Kotzebue Electric Association
Flow Battery Storage Systems
Quarterly/Final Report
10/2012
Prepared by Jesse Logan (KEA)

Funding
Denali Commission  $425,000
AEA           $300,000
CREBS Loan       $575,000

Total             $1,300,000

Project Summary:
The goal of this project is to test an advanced battery system and its’ application to Alaskan energy needs. Kotzebue Electric Association’s (KEA’s) interest is to evaluate a large flow battery in conjunction with wind power in order to improve overall system efficiency and reduce the amount diesel fuel used for electrical generation by time shifting energy from both the wind and diesel systems. Additionally, KEA is interested in the ability of advanced battery systems to provide frequency regulation, provide a substitute spinning reserve, and provide black start and emergency power capability. There are currently a number of batteries in the >1 megawatt capacity being developed by several suppliers. If these batteries become commercially available at the price points suggested by manufacturers their deployment could result in significant diesel fuel savings in similar communities with wind or other renewable energy sources.

Background and Recap:
In August, 2009, the Alaska Center for Energy and Power (ACEP), which is part of the University of Alaska and Kotzebue Electric Association (KEA) applied separately for funding to test advanced battery systems through the Denali Commission Emerging Technologies Grant Fund. These projects were organized differently based on the different project management needs, two classes of batteries, and the level of technology readiness. The larger Premium Power battery is most appropriate for Kotzebue, given KEA’s excellent track record of integrating new wind turbines with their existing diesel system, with some support from ACEP on data collection and analysis. The smaller batteries were proposed as laboratory tests at ACEP, which proved to be of considerable value during previous testing of the VRB battery, as clean performance data could be collected to assess the validity of the claims made by the supplier. During the second round the Denali Commission requested that the two proposals be combined for a total of $855,000. This was partially awarded. Since October of 2009 KEA has worked with ACEP to re-scope the work plan to address the reduced funding level of $500,000, while meeting the original objectives of the project to demonstrate viable storage options to augment wind-diesel systems in rural Alaska. The re-scoping was further complicated by the existence of another proposal by KEA (see below), which affected the prioritization of effort on this project.

KEA had applied for funding for the Premium Power zinc-bromide battery through the Cooperative Research Network (CRN) to the Department of Energy. This proposal was not funded. Therefore, the re-scope of the joint ACEP/KEA funding through the Denali Commission will focus the majority of funds to KEA’s demonstration project. However, this amount is insufficient to outright purchase the Premium Power battery, as it would amount to one-third of the commercial installation price.

During the winter of 2009-2010 KEA and ACEP reached an agreement on project funding from the Denali Commission, which is reflected in the simple budget shown above. KEA proceeded with purchasing agreements with Premium Power and expected to receive a unit during the end of barge season in 2010.

In the spring of 2010 KEA received production status reports from Premium power estimating a unit completion date at the end of May 2010, with testing beginning in June 2010. This would have put KEA on track for the summer construction and barge deadlines. KEA estimated receiving the unit in Kotzebue in August or September 2010 on the last barge of the season. However, initial testing of the battery by Premium Power indicated the need for fluid upgrade in the unit. This delay caused the battery to miss the 2010 summer barge season. KEA explored other shipping options, such as utilizing the transportation barge of other private late-season construction projects in the region. However, the fluid upgrade launched a new series of tests on all four quadrants of the battery unit. Premium Power began Factory Acceptance Testing anew on the unit in July of 2011 with expected arrival at the port in Seattle in time to make the last barge of the shipping season. A colleague (Dr. Dennis Witmer) traveled to the Premium Power facility to witness the Factory Acceptance Test (FAT) in the summer of 2011.
KEA received the unit in Kotzebue in September of 2011. This was the first unit made commercially available by Premium Power.

**Work performed in preparation for the arrival of the Premium Power TransFlow 2000:**

- KEA had completed the necessary design drawings and well into the installation of the new transformers as well as additional preparations to the battery site location.
- EPS engineer, wiremen and programming engineer were on site to complete the installation of the wiring and programming to the Battery switchgear.
- KEA personnel had completed the primary wiring installation from the Battery Switchgear to the Battery Transformer and the secondary run to 5 fused disconnects.
- The Battery switchgear had been energized both via SCADA in remote mode and via local mode and the relaying and controls had been tested and proven functional. The Battery transformer was tested and is operation at the correct voltage. Phase rotation was tested on the battery and at each fused disconnect and was correct and uniform.
- The communication conduit between the substation SCADA controller and the Battery was installed and the communication wiring was installed after the Battery in placed in the substation.
- The secondary connections between the five fused disconnects and the Battery was installed after the battery had been inspected by Premium Power and the liquid had been installed into the Battery Tanks.

The flow battery arrived in Kotzebue on Sunday September 25 and was moved into place Monday September 26 2011. KEA worked with Premium Power during the installation and pre-commissioning phase.

**Work Performed During Installation and Pre-Commissioning:**

- EPS engineer, wiremen and programming engineer were on site to complete the installation of the wiring and programming to the Battery switchgear.
- EPS programmed the switchgear relaying and metering and worked on the SCADA switchgear reporting.
- KEA personnel completed the primary wiring installation from the Battery Switchgear to the Battery Transformer and the secondary run to 5 fused disconnects.
- The Battery switchgear was energized both via SCADA in remote mode and via local mode and the relaying and controls were tested and proven functional. The Battery transformer was tested and was operation at the correct voltage. Phase rotation was tested on the battery and at each fused disconnect and was correct and uniform.
- The communication conduit between the substation SCADA controller and the Battery was installed as well as the remainder of the communication wiring.
- KEA was working with Premium Power mechanical engineer, Dan Jepeal, to design a supplemental heating system for the TF2000 (the battery). Supplemental heating was found to be needed during periods of battery downtime.
- Commissioning trip Dec 10-17, 2011 by Premium Power to replace PVC stack hoses with Teflon hoses.
- KEA was monitoring battery for leaks and also cooling system temperature.
- Premium Power is planned a field commissioning trip for early February 2012. Needed hoses were to be replaced and electrical testing was resume and initial charge/discharge cycling was planned.
- EPS had been gathering data and working on the dispatching system for both the battery and KEA’s new EWT wind turbines.

During the spring of 2012 KEA installed and commissioned two 900kW EWT wind turbines to add to the existing wind farm. The total wind capacity of KEA is now 2.94MW. This capacity exceeds KEA’s average peak load (2.7MW) and KEA was looking forward to Premium Powers commissioning trip which was delayed from Dec 2011 until March 2012.

**Commissioning Trip March 2012:**

Premium Power technicians Sam and Dan returned to Kotzebue on Thursday, March 22, 2012 to attempt to start and charge the battery. Communications were reestablished with the unit, using an isolation card. The KEA SCADA system communicated with the battery through a PLC and RS 232 connection, while Premium Power could communicate with the battery directly over the internet. On March 27, 2012, it was indicated that communications have been established with PP headquarters, but it was not clear if this meant that PP could “see” the KEA SCADA system, or if the KEA SCADA system could communicate with the internet.

However, the battery had developed some unexpected leaks, and electrolyte was discovered in the secondary containment in several places. The most significant leak was about 45 gallons, in a quadrant where all the electrolyte had been drained out of the stack—indicating that the leak had occurred somewhere in the bottom of the unit. However, the exact location of the leak was not determined. It is thought that this leak may have been caused by the extreme cold weather affecting seals associated with hose clamps—the plastic pipes and hoses under the clamps are likely to contract more in cold weather than the metal bands of the clamps, and so a leak may have developed in one of these areas. The new Teflon tubes were all fine, but other parts of the system are made with PVC piping and rubber hoses. PP technicians intended to return to company headquarters and come up with a solution to this issue and then return to Kotzebue and make the necessary repairs.

**Current Status: Battery Recalled**

In the late spring/early summer of 2012 it was announced that Premium Power was undergoing corporate restructuring. There have been some changes made in the management of Premium Power as new investors have been brought in. Most importantly, Gary Colello is no longer
company CEO, although he is still employed by the company, and a search is underway to find a replacement. Currently the company is being managed by a committee of three until a new CEO is found. The good news is that the company has a new influx of cash, and will remain viable while developing their products.

One of the changes appears to be that Premium Power is likely to move away from the trailer mounted Transflow 2000 design, and move towards a 125 kW package. The trailer mounted design is transportable (though the shipping to Kotzebue required a total of 5 separate shipping units—the trailer plus 3 containers with electrolyte, and one of spare parts). The major difficulty with the trailer mounted system is that there is very little room to work on the system.

On May 15, 2012 a teleconference with KEA and Premium Power—Ali Amirali and Doug Alderton, as well as consultant Dennis Witmer, took place to discuss the changes in Premium Power management—the old managers are gone. There has been a significant infusion of new capital, a new board, as well as new management at Premium Power.

The focus was on product performance and reliability—taking the company from a development company to a product company. Premium Power has retained key technical and engineering staff—hired consultants Erigo (battery consultants) and Cambridge (materials for membranes). Premium Power remains committed to the product with a focus on making their projects successful. (As well as trying to resolve issues with existing customers such as KEA).

As noted above, the product will change housing from trailer unit (Transflow 2000) to a 20 foot containerized unit. “Maintainability of the trailer” is not good. KEA experienced issue of fittings that loosened during shipping that could not be accessed in the field.

### Notable Premium Power changes:

- PP considers Alaska to be a key market.
- Premium Power will now purchase inverters from others, and use standard interfaces for any SCADA system.
- Erigo Technologies—Chemists, physicists, will be doing battery diagnostics, and failure mode analysis.
- Company will focus on core technology.
- DC—60-70% efficiency (AC efficiency will be reduced by pump parasitics). The teleconference power point showed data, including decrease in stack performance over time, and the development of outliners that fail. Also, as the units are scaled up, the efficiency decreases.
- Aiming for repeatability in manufacturing. Premium Power is aiming to return to product manufacturing in 1Q13.
- Premium Power is willing to provide test information, and willing to talk to anyone on the team.
- Premium Power is willing to ship one quadrant in summer 2013, ship balance of unit in summer 2014.
- Premium Power will pay all shipping from now on.
• Electrolyte freezing—stratified—it is unclear if the electrolyte will recombine—will test with a laboratory, try to determine if electrolyte is good.

Premium Power has recalled the unit: the battery was shipped back to the manufacturing plant at the end of the summer of 2012.

**Future Plans:**

KEA is aware that due to unforeseen problems with the unit that KEA will be unable to take ownership of the battery before the expiration of this grant program. KEA is hopeful that a way forward with the original funding can be found with the Denali Commission so that KEA can retain the bulk of the funding designated in the agreement for purchasing of the unit.

As noted above, Premium Power expects to be ready to ship one quadrant of the battery unit in 2013 with the remaining quadrants ready for shipping in 2014. Due to Kotzebue’s remote arctic location shipping is limited to 3 months and only during summer.

To date the project is on budget as set out in the original grant agreement. The total amount of funding provided by the Commission to KEA is insufficient to purchase the battery outright. KEA has moved forward with the purchase of the Premium Power battery by utilizing several funding sources including state and federal grants and a low interest CREBS loan.

KEA has been some unexpected problems with this project (as noted above). Premium Power is going through reorganization and is putting together a plan to address the unit. Premium Power appears to be committed to this project (and to its other customers), and remains intent on getting the battery operating for this demonstration.

Though a demonstration was unable to be performed during the timeline of this grant program, KEA is confident that one will be successful in the near future. Most operational data is retained as proprietary within the Premium Power organization. However, limited data was available to KEA. Attached (below) is a draft report of recent modeling done by Dennis Wtimer based on KEA’s experience with the Transflow 2000 that should be of some use to the Alaskan community. Additionally, a paper entitled, “Model of the Energy and Economic Value of a Flow Battery in a Wind-Diesel-Battery Hybrid System: Based on the Premium Power Battery Demonstration at Kotzebue Electric Association” is being prepared for publication. It is important to note that the draft below, the upcoming publication, nor the MatLat/Simulink model that was created (which both papers are based on) would have been possible without the work performed to date by KEA and the support of the Denali Commission, ACEP, and AEA for this project.

KEA is looking forward to the opportunity to install, commission, test, and gain valuable operational knowledge of integrating this technology with a wind-diesel power plant.
The following is a draft of a recent modeling report by Dennis Witmer of Energy Efficiency Evaluations that shows modeling and results for a conceptual system that is based on data from KEA’s SCADA system.

Premium Power Battery Modeling

In a High Penetration Wind Diesel Hybrid System Based on Kotzebue Electric Association Data

Dennis Witmer
7/29/2012

Preliminary modeling report
Premium Power battery in High Penetration Wind Diesel Hybrid System

As new utility scale battery technologies become available, one potential high value application is to use these batteries in high penetration Wind-Diesel-Battery hybrid configurations. There are several ways in which a large scale battery could be useful in these configurations—first, 1) to inject power as needed to stabilize the instantaneous load and available wind (on a scale of seconds), 2) to allow a “diesel off” mode (provided the battery has sufficient storage to allow sufficient time to start the diesel—several minutes), and 3) to allow “load shifting” meaning that the battery can be fully charged and allow the diesel engine to remain off for some time after the wind has diminished, allowing additional fuel savings.

This modeling effort is an attempt to evaluate the possible benefit of the Premium Power Transflow 2000 battery purchased by the Kotzebue Electric Association for a demonstration in Kotzebue. While the battery is too small (500 kW output) to provide all the benefits listed above (even during high wind events, it would not likely be possible to operate in a diesels off mode, nor is a diesels off load shifting period possible), it was hoped that the demonstration would
provide sufficient information for understanding how this battery might prove useful in smaller communities.

For this modeling exercise, the ideal system would be one where the available wind is significantly higher than the average load (allowing the storage of electrical energy in the battery). A 24 hour data set was available from the KEA SCADA system, from a day in February 2009. This data set was scaled appropriately to reduce the load to an average of about 500 kW (20% of the Kotzebue load), while increasing the wind to mimic the new wind farm configuration (2.9 MW maximum wind). So while the load and wind profiles are based on actual data, it has been scaled to match the size of the battery, and therefore does not represent any real event.

The model was created in MatLab Simulink using a version that does not include the “state” function set (the preferred programming environment).

Data Channels

Load—Based on a 24 hour load profile from Kotzebue—scaled to 20% of actual values. This load profile is most likely smoother than would be found in a village of the same average load.

Wind output—Based on the same 24 hour period from KEA SCADA data, multiplied by a factor of about 5 to mimic the output of a 2.9MW wind farm. Since the KEA data is based on 17 small wind turbines, some averaging has most likely occurred.

Diesel Engine—the diesel performance is based on nominal efficiency curves based on a Caterpillar 800 kW gen set, appropriately scaled for the 600 kW load. The model does not allow the diesel to operate below a 25% (200 kW) load, so during the initial phase of the wind event, the diesel engine is operating during the initial charging of the battery. Only when the battery reaches a minimum state of charge (500 kW stored energy) is the diesel engine shut off. The diesel engine is started again when the battery state of charge falls to 200kW-hr stored energy.

Battery operation—the battery model is based on information proved by Premium Power, including the electrochemical current-voltage curves for both charge and discharge. The battery also has parasitic losses, especially for fluid pumps. While it is known that these pumps use approximately 30 kW at full flow, it is not known what the parasitic levels are at other power levels. Given this, a decision was made to assume that the parasitic energy is proportional to the battery current, meaning that at zero current, the battery parasitic power is also zero. An inverter efficiency of 99% is also assumed. Battery power is limited to 500 kW in both charge and discharge. The battery cannot be discharged while the diesel generator is operating.

Use of wind energy—When no wind power is available, the system operates as a simple diesel power system, with the battery neither using nor providing energy. When the wind begins to
rise, the wind energy is first applied directly against the electrical load, and the diesel load drops, reducing fuel consumption. When the diesel load reaches 25% of capacity, additional wind energy is used for charging the battery. When the battery state of charge is 500 kW-hr of stored energy, the diesel engine is switched off. If the wind continues to rise, the battery continues to charge until a maximum of 2000 kW-hrs is reached. If the wind falls below the load, the battery will discharge, until a level of 200 kW-hr (approximately 10% of battery storage capacity) is reached, and the diesel engine is restarted.

If wind energy is available above the level needed to charge the battery, it is assumed that this energy can be diverted to a heat load (electric boiler or residential use), up to a level of 1000 kW. Additional energy beyond that point is sent to a dump load.

Model results are shown in the figure below:
The load is shown in gray; the wind is in black at the top. Battery current is in red. The diesel load is shown in blue. The cumulative diesel fuel cost is shown as the rising line followed by a long flat zone (no diesel fuel being used). Heat load is shown in sky blue, dump load in purple.

Initial operation is as a straight diesel system. As the wind rises, diesel fuel consumption decreases, and the diesel engine maintains a minimum load of 200 kW, and the battery begins to charge. There are several restarts of the diesel during this period, as the wind rises and falls. The wind continues to rise, eventually charging the battery to capacity, at which time the load is shifted to the heat load. When the wind rises again, the heat load saturates at maximum load, and energy is diverted to the dump load. The wind then falls, eventually falling below the load, at which point the battery injects power into the system. When the battery reaches 200 kW-hr, the diesel engine restarts. The wind rises again, and charges the battery again.