Small Wind Power at Morrisville State College: A Case Study

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Renewable power generation through wind has seen unprecedented global expansion over the past decade and is projected to continue to grow. The U.S. Department of Energy predicts that wind power can supply 20% of the nation's electricity by 2030. In the process, wind energy may reduce projected CO_2 emissions (the leading greenhouse gas) by 25%. According to the American Wind Energy Association, the U.S. wind industry added more than 8,500 MW of wind power to the grid in 2008 bringing the installed total wind power capacity to more than 25,000 MW and making the U.S. the world leader in wind energy production. Although wind power generation capacity from a very small wind turbine (usually 10 kW or less) may be negligible compared to what can be produced from commercial wind farms, the potential impact of small wind systems is immense since these systems allow for distributed power generation and enable individuals to cut their energy bills while helping to protect the environment. Small wind turbines use wind energy to produce clean, emissions-free electrical power for farms, ranches, individual homes, and small businesses. Unlike utility-scale turbines, small turbines are usually suitable for use on properties with limited acreage (as little as one acre of land) in most areas of the country.

The small wind turbine located at Morrisville State College's Dairy Complex was installed in June 2004 and the unit has been in operation since 9 March 2006 (average electrical generation from the system is 5,580 kW.hr/year). The total installed cost of the system was $47,750. Seventy percent of system cost ($33,425) was covered by New York State Energy Research & Development Authority (NYSERDA).

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1. Small Wind Turbine Overview

Manufacturer:	Bergey WindPower Co. (BWC)
Model:	Excel-S
Rotor Specifications:	Three-blade (fiber-reinforced plastic) upwind turbine aligned into the wind by a tail assembly
Tower Type:	Guyed lattice
Tower Height:	120 (37 m)
Interconnect:	Grid intertie
Turbine Specifications*:	Start-up wind speed: 7.5 mph (3.4 m/s) Cut-in wind speed: 5 mph (2.4 m/s) Rated wind speed: 31 mph (13.9 m/s) Rated power: 10 kW Cut-out wind speed: None Furling wind speed: 35 mph (15.6 m/s) Maximum design wind speed: 125 mph (55.9 m/s) Type: 3-blade upwind Rotor diameter: 22 ft (6.7 m) Blade pitch control: None (fixed pitch) Over-speed protection: Auto furl Gearbox: None (direct drive) Temperature range: -40 to +140 ^{o}F (-40 to +60^{o} C) Generator: Permanent magnet alternator Output Form: 3-phase AC variable frequency, regulated through an electronic inverter (GridTek 10)
Performance Monitoring:	Ongoing

*Source: http://www.bergey.com/pages/excel_info

2. Wind Turbine Location

The 10-kW Bergey Excel Wind Turbine is located at Morrisville State College's Dairy Complex (Figure 1) where the electricity generated from the unit is utilized on-farm through a utility grid interconnect. MSC's dairy includes a free-stall barn that houses around 200 registered Holstein cows (and depends on more than 600 acres of farm land). An equal number of replacement dairy cattle are also raised and housed at the facility, bringing the total herd to about 400 animals. The Dairy Complex consists of a main free-stall barn, two heifer barns, dry cow and bred heifer barn, two calf barns, dairy show barn, and other auxiliary buildings for storage. The free-stall barn is cleaned with automatic alley scrapers. The college's cattle are fed on forages grown on the college's farm lands as well as feed concentrates.

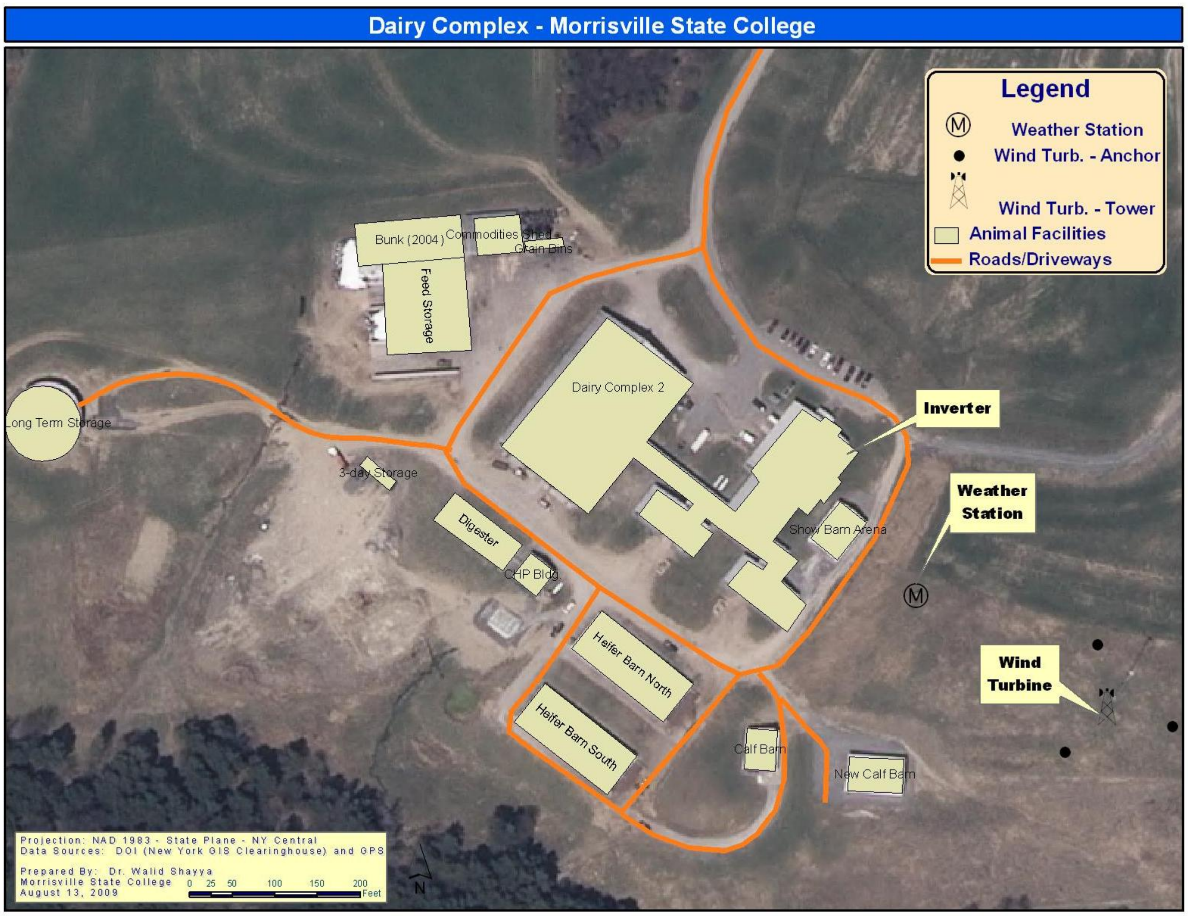

Figure 1. Map of Morrisville State College's Dairy Complex and surrounding area.

The 10-kW wind turbine is one of two renewable energy systems located at MSC's Dairy Complex. The second is a heated, hard-top plug-flow anaerobic digester that biologically treats dairy manure (and potentially other organic waste generated on campus) to produce a stable effluent with improved physical, chemical, and biological characteristics. Anaerobic digestion can minimize odor, generate biogas, and allow more effective nutrient use by crops. The produced biogas (about 60% methane) is captured and combusted to generate heat and power using a 50 kW engine/generator set. The plug-flow anaerobic digester is sized to treat manure from around 400 milking cows. On average, it generated 341,885 kW.hr/yr of electricity during the forty-two months of operation (Feb. 28, 2007 to July 31, 2011).

3. Justification for the Small Wind Turbine

Morrisville State College's mission is to educate students and to provide them with hands-on experiences using state-of-the-art facilities. The small wind turbine (Figure 2) helps renewable energy technology students (as well as those enrolled in environmental sciences, renewable resources, agricultural sciences, agricultural engineering, science and technology, and other disciplines) develop better understanding of underutilized technologies, energy and environmental conservation, and environmental stewardship. Specifically, the Renewable Energy Technology Associate of Applied Science (A.A.S.) program which was started in the 2009 Fall semester includes a number of specialized courses (e.g., RENG 220/320 – Wind and Hydro Energy Systems) that focus on renewable energy sources. The small wind turbine system provides for hands-on training on wind power and is an integral element of existing field-scale facilities (including the anaerobic digester) that provides Morrisville State College students with a strong grounding in renewable energy technologies.

Figure 2. View of MSC's small wind turbine.

The small wind turbine system was also intended for use in workshops and short courses offered through the Renewable Energy Training Center as well as formal and informal tours of the facility by people considering innovative renewable energy technologies for their properties, professionals that have heard of our projects, or alumni passing through. Since small wind systems allow for distributed power generation and enable individuals to cut their energy bills while helping to protect the environment, it was critical to use the system to conduct some applied research on small wind power. After all, small wind turbines use wind energy to produce clean, emissions-free electrical power for farms, ranches, individual homes, and small businesses.

Through the integration of education and applied research, Morrisville State College will continue its tradition of educating the new generation of technologists who will contribute to the development and sustainable growth of renewable energy systems that will ultimately increase the competitive edge of New York State.

4. Description of the Small Wind Turbine System

Morrisville State College's small wind turbine system (Figure 3) is manufactured by Bergey Windpower Co. (BWC). It is comprised of a 10-kW, EXCEL-S wind turbine, the GridTek 10 power processor, an energy meter (Figure 4), and a guyed-lattice tower. In addition, the installation involved a transformer (mounted on the wall below the inverter) for interconnection into the Complex's 3-phase system (Figure 5). The BWC Excel-S wind turbine is intended for grid-intertie applications. According to BWC's website (www.bergey.com), the Excel-S wind turbine unit was "designed for high reliability, low maintenance, and automatic operation in adverse weather conditions". "Connected to the grid, the BWC EXCEL-S can provide most of the electricity for an average total electric home at moderate wind sites". In addition to the equipment, the system involved a tower foundation, foundations and anchoring for the guyed-lattice tower, turbine and tower erection, three-conductor wire run between the tower disconnect switch and the GridTek 10, and electrical hook-up.

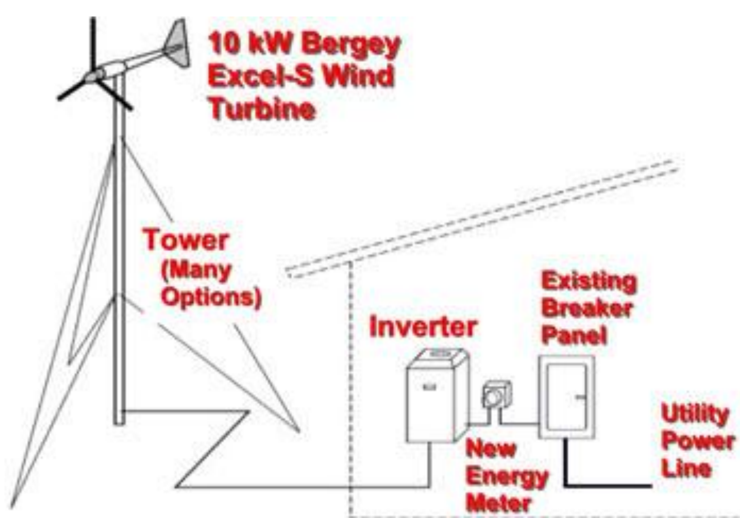

Figure 3. A schematic of the 10-kW, Bergey Excel-S wind turbine system (*source:* www.bergey.com).

Figure 4. A view of the energy meter (mounted to the left of a transformer).

Figure 5.   A view of the GridTek 10 power processor (top) and transformer (bottom) mounted on a wall across from the main entrance inside the main building of MSC's Dairy Complex.

The BWC Excel-S unit is a 22-ft (6.7-meter) diameter wind turbine (Figure 6). Like all BWC wind turbines, it operates at variable speed where power is generated in a direct drive, low speed, permanent magnet alternator. According to BWC's website (www.bergey.com), the output from the unit "is a 3-phase power that varies in both voltage and frequency with wind speed. This variable power (wild AC) is not compatible with the utility grid. To make it compatible, the wind power is converted into grid-quality 240 VAC, single phase, 60 hertz power in a synchronous inverter, the GridTek Power Processor."

Figure 6. A view of the BWC Excel-S wind turbine.

The GridTek 10 power processor (Figure 5) converts the wind power to utility power at 240 VAC, single phase, 60 Hz. It uses a 32-bit microprocessor and operates automatically. It has a single "Reset" button to be used when the unit needs to be reset and a digital display that shows the operational status of the unit, the rotational speed of the turbine's rotor (in rpm), and output power (in kW). In the event of a fault, the panel will identify the cause of the fault. The output from the GridTek 10 connects directly to the circuit breaker panel.

The guyed-lattice tower (Figure 7) is 120 ft (37 m) tall. At that height, it allows the BWC Excel-S wind turbine to be located at a height that maximizes wind speed by reducing wind shear (the change in horizontal wind speed with height due to friction). It also minimizes turbulence due to obstructions which will improve the effectiveness of the aerodynamics of the rotor blades and minimize vibrations, thereby reducing the strain on the blades of the wind turbine. The guyed-lattice tower included twelve 10-ft (3-m) welded sections and nine guy wires. According to BWC, the guyed-lattice tower is an efficient structure because the guy wires give the tower a wide base.

Figure 7. A view of the base of the 120-ft tall, guyed-lattice tower.

5. Small Wind Turbine Operation

The process for the development of a small wind turbine at Morrisville State College's Dairy Complex was initiated in 2003. However, it was not until early June 2004 when the foundations for the guyed-lattice tower (Figure 8) and anchors were poured (Figure 9). The system was installed during a "Wind Turbine Installation" workshop coordinated by New York State Energy Research and Development Authority (NYSERDA) and AWS Truewind, LLC, (AWS Scientific at the time) and conducted on campus between the 21st and 25th of June, 2004. Sustainable Energy Development Inc. (SED) coordinated the design and site assessment, and performed the installation (during the workshop) and the interconnection of the system after the college personnel prepared the site and poured the foundations. SED worked directly with Morrisville State College, New York Electric and Gas (NYSEG), and NYSERDA who funded the bulk of the cost on the project (70%).

Figure 8. A view of the pad for the guyed-lattice tower base.

Figure 9. A view of one of the three guy anchor pads after being poured.

Although installed in late June 2004, the interconnect on the wind turbine did not get finalized until December 1, 2005. The delay was primarily due to the need to establish that the grid interconnect met NYSEG's requirements. In addition, there were some issues with the inverter board that precluded the operation of the system until 9 March 2006 when it was finally fixed and the system commenced operation. Generally speaking, the system has been in operation since then and only needed to be reset a few times. Records dating back to October 30, 2007, have been kept and an analysis of the performance of the system has been conducted on monthly basis since then. Results of the monthly analysis are made available online as explained in the last section of this document. A summary of system operation since 30 October 2007 is provided in Table 1.

The average daily generated electricity from the small power turbine (since 1 November 2007) was 17.5 kW.hr while the average electrical output since that date was about 0.7 kW. The average daily wind speed during the same period amounted to 6.2 mph (2.8 m/s). The highest wind speed observed was 51.1 mph (22.8 m/s) recorded on April 1, 2008 while the highest daily generated electricity was 96.0 kW.hr observed on 2 April 2008 with corresponding average power output for the day of 4.0 kW. The wind speed was measured by one of the many sensors installed on a self-contained, fully-automated weather station located (as depicted in Figure 1) about 350 feet to the northwest of the wind turbine at a height of 9.8 ft (3 m). The station has been in operation since 2002 and collects weather data from a set of standard sensors.

As for the monthly records presented in Table 1, the highest electrical output from the small wind turbine was observed during the month of March, 2011. It included an electrical energy production of 1007 kW.hr which corresponds to an average monthly power output of 1.4 kW.

Until 3 August 2011, the system has generated a total of 30,144 kW.hr with an average annual electrical output of 5,577 kW.hr/yr over the life of the system (i.e., the period between 3/9/06 and 8/3/11). During the last forty-five months after extensive record-keeping was initiated (i.e., starting from 30 October 2007), the average annual electrical energy generation from the small wind turbine amounted to 6,393 kW.hr.

Several attempts were made to establish whether the generated electrical power can be predicted using measured wind speed from the anemometer installed at 9.8 ft (3 m) on the nearby fully-automated weather station. Although hourly and daily weather data were available for establishing a prediction using a regression model, the best results were achieved when the monthly average of average (or maximum) daily wind speeds from the weather station were used as depicted in Figure 10 (and Figure 11 using the maximum instead of average daily wind speed). Two trend lines appear on each plot along with corresponding regression equations generated using the least squares method. In each instance, the power regression line is expected to produce better predictions (than the simple linear regression line) of electrical power output given the higher coefficient of determination (R^2).

Finally, work is proceeding on analyzing data from several anemometers installed on the guyed-lattice tower as well as on a 131-ft (40-m) MET (meteorological) tower that was also installed close to the wind turbine in October 2009 (the anemometers were located on the MET Tower at different heights, including the height of the BWC EXCEL-S unit). The reason for this setup is to measure the wind speed (and direction) more accurately at the height of the turbine as well as model wind shear and turbulence at the site. Once available, the results will be made available on-line.

Table 1. Daily and monthly summaries of MSC's small wind turbine operation during the period of 1 November 2007 to 31 July 2011.

Month	Generated Electricity (kW.hr)	Average Daily Generated Elect. (kW.hr)	Average Electrical Output (kW)	Daily Wind$_{avg.}$		Daily Wind$_{max.}$					
				(mph)	(m/s)	Average (mph)	Average (m/s)	Max. (mph)	Max. (m/s)	Day of Wind$_{max.}$	Time of Wind$_{max.}$
November 2007	656.0	21.9	0.9	5.4	2.4	20.9	9.3	38.2	17.1	*11/29/07*	*3:52 PM*
December 2007	896.0	28.9	1.2	7.3	3.3	24.3	10.9	41.1	18.4	*12/23/07*	*7:15 AM*
January 2008	792.0	25.5	1.1	7.3	3.3	23.0	10.3	43.2	19.3	*01/09/08*	*9:33 AM*
February 2008	704.0	24.3	1.0	6.5	2.9	24.0	10.7	40.3	18.0	*02/17/08*	*11:52 AM*
March 2008	920.0	29.7	1.2	6.4	2.9	23.9	10.7	36.4	16.3	*03/25/08*	*8:16 PM*
April 2008	704.0	23.5	1.0	7.3	3.3	22.9	10.2	51.1	22.8	*04/01/08*	*10:07 PM*
May 2008	509.7	16.4	0.7	6.3	2.8	22.6	10.1	35.0	15.6	*05/19/08*	*2:27 PM*
June 2008	268.7	9.0	0.4	5.0	2.2	20.3	9.1	32.8	14.7	*06/10/08*	*5:12 PM*
July 2008	172.1	5.6	0.2	4.6	2.1	19.4	8.7	40.0	17.9	*07/20/08*	*3:11 PM*
August 2008	216.8	7.0	0.3	4.4	2.0	18.3	8.2	27.1	12.1	*08/15/08*	*3:51 PM*
September 2008	278.3	9.3	0.4	4.4	1.9	17.6	7.9	43.9	19.6	*09/15/08*	*1:27 AM*
October 2008	325.9	10.5	0.4	5.0	2.2	19.4	8.7	32.8	14.7	*10/02/08*	*12:19 PM*
November 2008	613.1	20.4	0.9	5.4	2.4	19.8	8.9	35.0	15.6	*11/13/08*	*9:37 AM*
December 2008	736.3	23.8	1.0	7.2	3.2	25.9	11.6	47.9	21.4	*12/24/08*	*10:54 PM*
January 2009	511.1	16.5	0.7	6.7	3.0	23.1	10.3	37.8	16.9	*01/28/09*	*9:00 PM*
February 2009	746.7	26.7	1.1	7.6	3.4	24.4	10.9	40.7	18.2	*02/12/09*	*1:26 PM*
March 2009	720.8	23.3	1.0	7.4	3.3	22.5	10.1	35.3	15.8	*03/11/09*	*2:55 PM*
April 2009	841.4	28.0	1.2	7.5	3.4	25.4	11.4	39.6	17.7	*04/04/09*	*9:19 AM*
May 2009	528.5	17.0	0.7	6.7	3.0	22.8	10.2	38.2	17.1	*05/09/09*	*8:07 PM*
June 2009	201.7	6.7	0.3	5.2	2.3	18.0	8.1	28.5	12.8	*06/25/09*	*4:37 PM*
July 2009	257.0	8.3	0.3	5.3	2.4	18.1	8.1	27.8	12.4	*07/13/09*	*11:55 AM*
August 2009	160.0	5.2	0.2	4.8	2.2	17.8	8.0	32.8	14.7	*08/18/09*	*4:29 PM*
September 2009	204.4	6.8	0.3	5.3	2.4	17.5	7.8	25.7	11.5	*09/29/09*	*5:58 PM*
October 2009	499.2	16.1	0.7	5.8	2.6	19.8	8.9	40.0	17.9	*10/07/09*	*5:45 PM*
November 2009	457.6	15.3	0.6	5.9	2.6	19.4	8.7	38.2	17.1	*11/28/09*	*3:18 AM*
December 2009	934.9	30.2	1.3	7.3	3.3	23.8	10.6	39.3	17.6	*12/11/09*	*1:07 PM*
January 2010	580.9	18.7	0.8	6.6	2.9	21.4	9.6	41.1	18.4	*01/25/10*	*3:50 AM*
February 2010	509.1	18.2	0.8	7.1	3.2	22.9	10.2	35.0	15.6	*02/26/10*	*12:24 AM*
March 2010*	***777.4***	25.1	1.0	7.6	3.4	22.0	9.9	40.7	18.2	*03/13/10*	*3:50 PM*
April 2010*	***597.3***	19.9	0.8	6.5	2.9	23.2	10.4	36.8	16.4	*04/21/10*	*4:22 PM*
May 2010	532.0	17.2	0.7	6.1	2.7	22.5	10.1	43.6	19.5	*05/08/10*	*4:16 PM*
June 2010	366.0	12.2	0.5	5.8	2.6	20.6	9.2	36.8	16.4	*06/05/10*	*1:37 AM*
July 2010	264.0	8.5	0.4	5.3	2.4	20.0	8.9	34.3	15.3	*07/17/10*	*7:48 PM*
August 2010	152.0	6.9	0.3	5.2	2.3	18.0	8.0	27.8	12.4	*08/06/10*	*1:07 PM*
September 2010	296.0	10.6	0.4	6.1	2.7	20.7	9.3	31.4	14.0	*09/28/10*	*12:17 PM*
October 2010	591.3	19.7	0.8	6.6	2.9	22.2	9.9	35.3	15.8	*10/15/10*	*9:04 PM*
November 2010	681.1	22.7	0.9	6.7	3.0	21.4	9.6	39.3	17.6	*11/17/10*	*5:33 PM*
December 2010	696.8	22.5	0.9	7.1	3.2	21.5	9.6	34.3	15.3	*12/27/10*	*6:24 PM*
January 2011	230.7	17.7	0.7	5.3	2.4	19.2	8.6	33.2	14.8	*01/21/11*	*4:20 PM*
February 2011	742.1	26.5	1.1	7.3	3.3	25.4	11.3	44.6	20.0	*02/18/11*	*10:33 PM*
March 2011	1007.2	32.5	1.4	7.9	3.5	24.6	11.0	36.4	16.3	*03/09/11*	*10:57 PM*
April 2011	836.4	27.9	1.2	7.7	3.5	25.2	11.3	37.5	16.8	*04/02/11*	*4:12 PM*
May 2011	502.7	16.2	0.7	6.0	2.7	19.5	8.7	33.6	15.0	*05/05/11*	*10:52 AM*
June 2011	205.5	6.8	0.3	5.2	2.3	19.2	8.6	32.1	14.4	*06/02/11*	*6:21 AM*
July 2011	246.6	8.0	0.3	5.2	2.3	19.7	8.8	32.1	14.4	*07/13/11*	*2:53 PM*
Average (if applicable)	**526.0**	**17.6**	**0.7**	**6.2**	**2.8**	**21.4**	**9.6**	**36.8**	**16.4**		
Minimum (if applicable)	**152.0**	**5.2**	**0.2**	**4.4**	**1.9**	**17.5**	**7.8**	**25.7**	**11.5**		
When the Min. Occurred	*August 2010*	*August 2009*	*August 2009*	*September 2008*		*September 2009*		*09/29/09*		*at*	*5:58 PM*
Maximum (if applicable)	**1007.2**	**32.5**	**1.4**	**7.9**	**3.5**	**25.9**	**11.6**	**51.1**	**22.8**		
When the Max. Occurred	*March 2011*	*March 2011*	*March 2011*	*March 2011*		*December 2008*		*04/01/08*		*at*	*10:07 PM*

**Note: The system was down from 14 March 2010 to 8 April 2010 due to a blown fuse (generated electricity figures for the two months are not actual).*

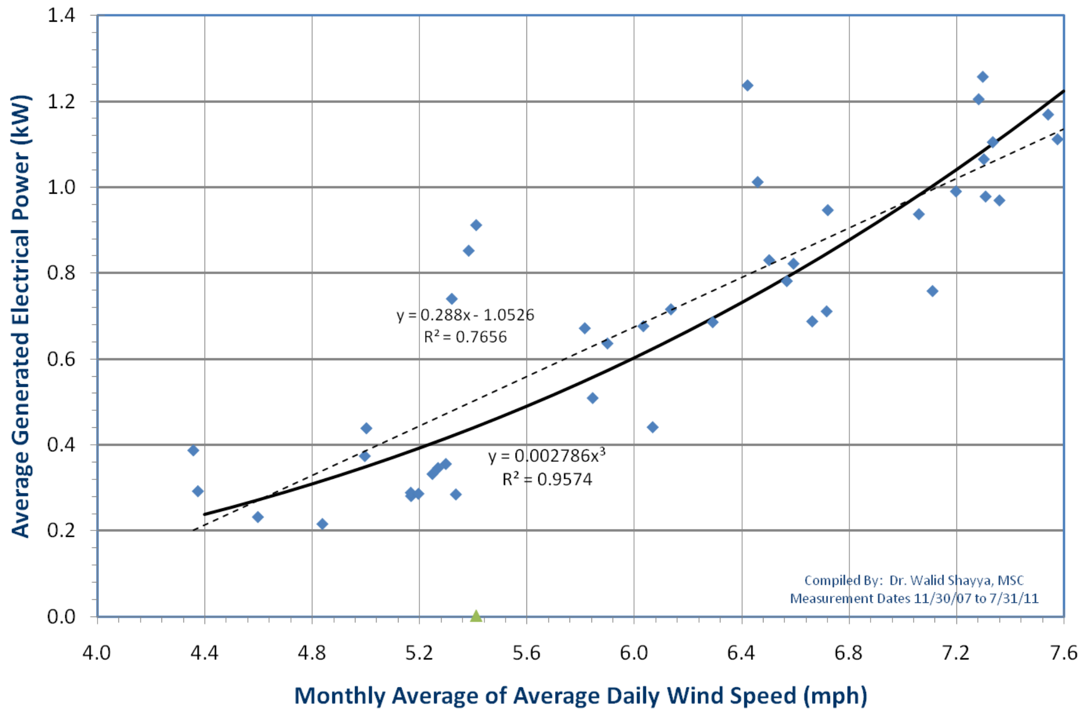

Figure 10. Plot of generated electrical power versus the monthly average of average daily wind speed.

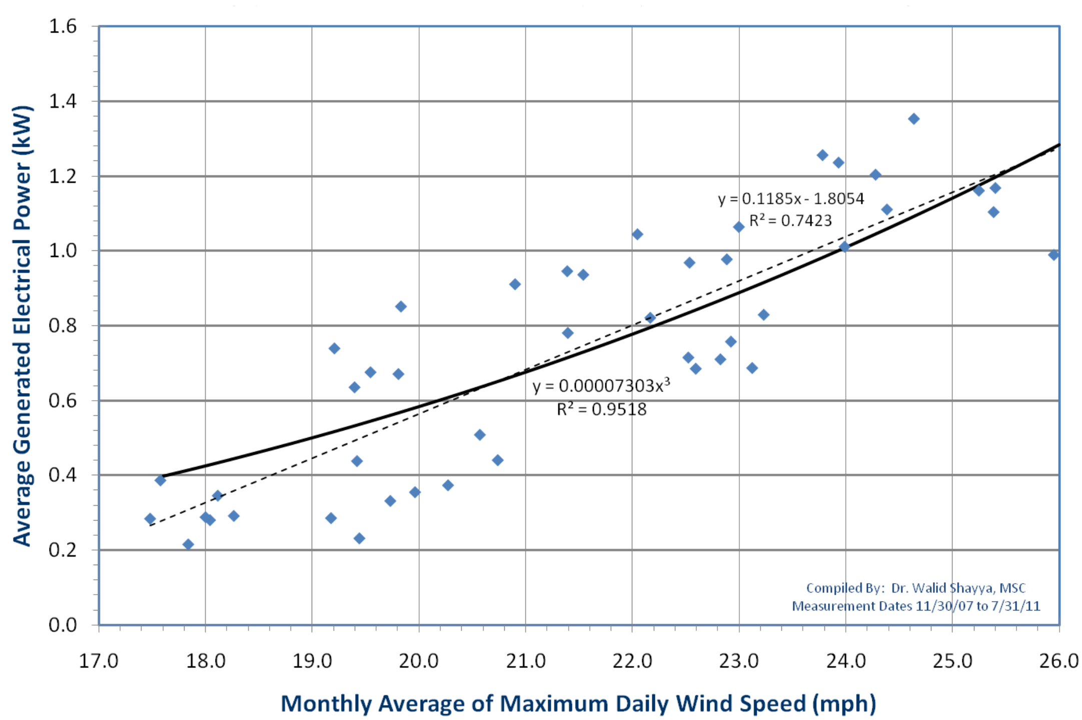

Figure 11. Plot of generated electrical power versus the monthly average of maximum daily wind speed.

6. Economic Information

Existing economic information on the system includes the initial capital and installation costs as well as the potential savings in electric energy costs due to the installation of the system. Initial capital costs on the system amounted to $47,750. The NYSERDA incentive was 70 % of capital and installation costs ($33,425), and MSC covered the balance ($14,325) through cash, material, and labor contributions (material and labor for site preparation, foundation, and electrical wiring). The breakdown of system costs is presented in Table 2.

Grid electric energy costs at the Dairy Complex along with the "demand" power requirements for the period of January 2006 to March 2010 are presented in Figure 12. Average savings in electric energy costs due to the installation of the small wind turbine may be assessed by establishing the value of the generated electrical power based on the average annual generated electricity (5,577 kW.hr/yr) with a "dollar value" being assigned to each kW.hr generated (a value of $0.11/kW.hr was used which represents the average cost of electricity for the period presented in Figure 12). This approach should be acceptable given that the generated electricity does not completely meet the electrical power demand at the facility. Based on that, an average annual benefit of $613 (a total of $3,316 until August 3, 2011) may be attributed to the operation of the small wind turbine. This figure is substantially lower than the anticipated benefit from the system and may be attributed to the low average wind speeds (6.2 mph or 2.8 m/s). Nevertheless, the integration of the small turbine system in experiential and technical training through the Renewable Energy Training Center and the two-year academic program on Renewable Energy Systems provide for numerous additional benefits from the small wind turbine.

Table 2. Capital and installation costs of the BWC Excel-S 10-kW wind turbine.

Item	Cost
10-kW BWC Excel-S Turbine (including GridTek 10)	$22,900
Guyed-lattice Tower (120 ft)	$8,100
Wiring Kit for Tower	$1,000
Transformer (240V to 208V)	$1,500
Freight	$1,750
Crane	$1,000
Foundation Material (concrete/rebar) and Labor	$5,000
Miscellaneous (wire/conduit) Electrical Material and Labor	$2,500
Labor for System Design and Installation	$4,000
Total	$47,750

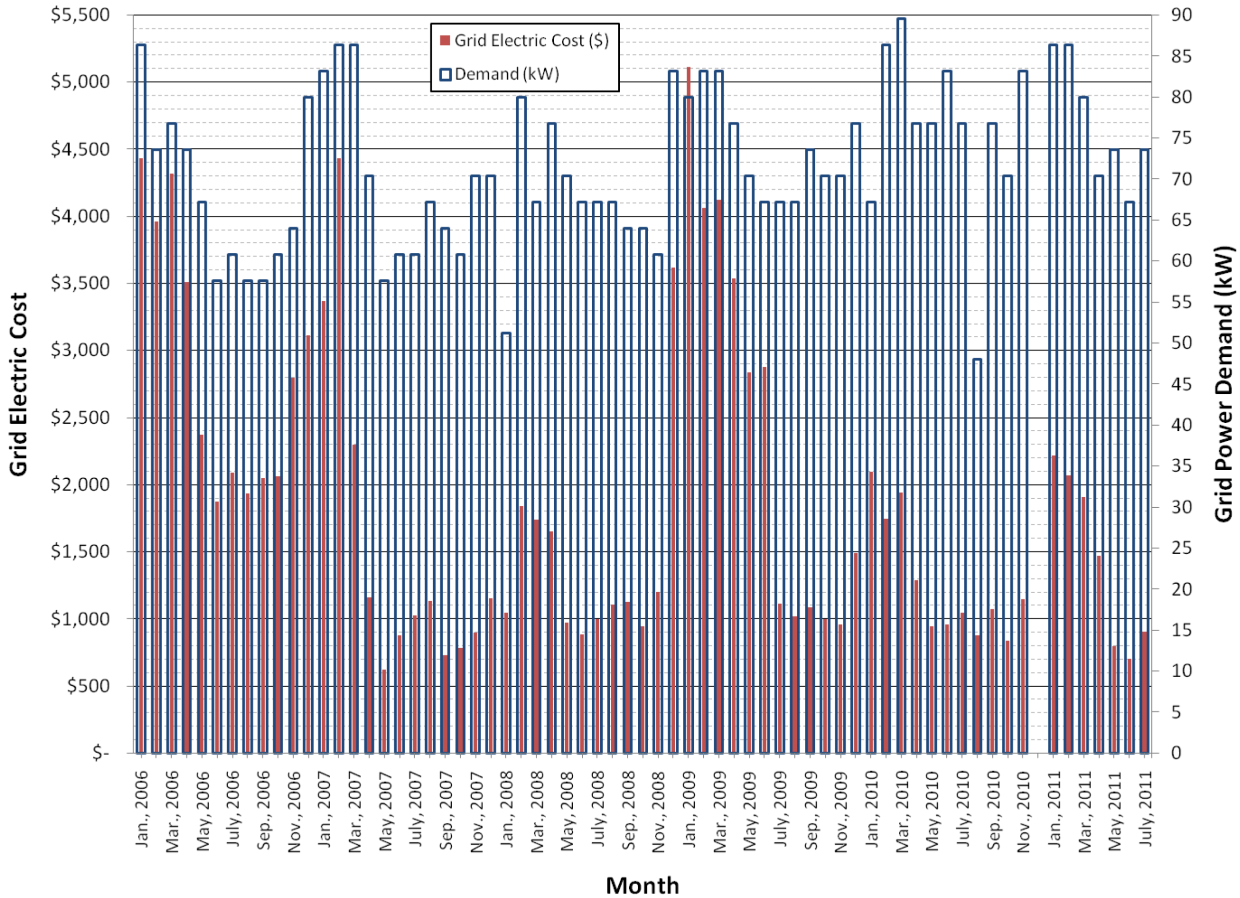

Figure 12. Grid electric energy costs at the Dairy Complex along with demand power requirements for the period of January 2006 to July 2011.

7. Additional and Contact Information

A website on the 10-kW wind turbine and pertinent renewable energy projects is maintained under Morrisville State College's main page. The website is available under the "Alternative Energy Projects" link accessible from the "Technology" tab which may be accessed from the home page of the college's website at www.morrisville.edu. The main page on "Alternative Energy Projects" can also be accessed directly using the following address: www.morrisville.edu/alternativeenergy/default.aspx. In addition, detailed tabular data on system operation may be accessed online at www.morrisville.edu/alternativeenergy/windturbine.aspx.

For additional questions, please contact any of these individuals:

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