Residential Wind Turbine Testing Using a Battery Charging Configuration

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Abstract

This paper describes the efforts put toward testing and validating four residential wind turbine systems set up in battery pack charging configurations. The goals of the research project will be described along with a description of the system design for each turbine. In addition, the format and sampling techniques of the collected data will be described along with example data collected from the project. Finally, the paper concludes with a discussion of possible future projects associated with the wind turbine site and test facility.

Background

This project begin in 2008 as part of a state grant intended to provide a "consumer reports" viewpoint regarding the cost, installation, functionality and suitability of a residential wind turbine system for consumers in Minnesota. The grant allowed for the purchase and installation of four different wind turbine systems on campus at a designated site with a minimum of wind obstructing trees and structures and having a small site building to be used for battery energy storage, data collection and associated electronic equipment, and for the storage of project tools. The systems were chosen based on rated power output, cost, availability, and suitability for a battery charging configuration. The original project intent was to install grid connected systems. This was later changed to reduce interactions with the campus sub-grid and to allow fully independent operation[1]. The ability to generate power regardless of the grid status was considered a strong advantage even though the typical residential installation would incorporate a grid connect system. The four turbines were chosen from four different vendors and manufacturers and encompassed two different styles, vertical axis and horizontal axis. Two of the turbines are horizontal axis types and were installed via monopole at sixty feet (A standard height as suggested by various manufacturers.). Two of the turbines are vertical axis types and were installed via monopole at eighteen and twenty feet respectively due to manufacturer recommendation and standard installation design information. All four turbines are rated at power ranges between roughly two and three kilowatt peak outputs. The four systems are 1) Skystream 3.7 (Southwest

[1] To be compliant with electrical codes, any wind turbine supplying power to the grid must be capable of being isolated under conditions of grid instability (power outages) or for maintenance. This would necessarily lead to occasions of zero power output from the turbine.

Windpower), 2) ARE 110 (Abundant Renewable Energy), 3) UGE 3kW (Urban Green Energy), 4) S322 (Helixwind).

The test data consists of wind speed, wind direction and temperature data collected at roughly twenty feet and fifty five feet and per minute resolution of turbine output power (i.e. power factor corrected power derived from sampled voltage and current) for each turbine. The data is collected and stored in a computer located at the site. There were a significant number of delays in the installation and configuration of the systems due to a number of factors outside the control of the author and therefore the amount of test data collected as of 2010 is minimal, however early results demonstrate the capability of the installed systems and completion of the project tasks is ongoing. The next section will describe the system components for each battery charging system and the methodology for data capture.

Battery Charging Systems

The battery charging system for each of the four turbine installations was designed in a similar fashion and closely resembles each other. The Skystream turbine system is unique amongst the other systems due to its standard "grid-connect" configuration. The other three systems are designed for a battery charging system interface and are able to connect to the electric grid using alternative manufacturer/distributor supplied equipment. The configuration for these three turbine systems will be referred to as configuration A. The Skystream turbine system will be referred to as configuration B and will be described separately. All four turbine systems were configured using a four-battery 48V nominal battery pack constructed of deep cycle sealed Absorbent Glass Mat (AGM) 200-Ahr batteries. These batteries were chosen for their cost effective energy storage and low maintenance reliability. A 48V pack was chosen to fit the recommended voltage level compatible with all turbine systems. The capacity was chosen to satisfy the maximum recommended minimum Amp-hour rating provided by the manufacturers/distributors. The goal of the project does not include efficient usage of the stored energy from the turbines so the cost and reliability were the primary drivers in the choice of battery technology. All systems were installed on monopole towers at heights based on manufacturer standard design drawings and available tower hardware. The Skystream and ARE 110 turbines were supplied with 60 foot towers. The UGE 3kW was also supplied with a monopole tower but at the height of 18 feet. The Helixwind turbine was supplied without a tower but a 20 foot monopole tower was locally manufactured according to Helixwind specifications and used in the installation. All foundations were either installed (i.e. poured) as specified in manufacturer drawings or installed according to revised drawings contracted through a local engineering design firm. The nature of the project (State of Minnesota funding) required State registered engineering certification of all foundations. This was accomplished via local subcontract. In addition, all turbine system electrical installation was completed by licensed electricians. This work was accomplished by Minnesota State University electrician staff and via subcontract and included extensive cabling through conduits both external and internal to the turbine site building housing the power conversion and data measurement electronics. Each turbine system was earth grounded and interfaced via high voltage disconnects to the external conduit system. The disconnects are located at the base of each tower for easy access as necessary. The external (buried) conduits were routed from the disconnects to the rear of the turbine site building and up through the rear wall. Inside the turbine site building against the rear wall are an additional high voltage disconnect connecting each turbine power conversion equipment to the external conduit cabling. It is possible to isolate each turbine electrically using either in-line disconnect (one internal to the building and the other external to the building). In addition, each battery pack is isolated from each turbine system power conversion electronics through the use of a high voltage DC disconnect. All turbine systems are isolated from the grid and isolated from each other. The following two sections describe the A and B battery charging configurations.

Configuration A

The three turbines covered under this configuration generate three phase AC power. The AC voltage is rectified and bucked (i.e. voltage scaled) using custom, manufacturer provided, power converters rated for the peak turbine output. The three phase power is delivered over a range of voltages and currents to the power conversion boxes and the resulting output is regulated DC power. The output is routed to a battery charge controller which acts as a switch selectively routing power either to the 48V nominal battery pack or high power diversion load resistors if the battery capacity is near its peak. The battery charge controllers used in each system exceed the rated peak power capacity of each turbine. Each of the three systems has a dedicated diversion load capable of meeting or exceeding the capacity of the battery charge controller connected to it. See the figure below for additional detail.

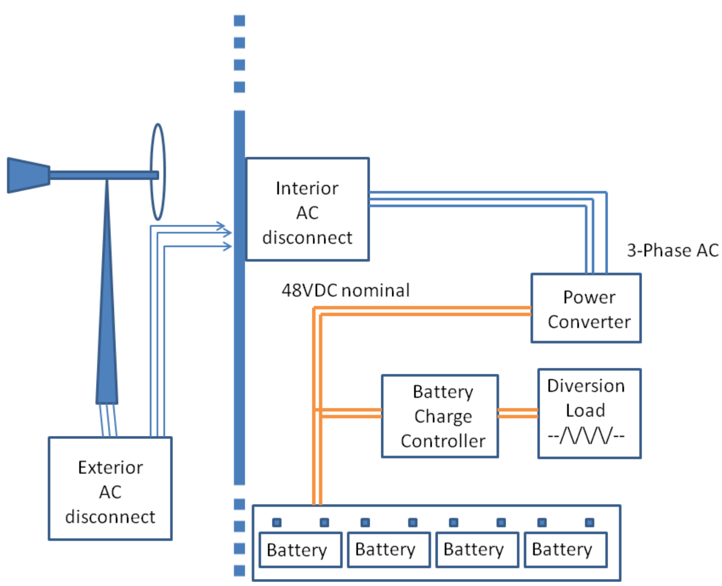

Figure 1: Configuration A Diagram

As mentioned previously, power from each turbine utilizing configuration A is delivered through two AC voltage/current disconnects prior to reaching the power converter. An additional DC voltage/current disconnect separates the battery pack from the rest of the system. In essence, each power source is connected to the system through a disconnect[2] since the battery pack can act as a power source or sink depending on the direction of the current flow. On the occurrence of battery pack failure, turbine failure or power conversion electronics failure, the failed system can be isolated from the rest of the system. In addition, each of these subsystems can be maintained (as necessary) under conditions of electrical isolation.

Configuration B

The Skystream turbine system is covered under this configuration. This configuration is unique to the project because of its grid-connect architecture. In essence, this configuration allows the Skystream system to see a virtual "grid" connection thus allowing the turbine to activate and generate power for the battery charging system. Similar to configuration A, this configuration includes disconnects at the base of the Skystream turbine tower and at the back of the site building interior wall where all conduits deliver power from the turbines. In contrast, the Skystream turbine delivers power as two $120V_{RMS}$ AC line-to-neutral lines with a shared neutral line similar to the $240V_{RMS}$ AC delivered to a typical household. The interior disconnect then delivers power to an autotransformer. The autotransformer takes the 240VAC input and delivers 120VAC to a combined inverter/charger from Outback Power Technologies, Inc. The autotransformer is necessary since if only one 120VAC line from the turbine is used, total power output from the turbine will be limited. The inverter/charger allows bi-directional power flow and is not being used according to its intended functionality. Its intended functionality is to act as an inverter for providing AC power from a 48V nominal DC source. However, the device is also designed to provide a power flow back to a battery system (DC source) at a power level less than the inverter function capacity. This limitation on the charging power flow required that a somewhat oversized device be used. This charging capability is intended, by the manufacturer, to be used under conditions where a temporary reversal of power flow is necessary. This involves the device being used in parallel with the "grid" as a standby power source. On the occasions that battery power is necessary due to the lack of "grid" power, the charger function would be used temporarily after the "grid" became available to recharge the battery pack. In summary, the inverter/charger is intended to be used primarily as an inverter but with limited charging capability to maintain the DC power source. For this configuration, we are using the inverter/charger primarily as a charger however the inverter functionality is crucial to its utility in the configuration. The Skystream turbine is designed for "grid" connect and expects to see $120V_{RMS}$ AC line-to-neutral on at least one of its lines before it will close its internal contacts. In other words, the Skystream will not deliver any power without a viable AC line connection. We provide a virtual "grid" through the inverter. Once the virtual "grid" is seen by the turbine and under wind speed conditions exceeding the cut-in speed, the turbine will begin to rotate and supply power through the

[2] National Electrical Code (NEC) 2008

inverter/charger to the battery system. As in configuration A, this configuration incorporates a battery charge controller in parallel with the battery pack and a diversion load exceeding the capability of the charge controller. Finally, this configuration includes a battery protection feature. A relay box is included between the autotransformer and the interior AC disconnect enabled over a limited range of battery pack voltage. If the battery pack voltage exceeds the upper voltage limit or falls below the lower voltage limit, the relay will open. Opening of the relay removes the $120V_{RMS}$ AC line-to-neutral signal to the turbine from the inverter/charger and effectively disables the turbine. See the diagram below for additional detail.

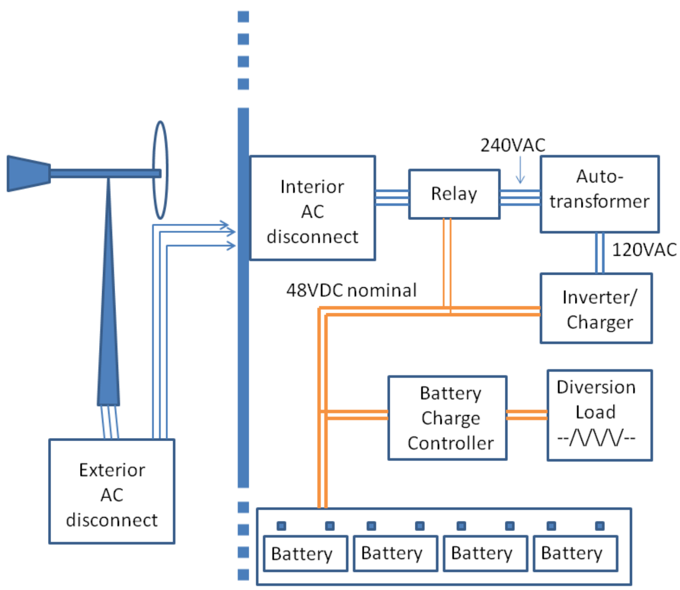

Figure 2: Configuration B Diagram

Data Collection

The data collected consists of weather related information including wind speed and direction at roughly 52 feet above ground level (AGL) and 20 feet AGL and outside temperature. This data is collected using two small wired weather stations interfaced to a computer within the turbine site building. The turbine output power measurements consist of output voltage and current or power. If power measurements are unavailable directly from the instrumentation, sampled voltage and current can be used to derive power factor corrected real power. Power factor corrected real power is available from two of the turbine system commercial instrumentation devices. The other two systems have yet to be instrumented although similar measurements are intended for these systems as well. The Skystream turbine system is instrumented with a T.E.D. (The Energy Detective) power meter which reports real power and RMS voltage through a USB link. The ARE 110 turbine system is instrumented with an Outback Power Technologies, Inc. charge controller with external MATE controller interface. The

MATE interface allows the measured power to be recorded via USB link to the data acquisition computer. Sampling rates for power measurements can be configured as high as one sample per second. Sampling rates for the wind and other weather data is as high as one sample per minute. Since we wish to correlate the power measurements with wind data the measurements are recorded at a sample rate of one sample per minute. This provides reasonable resolution for long term wind power data reporting. A sample of the Skystream data over the course of one day is shown below.

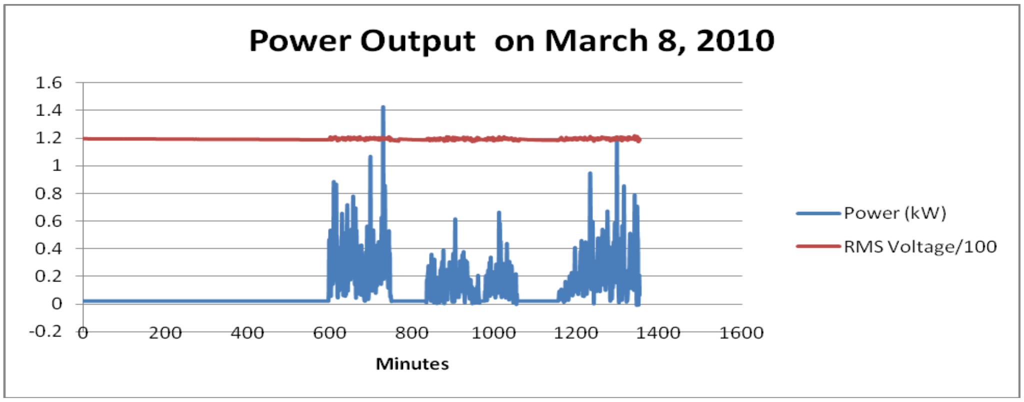

Figure 3: Power and voltage measurement data from the Skystream 3.7 turbine system.

Future Steps

The project is in its final year and we expect all operating systems to be instrumented and providing data prior to the end of the project period. After the conclusion of the current project tasks, we plan to continue operating the turbine systems in an effort to collect long-term reliability data and to continue providing a testing facility for additional small wind turbine designs. We hope the turbine site can provide an opportunity for undergraduate and graduate student conducted research in areas related to the current project such as electric to heat energy conversion using the diversion load power or further developments in AC/DC power instrumentation.

References

Southwest Windpower Inc. (2009), *Skystream 3.7 Battery Charging Guide, Rev A*

Biography

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Dr. Vincent Winstead is an associate professor in the electrical and computer engineering and technology department at Minnesota State University, Mankato. He completed his Ph.D. degree at the University of Wisconsin, Madison in Electrical Engineering.