produced approximately 32,000 kilowatt-hours (kWh) which is equivalent to $1,600 at a cost of $.05 per kWh. The total height of the lattice tower and the blades reach a height of approximately 140 ft. Figures 2 and 3 show the area where the wind turbine is installed.

Figure 2 - Installation of 95 kW Wind Generator

Figure 3 - Wind Generator in Operation

The control system monitors the instantaneous, daily and monthly wind turbine output as shown in Figures 4, 5, and 6. All of the energy generated by the wind turbine is fed directly into the plant power system where it can be either consumed or stored by the new battery storage system.

Much of the wind occurs at night and in the early morning hours during non-peak energy times. Through the incorporation of an energy storage system, the wind turbine output is maximized by storing this energy and dispatching it during the peak energy period of the day. The wind turbine has performed as expected. If the wind turbine is generating electricity during the peak time of the day, the output is consumed rather than stored by the battery system.

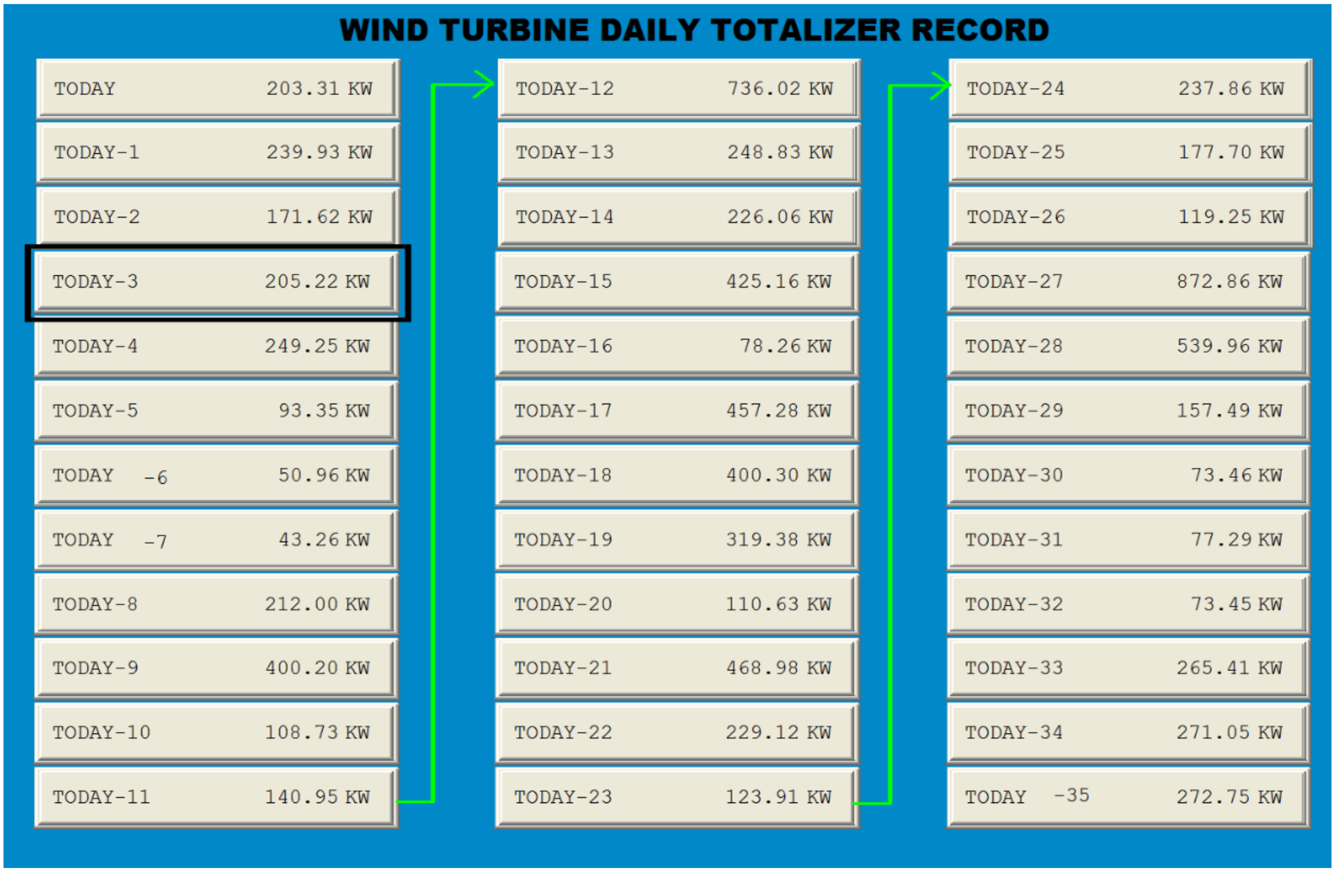

Figure 4 – Example of Wind Turbine Daily Totalizer Record

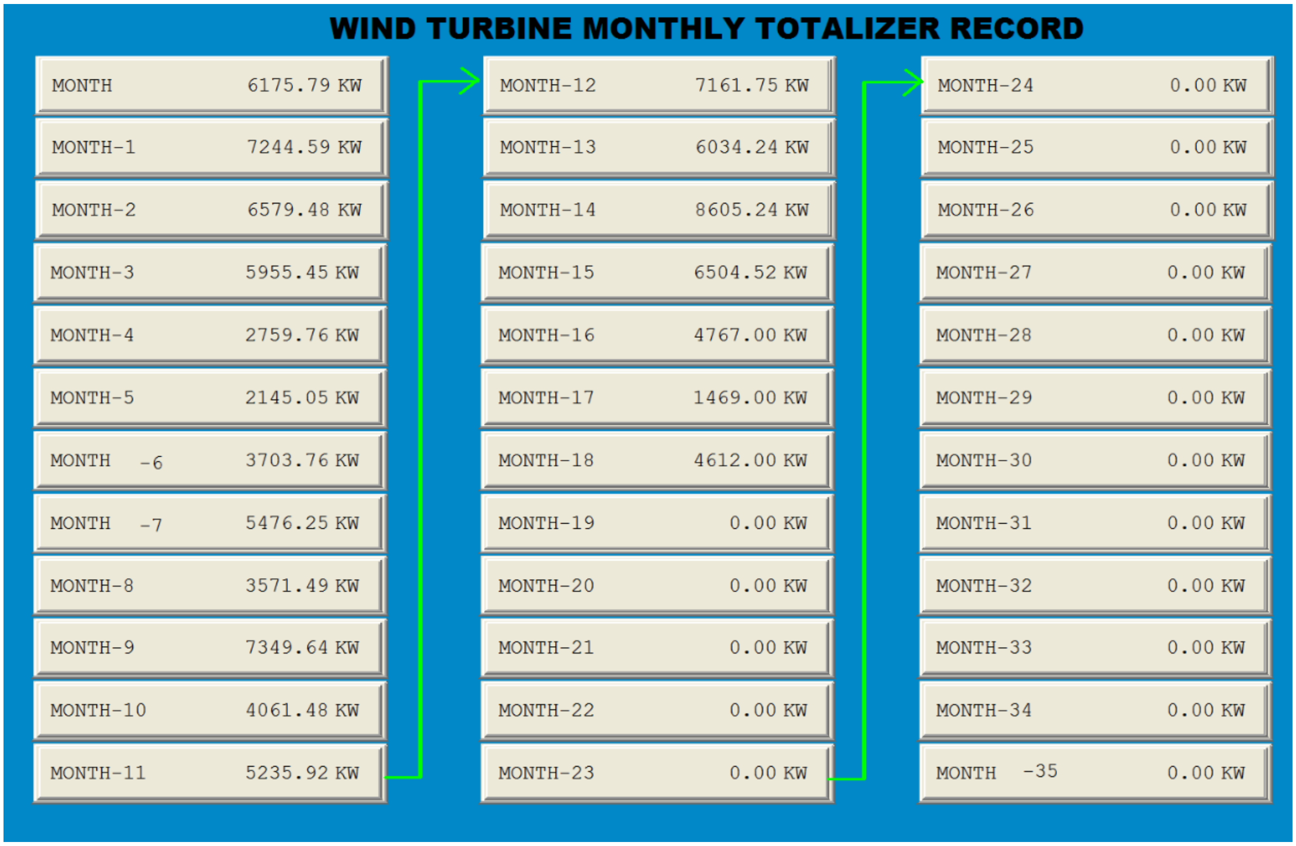

Figure 5 – Example of Wind Turbine Monthly Totalizer Record

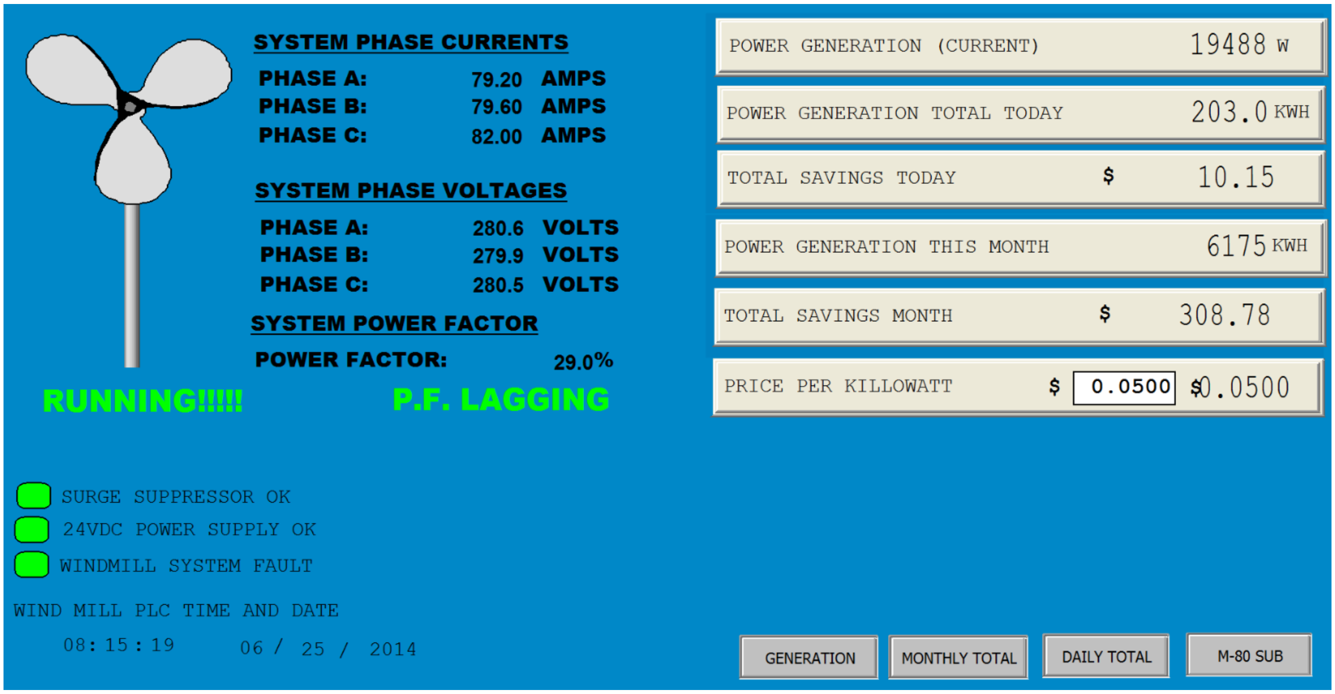

Figure 6 – Example of Wind Turbine Status Report

3. Storage System

A shortcoming some renewable generation resources (e.g. wind, solar) is electrical energy is only generated when the wind blows or the sun shines, not necessarily when the energy is needed. By coupling the renewable generation with electrical energy storage, the renewable resource becomes "dispatchable on-demand" and much more valuable for offsetting peak electrical costs. ATK spent considerable effort in researching flywheel technology for the storage system with a company called EMB Energy. The storage system originally was an underground 500 kW flywheel storage array. Rocky Mountain Power was also involved in the technical interchange and was working alongside EMB Energy to demonstrate a breakthrough in energy storage for electric power systems. ATK was only purchasing a portion of the overall system, to be installed on ATK property at a discounted price.

The energy storage system consisted of (1) a high tech 25' diameter fiber composite flywheel, (2) a unique passive magnetic bearing system, and (3) an electrostatic motor generator. These three technologies were to operate in a vacuum with electrical feeds to power electronics that interact with the utility's AC power system. While specific design details were proprietary, it can be stated that the combination of these three technologies has the potential to greatly drive down the unit price of flywheel-based electrical energy storage because of the extremely high speed flywheel and near frictionless bearings.

The design called for a column of flywheels stacked one on top of the other below ground level. There would be a total of 10 flywheels in each array in tunnels about 80 feet deep (See Figure 7). Each flywheel would produce approximately 250 kWh of electricity. Therefore each 10 flywheel array would have a capacity of approximately 2.5 megawatt-hours (mWh). The system would be expandable with 10 more arrays for a total of 100 flywheels with a capacity of 250 mWh.

EMB was testing their flywheel design in a California laboratory. They were trying to perfect a near frictionless bearing that operated in a vacuum. ATK waited for this technology and testing to develop but in the end, EMB lost funding for the project and it was cancelled.

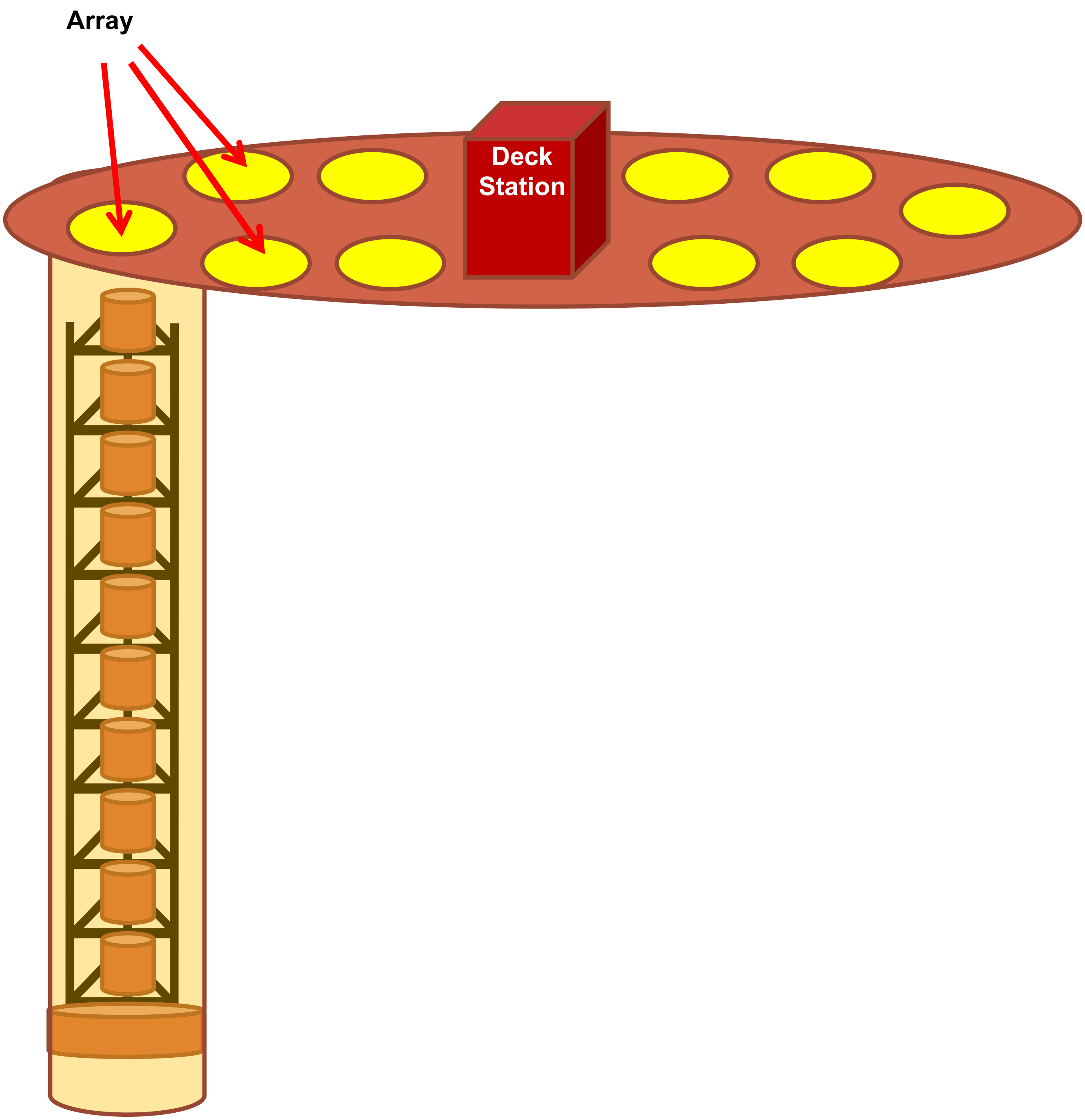

Figure 7 - Flywheel Layout with one array shown

a) Battery System Overview

The flywheel solution was the first option for energy storage. When that solution was unsuccessful, ATK pursued a battery storage option. The battery storage option was much more expensive than the proposed flywheel energy storage system. Therefore, ATK was only able to purchase a 300 kW/1200 kWh battery storage system. The contract was awarded to Eagle Picher Technologies. Eagle Picher offered the highest capacity and energy of the systems proposed for the budget dollars allocated. They delivered a well-designed system on schedule and within budget.

Figure 8 - 300KW Battery Storage System

b) Battery System Description and Theory of Operation

The Battery Energy Storage System (BESS) is a 300 kW/1200kWh bidirectional energy storage system located not far from the wind turbine. The BESS is comprised of 600 12V Absorbed Glass Mat (AGM) lead-acid batteries installed in two 40-foot shipping containers. The shipping containers are outfitted with custom battery racks, three 100 kW inverters, full HVAC environmental controls, hydrogen detection, ventilation systems, and an automatic fire suppression system (See Figure 8). The wind turbine output is augmented by a circuit from the plant electrical substation to charge the battery system during off-peak hours. The battery system consists of three battery banks and three DC to AC inverters which are housed in two environmentally controlled cargo containers. Each battery bank consists of 200 each - 12 Volt, 180 Amp hour Sealed Lead Acid batteries (See Figure 9).

Figure 9 - Battery Racks in Container 2

Lead acid batteries were selected for their low cost. Lithium Ion batteries have a better specific power rating (~ 300 wh/kg compared to 180 wh/kg for lead acid) and lower maintenance than lead acid batteries but the cost was out of the budget range. The batteries are connected in three independent 5P40S (5 parallel banks, 40 series banks) configurations, each with a total storage capacity of 432kWh making a total nameplate storage capacity of 1296kWh.

Each leg of the batteries is connected to a single Princeton Power Inverter model GTIB 480-100 (See Figure 10). The inverters are capable of charging or discharging at 100 kW each with a peak efficiency of 98.0%. The inverters have a 280-600V DC input range and tie directly to the in-plant power lines at 480 VAC 3-phase.

Figure 10 - Battery System Inverter

The weight of each battery is 125 pounds. A breakdown of the total weight of the battery storage system is detailed in Figure 11. Each container is insulated and lined. Both containers are equipped with a 4-ton air conditioning unit. Climate control is critical to optimize the performance and durability of the batteries and other system components. Both containers are also equipped with a "dry-type" ANSUL-101 fire suppression system to automatically extinguish any fire/flames. The system is actuated by ceiling mounted fusible link sensors and nozzles. It can also be manually activated by a hand lever near the entrance of each container.

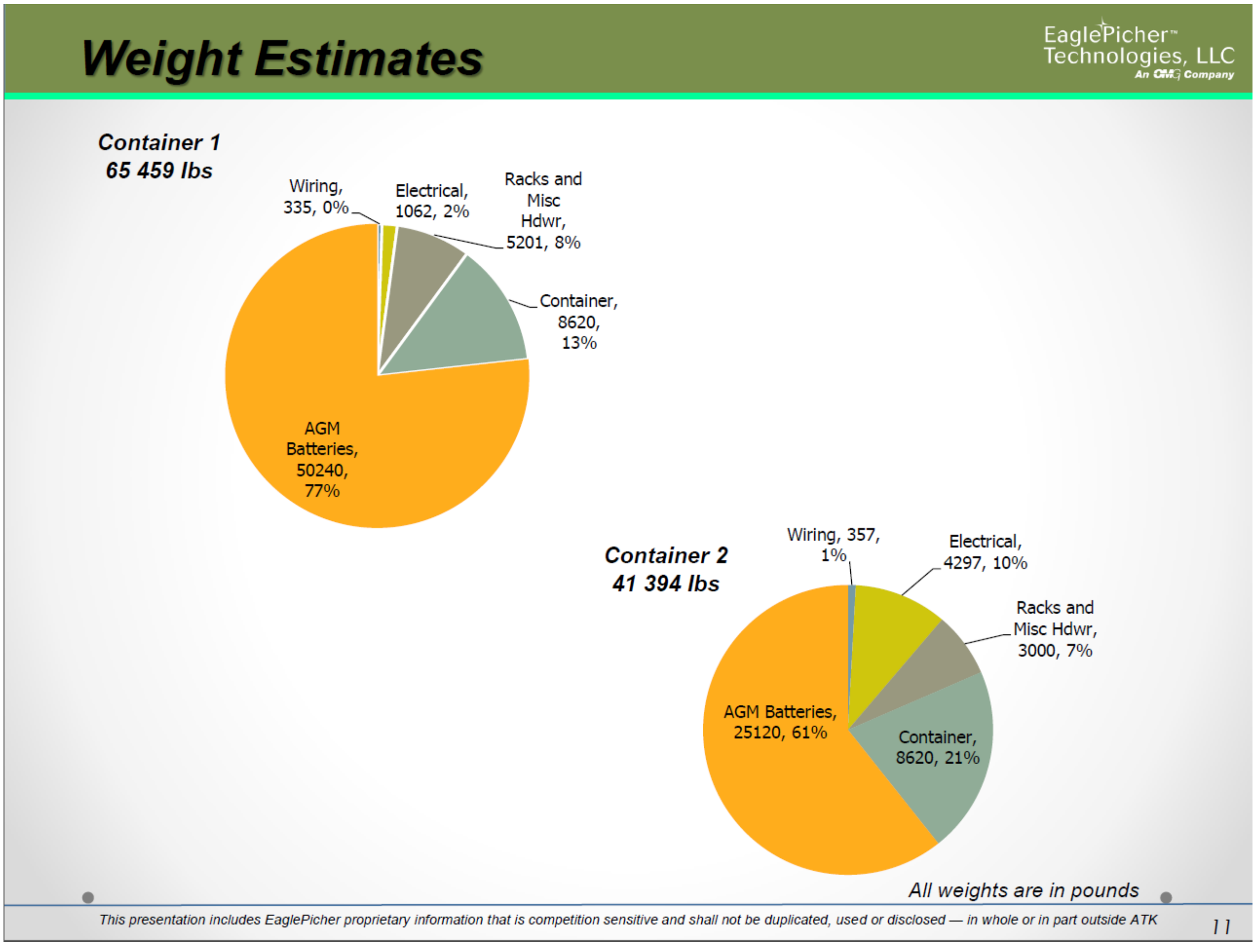

Figure 11 – Battery System Estimated Weight

The containers are equipped with a ceiling mounted hydrogen gas detector. The monitor activates the exhaust fan when the hydrogen concentration reaches 1%. An alarm sounds if the concentration reaches 2%. If either alarm level is reached, the control system is notified, and automatically places the system in a safe state by disconnecting the batteries and shutting down the inverters.

The system is centrally monitored and controlled from a Linux-based PC installed in the control/communications box in the BESS cargo container 1. This PC is networked to the inverters, digital I/O modules, and the ATK Allen Bradley data acquisition PLC over an internal Ethernet LAN.

c) Operation of Battery System

The intent and purpose of the battery storage system is to fully charge the batteries at night and deploy the stored energy during the day when ATK's energy consumption is at its peak. The local utility, Rocky Mountain Power (RMP), calculates customers energy rate based on the maximum peak consumption during the billing period. Thus, by storing energy at night and deploying it during peak demand, energy costs are theoretically lower.

The life of a lead acid battery is significantly reduced if it is discharged below 60% capacity. Therefore, the control system protects battery life by limiting the energy released while in the discharge state. ATK's data acquisition and control system monitors the plant power usage and turns on the batteries at a preset threshold. This pre-set threshold is generally selected each month and entered into the data acquisition and control system user interface. This threshold is based on historical data provided by RMP on the utility bills. The threshold can be fine-tuned throughout the month as the plant power usage is monitored. On the user interface screen, as shown in Figure 12, the preset threshold is set to 12,500 KW for the month of August.

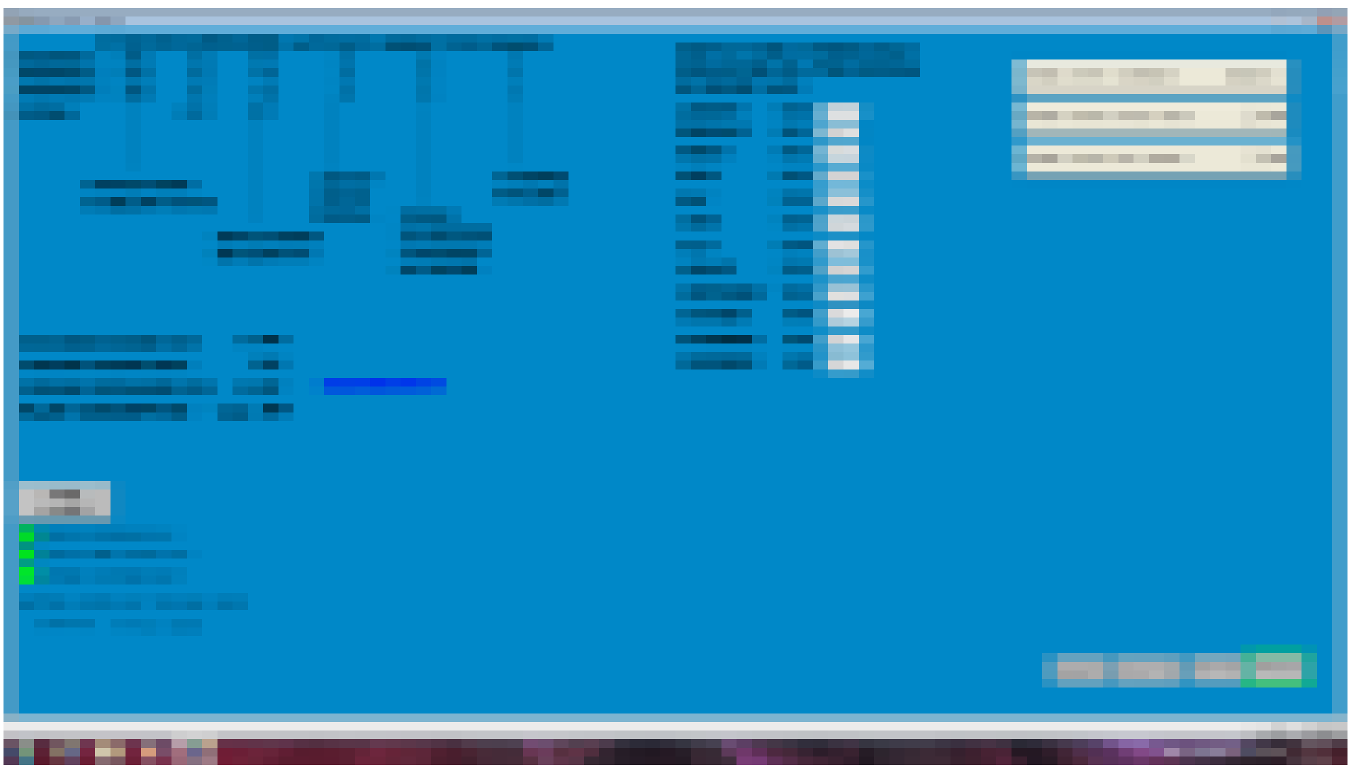

Figure 12 – Battery System Control Screen

4. Data Acquisition and Control System

An intelligent system-wide automation system to monitor and control the renewable energy devices was developed. This was accomplished using Allen Bradley PLCs on an Ethernet network. A PLC was installed at the wind turbine location and also at the battery discharge system location. Local input and output cards located in the PLC rack monitor and control the wind turbine and the battery system. The PLCs are connected to the plant-wide Ethernet network. An Allen Bradley RSView operator interface terminal is located in the Maintenance Shop. This terminal is used to monitor the power generated from each device. Alarms are also generated on the terminal. Maintenance personnel monitoring the terminal can take quick action to resolve the alarm conditions. The battery storage system discharge rates can be controlled along with the time of day the discharge occurs.

Figures 13 -15 are trends that show the facility power usage (blue pen), the battery discharge system output (olive green pen), and the wind turbine output (red pen). The facility power scale is located on the right side of the graph. The units are kW. The scale for the battery system and wind turbine is located on the left right side of the graph. The units for the left side are Watts. On the graphs below, the facility peak runs between 8 megawatts to 12.5 megawatts depending on the day. The output of the battery system is set to 250 kW and comes on during the peak energy usage time of day. It stays on for approximately 4 hours. The wind turbine output varies from 0 kW to 120 kW.

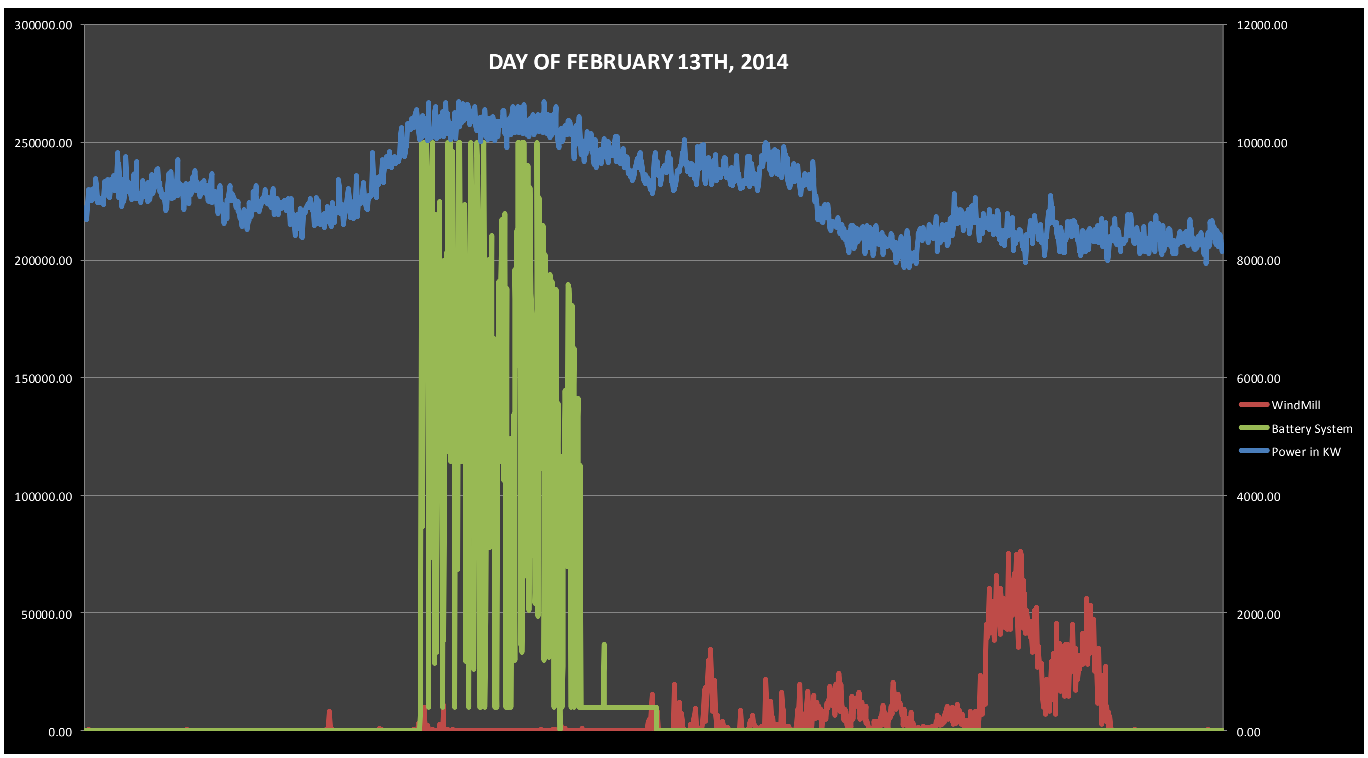

Figure 13 – Daily Trend Example

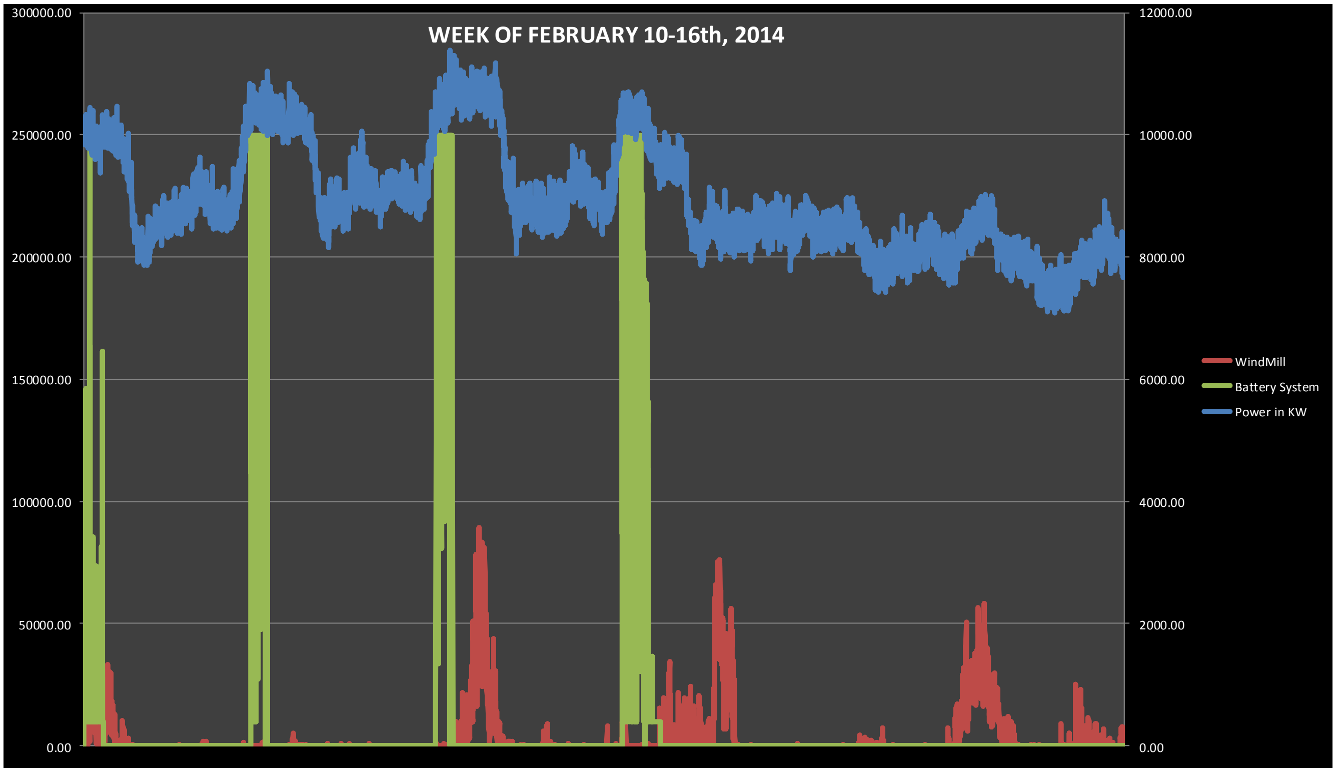

Figure 14 – Weekly Trend Example

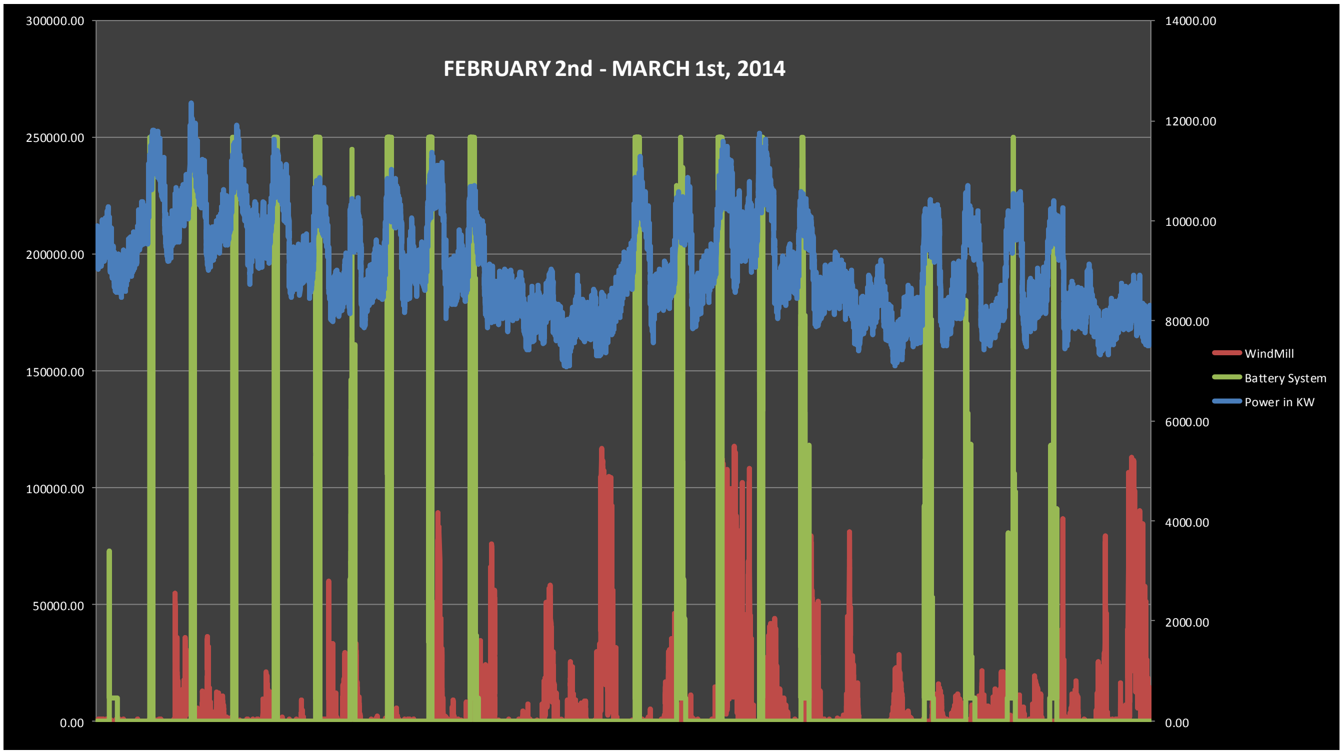

Figure 15 – Monthly Trend Example

The plots clearly show the battery storage system energy being discharged exactly during the peak energy times of the period represented in each plot. Also evident is the wind turbine not generally producing power during the peak energy time of the day. Rather, the wind turbine is producing the most electricity at a time when the battery storage system is in the storage mode instead of the discharge mode. The battery system and wind turbine are complementing each other well, integrating them in a tangible, real-world setting.

5. WASTE HEAT GENERATION SYSTEM

The project concept was to generate electricity from a waste heat source. In this case, flue gas from a set of 600 HP boilers was the desired heat source. The boilers produce steam for a portion of the ATK plant site providing building and process heat. After a very prolonged search to find a vendor who could build a small waste heat recovery generator, Transpacific Energy (TPE) was contracted to provide it using an Organic Rankine Cycle method.

The Rankine cycle describes a thermodynamic cycle of steam heat engines (turbines) commonly found in power generation plants. A typical diagram for an Organic Rankine Cycle is shown in Figure 16. Current Organic Rankine Cycles (ORC's) use pure refrigerants instead of water. However they are limited to a very narrow temperature range, usually 200°F-300°F and have low efficiencies. TPE proposed an environmentally sound refrigerant mixture custom tailored to reduce heat losses, maximize heat recovery for efficient power production, and extend the temperature range.

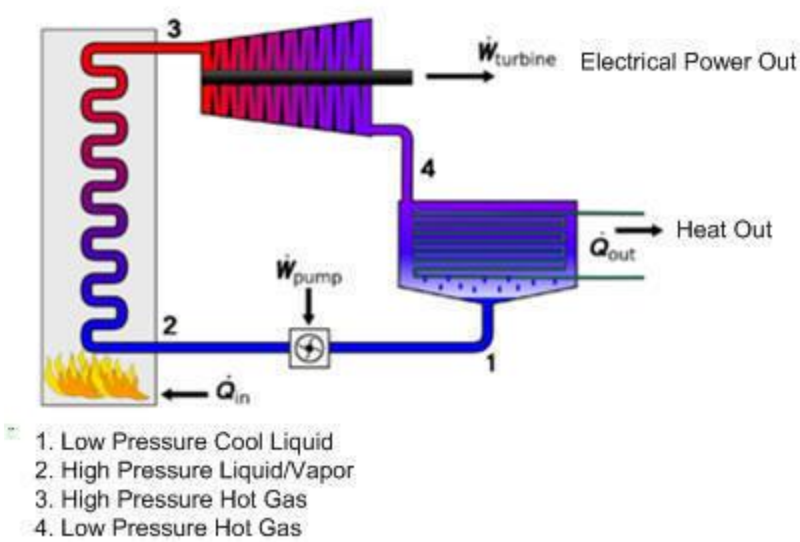

Figure 16 – Organic Rankine Cycle

Transpacific Energy boasted a patented refrigeration blend that was more efficient than any on the market for this application. A custom turbine generator was designed for the Organic Rankine cycle energy conversion, where high-pressure vapor (steam) is expanded through a turbine and drives a generator. The turbine generator unit (TGU) was particularly suited to recovering energy from low temperature heat sources like a boiler exhaust system.

In design, the hot exhaust flue gas from the two boilers located in Building M014 at ATK's facility in Promontory, UT was to be ducted through the waste heat recovery generator to spin a turbine generator at approximately 20,000 RPM. The rated output of the Turbine Generator was 134 kW when fully loaded. All of the energy generated by the waste heat recovery generator was to be directly fed onto the plant power system and consumed.

Problems arose during the integration phase at Isotherm Inc. located in Texas. Isotherm was contracted by TPE to provide the heat transfer equipment and design the skid with the electric turbine included. The assembled skid mounted equipment located at Isotherm is shown in Figure 17. During the design reviews, the pressure drop across the skid was never provided until the end of fabrication. It was then calculated to be 3 psi. When TPE negotiated the initial contract, they took exception to providing the blower that would route the steam through the ORC unit and the responsibility fell back on ATK. All indications from TPE at the time were this blower capacity was not large. However, with the calculated 3 psi pressure drop, a 100 HP blower would be needed to force the hot exhaust flume air through the ORC unit. Coupling the blower power requirements with the other parasitic loads (15 KW) inherent to the machine, it became obvious the ORC unit would be consuming more power than it produced.

Figure 17 – ORC Skid

At that point in time, ATK and the NETL project manager agreed the best course of action was to terminate the contract with TPE for the heat generation unit rather than incur more costs by shipping the unit to Utah, modifying the boiler exhaust stacks, purchasing a 100 HP blower, and completing the installation. Accordingly, the ORC contract with TPE was terminated and the equipment sold. The project was credited with the sale price of the equipment. It is unfortunate the equipment could not be installed to test the effectiveness of the ORC unit but ATK did not want to invest more capital funds in an inefficient process.

In theory, the output of the ORC unit would have tied to a circuit feeding the battery storage unit and used in conjunction with the wind turbine to charge the batteries during non-peak energy times of the day. The wind turbine alone only supplies about 1/10 of the power needed to recharge the batteries. The ORC unit in theory would have made up the rest of the power needed for full battery charge.

6. Lessons Learned

One of the early lessons learned on this project was with the wind turbine project. With only about $500K in the budget for a wind turbine, purchasing a new one was out of the question. Refurbished wind mills were bid that brought unknown challenges to the table. Most refurbishment companies want most of the project money down when issued a PO in order to procure a used wind turbine and materials for the rebuild process. Such was the case with J.P. Sayler. Once a PO was issued to J. P. Sayler, the wind turbine they were going to buy had been sold to someone else but they did not inform us of this fact immediately. When they did inform ATK, they indicated it would not be a problem to procure another one. When they finally found another, it was much more expensive than the original. They wanted to pass on the additional cost to ATK but it was out of our budget range. At that point, ATK terminated our dealings with J. P. Sayler.

Efforts to recoup the down payment have been in vain. Everything has been done by the ATK legal department short of filing a law suit to recoup the money. In the end, ATK decided it would be more costly to file a law suit than dropping the case. The lesson learned in this case was to formulate the contract wording to ensure any down payment is applied to an existing wind turbine immediately followed up with verification or a full refund shall be issued to ATK. This could have been done through an escrow account. We should have been more cautious by reviewing vendors carefully and calling multiple references prior to issuing any purchase orders.

Another lesson learned came from ATK's experience with the Waste Heat Generation System. ATK included in the original specification a blower to bring waste steam from the flue gas stack to the ORC unit. When Transpacific Energy submitted their quotation, they would not take responsibility to provide the blower as required by the specification. They claimed they did not have enough information to price it, nor would they have enough information until the ORC skid was designed. ATK did not realize the significance of this action at that point in time.

It is clear now that Transpacific Energy could not meet the specified efficiencies with the blower as part of their system. ATK should have held Transpacific Energy to the specification requirements and attempted to negotiate a price for the blower as part of their scope of work. Part of the problem was the original ATK mechanical engineer who started the project left the company. This created some confusion on what was to be included with the waste heat generation system and what was not. It wasn't discovered until later on that the blower was not included.

7. Conclusion

A 3.4% demand reduction requires significant kW and kWh capacity when an industrial facility has a high load factor, and is difficult to achieve. The available technology to store energy and shift demand is both relatively new and expensive. We were able to demonstrate that energy produced from renewable energy sources could be effectively stored by battery technology. As flywheel and battery technology develop and prices come down, these may become viable options for the future.

A secondary objective of this project was to develop and commercialize a low cost, IT standards based, customer owned Distributed Generation automation system and a bi-directional customer/utility gateway application for real time visibility and communications between the utility and the customer. We found that establishing the bi-directional gateway can be difficult, expensive, and time consuming. Agreements were never reached with the utility that could meet both their standards and the IT standards required by ATK for security reasons. The system that was installed provides real time visibility and communications but only to ATK.

Lastly, buying a re-conditioned wind turbine may not be as easy or cost effective as it seems.
One of ATK's main challenges on this project was maintaining the ATK cost share funding during a period of time when ATK was experiencing significant cutbacks in funding and manpower.

ATK employees took pride in being involved with the DOE in developing a greener, more sustainable energy future for all of us. The wind turbine is a great example. It is located in a highly visible location and most employees are able to see it as they arrive and leave work every day. They appreciate the fact ATK cares about energy conservation and reducing greenhouse gas emissions.

We appreciate the opportunity the Department of Energy gave ATK in developing energy reduction technology. There are many challenges to overcome as the country continues down this path but if we can help make renewable energy more dispatchable, and harness much of the energy currently being wasted, there will be a brighter and more sustainable future for us all.