Madison Windpower Project

Final Report

Prepared for

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ABSTRACT

This report covers the development and operation of the Madison Windpower Project in Madison County, New York developed by PG&E Generating. The project began commercial operation in October 2000 and consists of seven Vestas V66-1.65 MW OptiSlip® wind turbines for a total capacity of 11.55 MW. Long-term wind resource estimates predicted an annual hub-height average wind speed of 7.3 m/s. The net annual plant energy production was predicted to be 23,621 MWh, which would produce a capacity factor of 23.3%. The wind turbines were dispatched and controlled from the PG&E Pittsfield operations center, which was also responsible for substation maintenance. Vestas took charge of inspection, adjustment, and repair of the turbines (both scheduled and unscheduled) and established an operations and maintenance facility in the Madison area. The wind plant produced a total of 61,379 MWh of electricity for three years for an annual average of 20,460 MWh and an overall capacity factor of 21%. The capacity factor is lower than the expected value of 23.3% primarily due to lower than predicted wind speeds and turbine and grid outages. Average plant availability was 92 %, which was lower than the expected value of 95% because of the unanticipated frequency of mechanical turbine component failures and grid outages.

KEY WORDS

Wind energy

Renewable Energy

Clean Energy

Madison Windpower Project

Pacific Gas & Electric (PG&E)

Vestas V66-1.65 MW wind turbine

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SUMMARY

This report covers the development and operation of the Madison Windpower Project in Madison County, New York, which was initially developed by Atlantic Renewable Energy Corporation (AREC) and then acquired by PG&E Generating (PG&E). The project began commercial operation in October 2000 and consists of seven Vestas V66-1.65 MW OptiSlip® wind turbines for a total capacity of 11.55 MW. NYSERDA contributed $2 million towards the project to encourage large-scale wind energy development in New York State. NYSERDA also served as the lead agency for environmental permitting. Environmental Design and Research (EDR) was selected by PG&E as the lead subcontractor for preparing the project permit applications. AWS Scientific (AWS) was chosen as the Program Evaluator. Vestas American Wind Technology (Vestas) provided Engineering, Procurement, and Construction (EPC) services.

During the development stage, meteorological data was collected from one 50 m and two 10 m towers on the project site. Long-term wind resource estimates predicted an annual hub-height average wind speed of 7.3 m/s. By estimating losses to be 12%, the net annual plant energy production was calculated to be 23,621 MWh, which would produce a capacity factor of 23.3%.

The PG&E Board of Directors approved funding for the project in December 1999. Initial environmental planning and outreach activities indicated that there would be no significant environmental problems with the proposed project, although bird-monitoring studies were planned for the first year following project commissioning. NYSERDA issued a Negative Declaration in December 1999 as part of the State Environmental Quality Review, and Madison Windpower obtained authorization to receive payment from NYSERDA for plant construction. The Obstruction to Aviation Notification was filed with the FAA in December 1999. The FAA issued a permit a month later with the lighting and obstruction marking requirements. Vestas received a Town building permit for the construction of the operations and maintenance building in May 2000. PG&E decided to interconnect the plant with the nearby 115 kV line. The electrical interconnection agreement was signed with the New York State Electric & Gas Corporation (NYSEG) in May 2000 for the delivery of power to the New York Independent System Operator (NYISO).

The wind turbines were dispatched and controlled from the PG&E Pittsfield operations center, which was also responsible for substation maintenance. Vestas took charge of inspection, adjustment, and repair of the turbines (both scheduled and unscheduled) and established an operations and maintenance facility in the Madison area.

The actual monthly wind speeds were typically lower than the expected monthly wind speeds (as predicted by the long-term wind resource and energy production estimate), especially during the first and third years of the

project. This discrepancy is due to the lack of a full year of 50 m met tower data at the time of the original estimate, the 1.3% drop in the estimate based on the current data from the reference meteorological station at Syracuse, and the fact that the current met tower at the site is 10 m lower in elevation than the original 50 m met tower.

The wind plant produced a total of 61,379 MWh of electricity for three years for an annual average of 20,460 MWh and an overall capacity factor of 21%. The capacity factor is lower than the expected value of 23.3% primarily due to lower than predicted wind speeds and grid and turbine outages. Average plant availability was 92%, which was lower than the expected value of 95% because of the unanticipated frequency of mechanical turbine component failures and grid outages.

Availability problems were distributed among the turbines rather than concentrated on a single turbine. The energy production is fairly uniform due to the topography of the site. The less exposed turbines are higher in elevation, which partially balances their reduced exposure and increased wake losses.

The interconnection agreement between Madison Windpower and NYSEG requires that the power factor be greater than 0.95. The power factor was greater than 0.95 for all plant power production levels above 4 MW with few exceptions. For plant power production levels below 4 MW, low power factor readings are thought to be due to problems with the Supervisory Control and Data Acquisition (SCADA) system rather than the power factor correction equipment. Typical utility electrical standards require that the voltage be maintained within 5% of nominal voltage. The monthly average plant voltage was 112.9 kV, or approximately 98.2% of the nominal grid voltage of 115 kV. Voltage imbalance is defined as the maximum deviation from the average of the three phase voltages divided by the average of the three phase voltages, expressed as a percentage. Manufacturers of electric motors and generators typically recommend that users not exceed 1% voltage imbalance. The voltage imbalance averaged about 0.4% over the past three years. The voltage imbalance shows a seasonal dependency with the average value varying between 0.2% in winter and 0.5% in summer. The cause of this trend is unclear but indicates that there is a large seasonal load to one or two phases of the NYSEG line.

Outages are characterized as being major or minor in nature. A major outage occurs when the entire plant is shut down for more than a day or one turbine is shut down for more than a week. A minor outage occurs when the entire plant is shut down for more than one hour, or one turbine is shut down for more than a day. During these three years of plant operation, there were 17 major outages and 49 minor outages. Grid outages are problems that are not on the plant's side of the grid connection point. Most grid outages are due to low voltage on the 115 kV power line, which trips the substation breaker and requires a manual reset. Natural Causes are typically weather-related problems such as lightning and icing. Equipment and grid malfunctions caused by natural causes are included in this category. Most of the natural outages were due to icing during the unusually harsh winter of 2002-2003. Internal Mechanical & Electrical outages are unscheduled repairs. Most of these repairs were caused by defective bearings in the gearboxes. Consequently a replacement schedule had to be arranged for all of the transmission gearboxes. This malfunction shut down the turbines for an unexpectedly long amount of time. Scheduled maintenance was a small fraction of the outage downtime.

The operational performance of the Madison Windpower Plant demonstrates the need to have sufficient long-term meteorological data in order to predict a wind plant's energy production accurately. Continued evaluation of the estimate during plant operation can clarify trends and enhance understanding of the site's wind resource. As such, it is expected that the overall wind resource will be more favorable during the lifetime of the plant. This experience with the Vestas V66 turbines has shown some of the advantages and disadvantages of this model. For example, excellent lightning protection resulted in few outages due to static discharge. However, the gearbox bearing design was defective and caused a large percentage of the turbine outages. This knowledge will improve plans for future wind plants in New York.

INTRODUCTION
Section 1

This report covers the development and operation of the Madison Windpower Project in Madison County, New York.

OBJECTIVES

The Madison Wind Plant primarily was designed to take advantage of the favorable wind resource in Madison County, New York. Other objectives included evaluating the wind energy development process in New York State and assessing the Vestas V-66 1.65 wind turbine for future wind energy development.

PARTICIPANTS AND SCHEDULE

PG&E Generating (PG&E) acquired the project proposed in the Madison Township, Madison County from Atlantic Renewable Energy Corporation (AREC) on May 24, 1999. NYSERDA contributed $2 million towards the project to encourage large-scale wind energy development in New York State. NYSERDA also served as the lead agency for environmental permitting. Environmental Design and Research (EDR) of Syracuse, New York was selected by PG&E as the lead subcontractor for preparing the project permit applications. AWS Scientific (AWS) was chosen as the Program Evaluator. Vestas American Wind Technology (Vestas) provided Engineering, Procurement, and Construction (EPC) services. Table 1-1 lists the major project milestones.

REPORT OUTLINE

This report summarizes key activities and findings of the project. It includes a brief history of the project development, site description, turbine description, and O&M analysis. The O&M analysis covers wind conditions, plant performance, turbine performance, power quality, and outages. The report concludes with major lessons learned during the project and recommendations for future practices. Terms used in this report are defined in Appendix A.

Table 1-1: Madison Windpower Project Milestones

Event	Completion
Project acquired from AREC by PG&E	May 1999
Project kickoff meeting with NYSERDA	Aug 1999
Full Environmental Assessment Form filed	Nov 1999
Funding approved by PG&E Board of Directors	Dec 1999
Engineering, Procurement, and Construction Contract signed with Vestas	Dec 1999
Warranty, Maintenance, and Service Contract signed with Vestas	Dec 1999
Negative Declaration issued for State Environmental Quality Review by NYSERDA	Dec 1999
FAA Obstruction Lighting Permit issued	Jan 2000
Ground breaking ceremony	Apr 2000
Notice to proceed issued by NYSERDA	May 2000
Town building permit obtained for construction of operations and maintenance building	May 2000
Factory turbine tests and inspections	July 2000
Program evaluator subcontract signed with AWS Scientific	July 2000
Electrical interconnection agreement signed with NYSEG	Aug 2000
Turbine installation	May 2000 - Aug 2000
Ribbon cutting ceremony	Sep 2000
Completion of acceptance testing	Oct 2000
Commencement of commercial operation	Oct 2000
Period of independent monitoring	Oct 2000 – Sep 2003

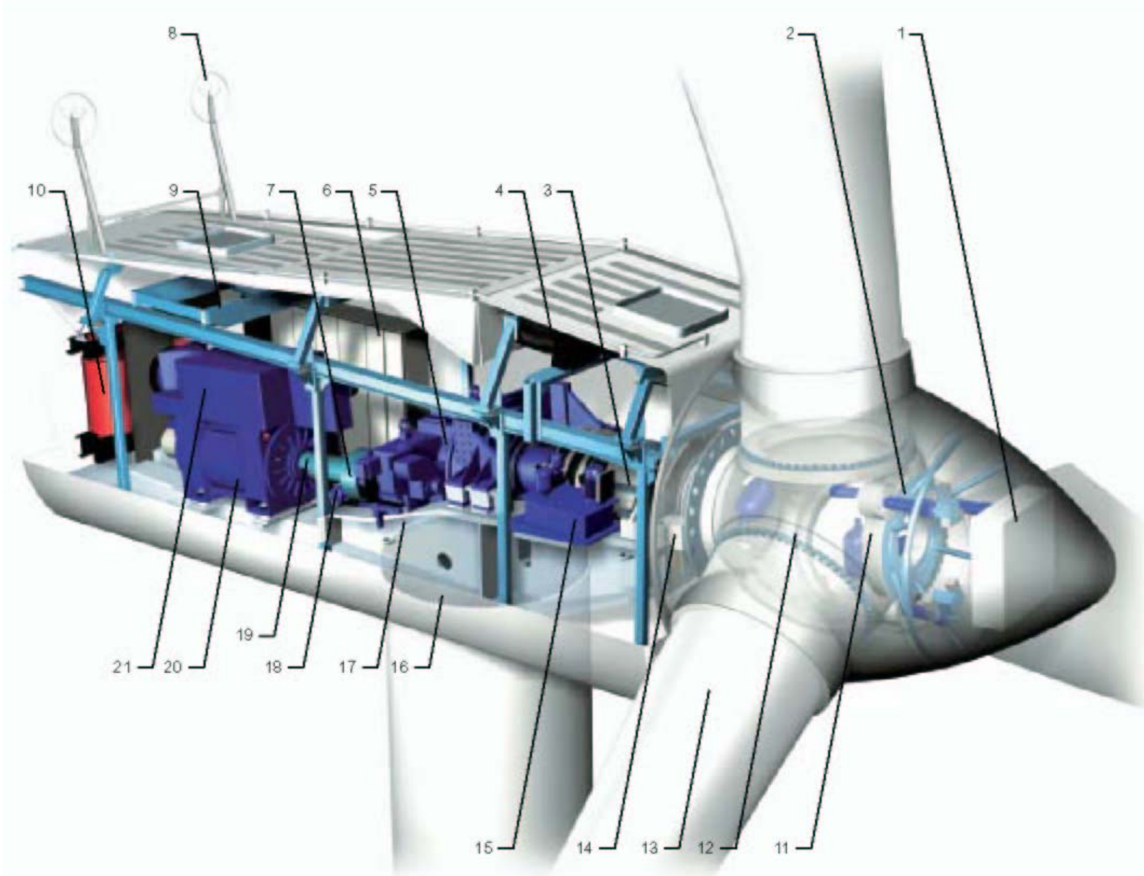
TURBINE DESCRIPTION AND SPECIFICATIONS[1]

Section 2

The project consists of seven Vestas V66-1.65 MW OptiSlip® wind turbines. This wind turbine model has a 66 m rotor diameter. Figure 2-1 shows the turbine components, which include:

- Blades: Three blades consisting of glass fiber reinforced epoxy are attached to the hub. Each blade is made of two blade shells that are bonded to a supporting beam. The blade is connected to the blade bearing with steel root inserts, and the blade bearing is a 4-point ball bearing bolted to the blade hub.
- Turbine Control Unit: Microprocessor-based control units monitor all turbine functions.
- Generators: In order to minimize noise and maximize energy production, the turbine has two asynchronous generators. The primary generator runs at wind speeds above approximately 7 m/s with a nominal rotor speed of 19.8 rpm. The secondary generator runs at wind speeds of approximately 7 m/s or less with a nominal rotor speed of 15.4 rpm. The OptiSlip® system allows the slip of the generator to vary electronically from 1-10% and thereby reduce the dependency between speed and load. This system reduces spikes in supplied power and mechanical loads caused by wind gusts.
- Gearbox: Power from the main shaft is transmitted to the generators through the gearbox, which combines planetary and helical stages. The gearbox connects to the primary generator through a maintenance-free composite coupling and connects to the secondary generator through a transmission shaft.
- Pitch Control System: The pitch system works with the OptiSlip® feature in order to keep the power at nominal high wind speeds independent of air density and air temperature. Blade pitch is adjusted through a hydraulic system.
- Nacelle: The nacelle components are encased in a glass fiber reinforced nacelle cover.
- Tower: The steel tubular tower raises the hub to 67 m.
- Yaw Drive: The yaw system uses four electrically driven yaw gears that mesh with a large toothed yaw ring mounted on the top of the tower.
- Braking: Braking is accomplished through full feathering of the blades.

[1] *General Specifications V66-1.65 MW OptiSlip® Wind Turbine 50 Hz and 60 Hz.* Vestas American Wind Technology, Inc.: March 1999.



1.	*Hub controller*	11.	*Blade hub*
2.	*Pitch cylinder*	12.	*Blade bearing*
3.	*Main shaft*	13.	*Blade*
4.	*Oil cooler*	14.	*Rotor lock system*
5.	*Gearbox*	15.	*Hydraulic unit*
6.	*VMP-Top controller with converter*	16.	*Yaw ring*
		17.	*Machine foundation*
7.	*Parking brake*	18.	*Yaw gears*
8.	*Ultra-sonic wind sensors*	19.	*Composite disc coupling*
9.	*Service crane*	20.	*OptiSpeed™ generator*
10.	*Transformer*	21.	*Generator cooler*

Figure 2-1: Vestas V66-1.65 MW Wind Turbine

PLANT DEVELOPMENT PROCESS

Section 3

PG&E Generating (PG&E) acquired the project proposed in the Madison Township, Madison County from Atlantic Renewable Energy Corporation (AREC) on May 24, 1999. Environmental Design and Research (EDR) of Syracuse, New York was selected by PG&E as the lead subcontractor for preparing the project permit applications. AWS Scientific (AWS) was chosen as the Program Evaluator. The Vestas V-66 1.65 MW turbine was selected for the project because it was a larger-scale version of the successful V-47. The project was planned to include seven turbines for a total plant capacity of 11.55 MW. A contract was signed with Vestas American Wind Technology (Vestas) for Engineering, Procurement, and Construction (EPC) services in December 1999.

WIND RESOURCE AND ENERGY PRODUCTION ASSESSMENT

Meteorological data were collected from a 50 m and two 10 m towers on the project site. The first 10 m tower was installed on November 9, 1994 and removed on January 1, 1996. The second 10 m tower was installed on May 3, 1998 and removed on April 4, 1999. The 50 m tower was commissioned on April 7, 1999. Almost two years of data were collected at the 10 m height, although only six months of data had been collected at the 50 m tower when the energy estimates were completed in December 1999. PG&E's meteorological consultant, Rich Simon, developed a wind resource estimate at turbine hub height (67 m) concurrently with AWS. The two estimates agreed within the established band of uncertainty. AWS predicted that the annual hub-height average wind speed would be 7.3 m/s. By estimating losses to be 12%, the net annual plant energy production was estimated to be 23,621 MWh, which would produce a capacity factor of 23.3%.

PERMITTING AND FINANCING

The PG&E Board of Directors approved funding for the project in December 1999. Initial environmental planning and outreach activities indicated that there would be no significant environmental problems with the proposed project. To alleviate concerns regarding avian impact, bird-monitoring studies were planned for the first year following project commissioning. NYSERDA, the lead agency for review of the project, issued a Negative Declaration in December 1999 as part of the State Environmental Quality Review. With the completion of review required under Article 8 of the Environmental Conservation Law, State Environmental Quality Review Act, Madison Windpower received authorization to receive NYSERDA payment for plant construction. The Obstruction to Aviation Notification was filed with the FAA in December 1999 and a permit was received from the FAA a month later with the lighting and obstruction marking requirements. The EPC contractor received a Town building permit for the construction of the operations and maintenance building in May 2000. PG&E decided to interconnect the plant with the nearby 115 kV line. The electrical interconnection agreement was signed with the New York State Electric & Gas Corporation (NYSEG) in May 2000 for the delivery of power to the New York Independent System Operator (NYISO).

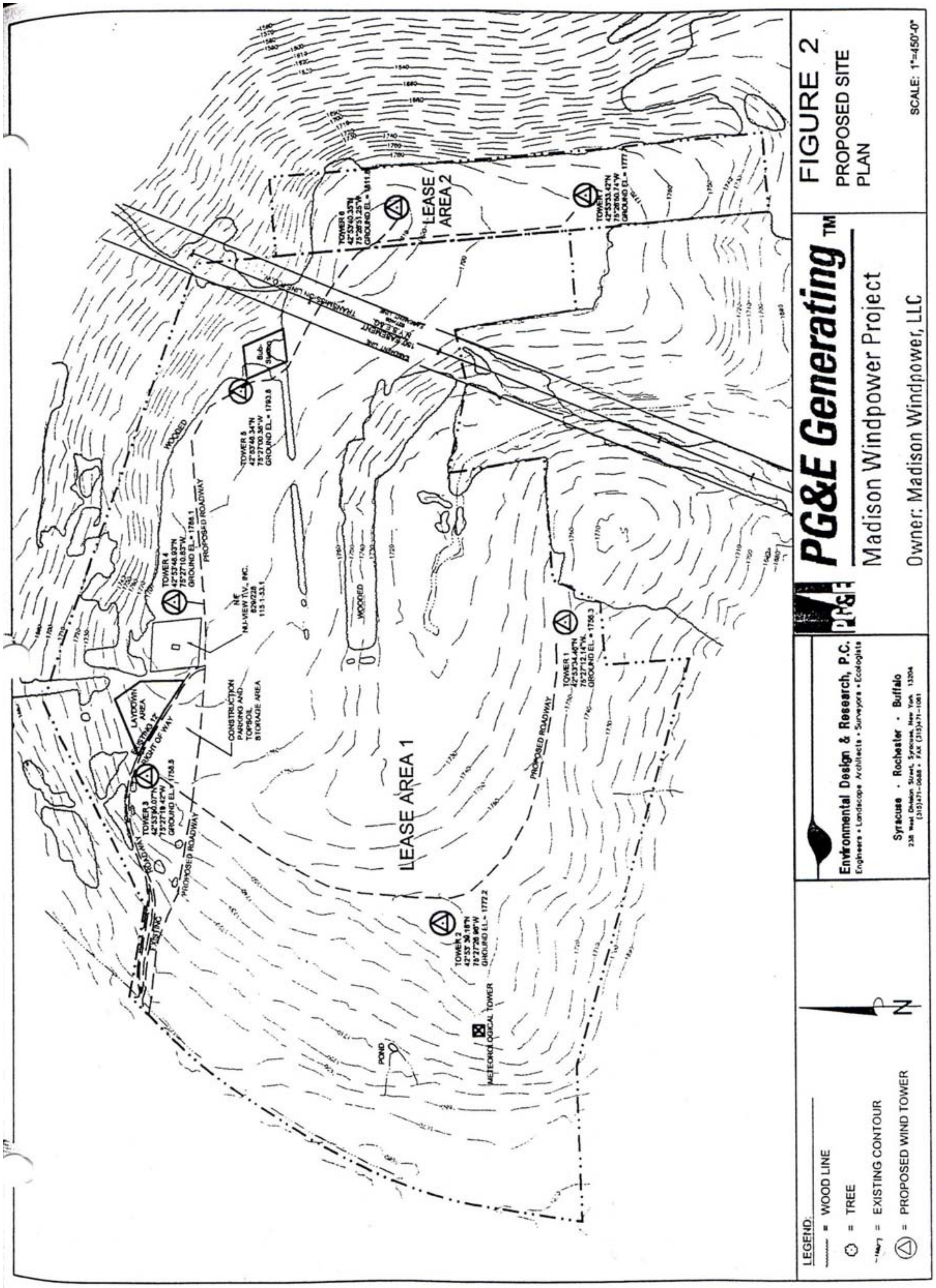
PUBLIC OUTREACH

In order to facilitate open communication between the developer and the local community, Madison Windpower developed a public outreach plan. Madison Windpower met with local government and civic organizations to disseminate information about the project and receive public feedback during the permitting and construction phases. NYSERDA sponsored a public meeting in Madison on November 23, 1999 as part of the SEQRA application review process. Madison Windpower established a community liaison to promote and maintain communication with key audiences and exchange information between the community and project management.

CONSTRUCTION AND COMMISSIONING

Figure 3-1 shows the final layout of the wind plant. Construction of the plant began in May 2000. The entrance road and hill roadway had to be redesigned in order to handle storm water runoff conditions. Heavy rain hampered early construction efforts, and, due to a labor strike, Verizon failed to install the dedicated telephone lines required for remote disconnection of the substation from NYSEG offices in Binghamton and remote control of the plant from PG&E offices in Pittsfield. In spite of these difficulties, construction proceeded rapidly due to the excellent craft skills and work habits of the local contractors. Prior to full operation, Madison Windpower operated the turbines under a temporary agreement with NYSEG and NYISO in which the plant was allowed to operate manned 12 hours per day with a maximum output of 4.0 MW. Consequently all of the turbines completed their 100-hour test in early October. Once Madison Windpower and NYSEG reached a verbal agreement regarding the substation relay settings, 24-hour non-manned operation of the substation was permitted by NYSEG. The plant began commercial operation on October 12, 2000 within one month of the original schedule.

Figure 3-1: Final Turbine Layout



OPERATIONS AND MAINTENANCE

The wind turbines were dispatched and controlled from the PG&E Pittsfield operations center, which was also responsible for substation maintenance. Vestas took charge of inspection, adjustment, and repair of the turbines (both scheduled and unscheduled) and established an operations and maintenance facility in the Madison area. The maintenance staff included an office coordinator, a site supervisor, three permanent technicians for the Madison site, and one temporary technician. Regular maintenance was scheduled at six-month intervals. The PG&E Pittsfield operations center personnel notified the maintenance staff of any necessary unscheduled repairs. The necessary maintenance events are described in further detail in the Outages section in this report.

ACCEPTANCE TESTING[2]

Section 4

The purpose of acceptance testing is to confirm that the turbine has been installed according to specification and is functioning properly. Vestas has an established start-up procedure for the V66 turbine. Using this protocol the commissioning staff checked the following:

- Power connection: grid power supply; power supply to turbine motors, sensors, and computers
- Meteorological parameters: wind speed, ambient temperature, and wind direction
- Turbine setup: voltage calibration
- Security system: emergency stop buttons, vibration sensor
- Hydraulic system: hydraulic pump, relief valve, fluid leakages, pitch system, brake
- Hub sensors: pitch position sensor, oil leak indicator
- Yaw system: proper yaw direction
- Pitch system: pitch rotation and velocity
- Rotor and generator: generator connections, rotation, and braking
- Gear oil system: oil pressure
- Temperature sensors
- Capacitors and thyristors
- Nacelle position: calibration for absolute wind direction
- Ventilators and heaters: pumps, fans, and oil leakages
- Remote control system
- Rotor Current Controller (RCC) communication

An AWS representative was present on behalf of NYSERDA for the turbine start-up and commissioning and confirmed that the commissioning staff showed that they were following the proper procedure and were exercising industry standard diligence. The turbines passed the acceptance testing and began commercial operation on October 12, 2000.

[2] *Start-up procedure: Vestas V66, 1.65MW, Item no.: 943633.R5*. Vestas American Wind Technology, Inc.: January 1999.

OPERATIONS AND MAINTENANCE ANALYSIS

Section 5

This section covers the performance of the Madison Windpower Project since its inception on October 12, 2000 through September 30, 2003. The performance of the wind plant is described in the following five sections: Wind Conditions and Plant Performance, Turbine Performance, Power Quality, and Outages. Performance results are summarized in a series of tables and figures; all graphs are located at the end of this section.

WIND CONDITIONS AND PLANT PERFORMANCE

As shown in Table 5-1, the wind plant produced a total of 61,379 MWh of electricity for three years for an annual average of 20,460 MWh and an overall capacity factor of 21%. The capacity factor is lower than the expected value of 23.3% primarily due to lower than predicted wind speeds and turbine and grid outages. Normal wind speeds were calculated in the energy production estimate analysis completed in December 1999. Average plant availability was 92%, which was lower than the expected value of 95% because of the unexpected frequency of mechanical turbine component failures and grid outages.

Table 5-1: Monthly Plant Performance

Month	Energy (MWh)	Grid-Adjusted Availability	Actual Wind Speed (m/s)	Expected Wind Speed[3] (m/s)	Capacity Factor
Oct-00[4]	1,127	93%	7.0	7.9	20%
Nov-00	1,795	91%	6.8	8.6	22%
Dec-00	2,433	89%	7.9	8.5	28%
Jan-01	1,695	93%	6.6	8.2	20%
Feb-01	2,356	88%	8.8	8.2	30%
Mar-01	1,577	86%	6.5	8.2	18%
Apr-01	1,956	97%	7.3	7.3	24%
May-01	1,509	97%	6.9	6.8	18%
Jun-01	1,063	97%	5.8	6.1	13%
Jul-01	1,227	98%	5.9	6.1	14%
Aug-01	1,034	98%	5.5	5.4	12%
Sep-01	1,358	97%	6.6	6.3	16%
Oct-01	2,849	91%	8.6	7.9	33%
Nov-01	2,666	92%	8.5	8.6	32%
Dec-01	2,509	94%	7.7	8.5	29%
Jan-02	2,702	91%	8.2	8.2	35%
Feb-02	2,227	83%	8.3	8.2	29%
Mar-02	2,305	81%	8.3	8.2	27%
Apr-02	2,022	88%	7.7	7.3	24%
May-02	2,140	84%	7.9	6.8	25%
Jun-02	1,161	84%	5.9	6.1	14%
Jul-02	1,144	94%	6.1	6.1	13%
Aug-02	755	97%	4.2	5.4	9%
Sep-02	1,456	99%	6.2	6.3	18%
Oct-02	1,722	98%	6.7	7.9	20%
Nov-02	2,143	97%	7.6	8.6	26%
Dec-02	1,997	86%	7.2	8.5	23%
Jan-03	1,617	87%	6.5	8.2	19%
Feb-03	1,706	94%	6.8	8.2	22%
Mar-03	2,263	87%	7.5	8.2	26%
Apr-03	1,588	91%	6.4	7.3	19%
May-03	1,226	95%	5.8	6.8	14%
Jun-03	921	95%	5.7	6.1	11%
Jul-03	1,021	98%	5.7	6.1	12%
Aug-03	807	100%	5.1	5.4	9%
Sep-03	1,302	87%	6.4	6.3	16%
Totals/Means[5]	**61,379**	**92%**	**6.8**	**7.3**	**21%**

The monthly energy production and the monthly power production both correlate well with the trend of the average monthly wind speeds as shown in Figures 5-1 and 5-2, respectively. Wind speeds at the site vary on a seasonal basis with the highest speeds experienced in the winter and the lowest speeds in the summer.

[3] The expected wind speeds are derived from the energy production analysis completed in December 1999. These wind speeds differ from those used in the quarterly reports, which were based on Rich Simon's wind resource and energy production analysis.
[4] Partial month (began October 12, 2000)
[5] Means are weighted by the number of days in the month.

As shown in Figure 5-3, the actual monthly wind speeds were typically lower than the expected monthly wind speeds, especially during the first and third years of the project. Table 5-2 summarizes the magnitude and source of discrepancies between the expected and actual average 67 m wind speeds.

Table 5-2: Magnitude and Source of Discrepancies Between Expected and Actual 67 m Wind Speeds

Magnitude of Wind Speed Discrepancy (m/s)	Source of Discrepancy
0.1	The long-term 10 m mean wind speed estimate at the Syracuse reference station (KSYR) changed from 3.82 m/s to 3.77 m/s.
0.2	The met tower used in the original estimate was 10 m higher in elevation than the met tower used for performance verification.
0.1	During the past three years of plant operation, the region experienced below-normal wind speeds.
0.1	The 6.8 m/s calculation used data shear-adjusted from the 10 m anemometer for June – July 2002. A difference of 0.1 m/s results if only data measured directly at 67 m are used.

The original wind speed estimate for the Madison Windpower Project was developed in December 1999. This estimate was derived from two years of 10 m met tower data collected from two sources within the project area and six months of 50 m tower data. The data were shear-adjusted to predict the hub height (67 m) mean wind speed. Coupled with the 10 m wind speed observations at the Syracuse reference station (KSYR), AWS estimated the long-term mean 67 m wind speed at the Madison site to be 7.3 m/s.

The first source of discrepancy between the expected and measured wind speeds is due to a reduction in the long-term 10 m mean wind speed at the reference station in Syracuse (KSYR). With the addition of four more years of data at the KSYR site since the original estimate, the long-term 10 m mean wind speed dropped from 3.82 m/s in 1999 to its current value of 3.77 m/s. The corresponding change in the wind speed estimate at the Madison site is 0.1 m/s. This error (1.3%) falls within the +/-2% uncertainty inherent in any value derived from a six-year dataset.

The second source of discrepancy is due to the relocation of the met tower during construction. The elevation of the current monitoring tower is about 10 m below that of the original 50 m tower. This change in elevation requires a 0.2 m/s shear adjustment in the long-term mean wind speed estimate.

The third source of discrepancy is due to below-average wind speeds in the region. During the past three years the measured average wind speed at the Madison site has been 0.1 m/s (1.3%) below average. At KSYR, the mean wind speed for the same period is about 1.5 % below average.

The final source of discrepancy is due to a slight difference in the data used for comparison. The 6.8 m/s long-term 67 m mean wind speed estimate includes two months of 10 m data shear-adjusted to 67 m in June-July 2002 (no 67 m data was available during this period due to a lightning strike). A difference of 0.1 m/s results if only data measured directly at 67 m are used. The total of the four sources of discrepancy is 0.5 m/s, which explains the difference between the expected and measured wind speed.

In conclusion, the initial mean wind speed estimate of 7.3 m/s was reasonable given the limitations of the data available at the time. However, this post-construction investigation demonstrates the need for sufficient meteorological data and analysis to understand the wind resource.

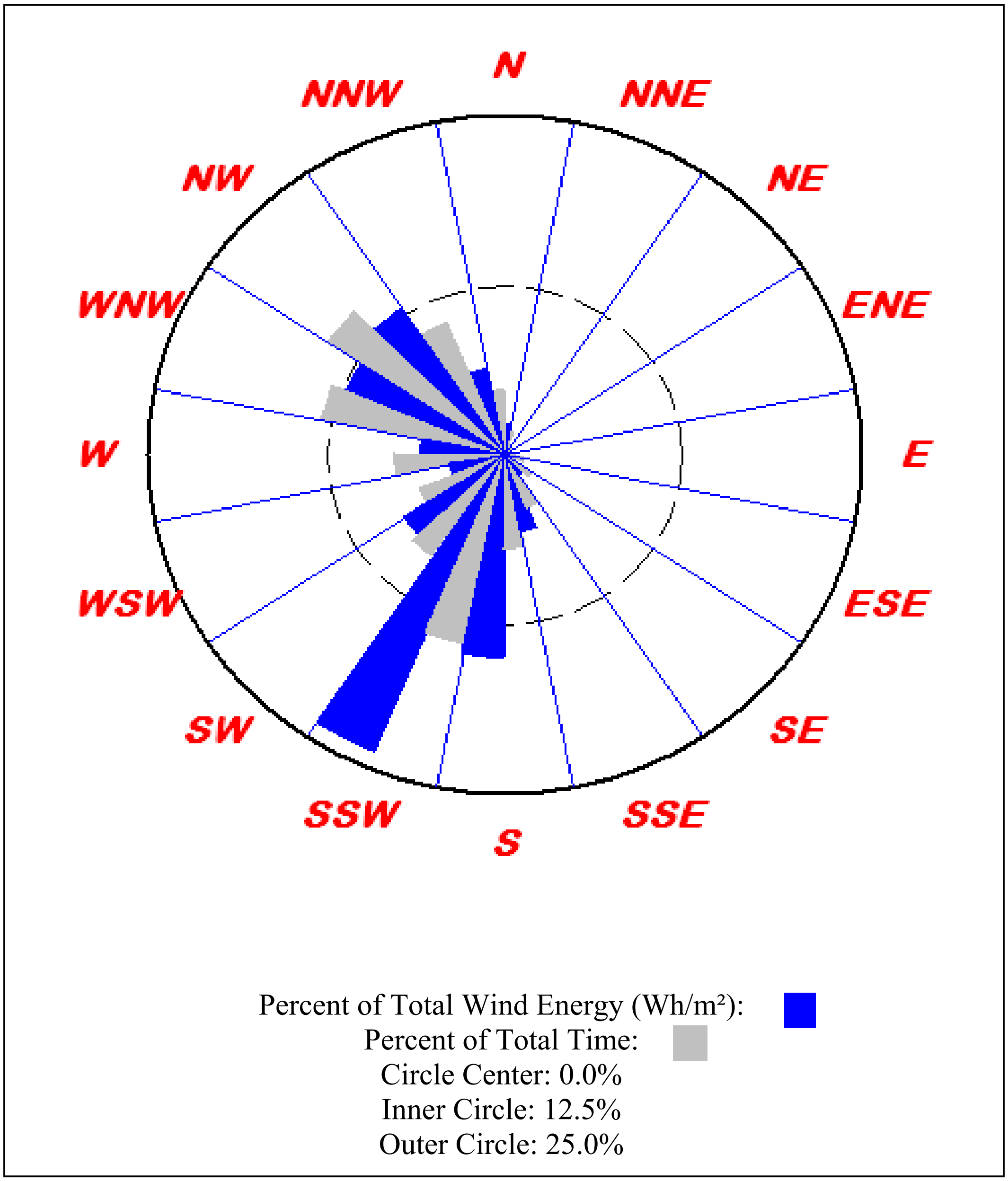
Figure 5-4 shows the monthly plant availability. Availability reduction typically was due to grid and turbine outages. Icing occasionally caused turbines outages, which further reduced winter availability.

Table 5-3 shows the distribution of the wind energy density among the sixteen wind direction sectors. By listing the wind energy density rather than just the wind frequency, this table accounts for the effects of both the wind speed and duration for each direction sector. Due to malfunctions of the wind direction sensor, valid data for construction of the wind rose is only available for October 2000 through May 2002. This information is shown graphically in the wind rose in Figure 5-5. Most of the energy is produced by wind coming from the southwest and northwest.

Table 5-3: Directional Distribution of Wind Energy Density

Direction Sector	Percent Wind Energy Density	Percent Frequency
N	2.3	4.8
NNE	0.5	1.8
NE	0.1	0.9
ENE	0.0	0.6
E	0.0	0.8
ESE	0.5	1.4
SE	1.8	2.2
SSE	5.8	4.2
S	15.0	6.9
SSW	23.7	14.3
SW	8.5	9.0
WSW	3.9	6.5
W	5.9	7.8
WNW	12.2	13.2
NW	13.1	15.0
NNW	6.6	10.7

Figure 5-5: Directional Distribution of Wind Energy Density



TURBINE PERFORMANCE

Table 5-4 presents the average monthly turbine performance data. The turbine performance data for each month are listed in Appendix B. Turbine performance generally follows the seasonal trends discussed in the Wind Conditions and Plant Performance section. Figure 5-6 shows the average monthly turbine energy production and availability. This figure shows that availability problems were distributed among the turbines rather than concentrated on a single turbine. The energy production is fairly uniform due to the topography of the site. Turbine 2 is best exposed followed by 3, 4, 5, 6, 7, and 1. The less exposed turbines are higher in elevation, which partially balances their reduced exposure and increased wake losses. The well-exposed turbines (e.g. Turbine 2) typically perform better than the others (e.g. Turbine 1) because they experience higher wind speeds. Turbine 7 has a significantly lower availability than the other turbines because it was offline from April through July 2002 while waiting for a gearbox replacement. Figure 5-7 shows the average power production for each turbine (not including turbine outages). This figure removes the effect of availability from the energy production results and shows more clearly that exposure to the wind is the most important factor that determines the energy production of the turbines within the plant. Figure 5-8 shows the total number of hours each turbine has generated since beginning operation. Lost generating time due to grid and turbine outages is discussed in the Outages section in this report.

Table 5-4: Average Monthly Turbine Performance

Turbine	1	2	3	4	5	6	7
Availability	91%	95%	93%	96%	93%	91%	85%
Energy (MWh)	221	274	257	262	235	237	215
Capacity Factor	19%	23%	22%	22%	20%	20%	18%
Normalized Capacity Factor[6]	20%	24%	23%	23%	21%	22%	21%

POWER QUALITY

The interconnection agreement between Madison Windpower and NYSEG requires that the power factor be greater than 0.95. As shown in Figure 5-9, the power factor was greater than 0.95 for all plant power production levels above 4 MW with few exceptions. Low power factor readings for plant power production levels below 4 MW are thought to be due to problems with the Supervisory Control and Data Acquisition (SCADA) system rather than the power factor correction equipment. The recorded power factor performance decreased substantially during April through July 2002. The power factor had previously been above 0.95 for all power values with few exceptions. This issue was due to the SCADA data not being available during this time period, so the power factor was calculated from the 10-minute average real and reactive power values. Despite the repair to the SCADA system, low power factor readings continued to be recorded for plant production levels below 1.5 MW. The recorded power factor performance again decreased substantially starting in October 2002 with many power factor readings below 0.95 for plant power production levels up to 4 MW. In this case the SCADA system had a COM failure situation that was repaired on October 13, 2003, which should resolve the power factor reporting issue.

Average grid voltage is presented as the percentage deviation from the monthly average of the voltage of each of the three phases. Typical utility electrical standards require that the voltage be maintained within 5% of

[6] The normalized capacity factor is capacity factor divided by the availability. This capacity factor removes the effect of outages.

nominal voltage. As shown in Table 5-5, the monthly average plant voltage was 112.9 kV, or approximately 98.2% of the nominal grid voltage of 115 kV. Figure 5-10 shows that the voltage varied more than ±5% from the average monthly voltage less than once a month on average.

Table 5-5: Plant Voltage

Month	Average Plant Voltage (kV)	Fraction of Nominal (%)	Month	Average Plant Voltage (kV)	Fraction of Nominal (%)
Oct-00	113.5	98.7%	Apr-02	112.2	97.6%
Nov-00	113.2	98.5%	May-02	112.8	98.1%
Dec-00	112.7	98.0%	Jun-02	112.8	98.1%
Jan-01	113.2	98.4%	Jul-02	112.3	97.7%
Feb-01	113.5	98.7%	Aug-02	112.1	97.5%
Mar-01	113.2	98.4%	Sep-02	112.7	98.0%
Apr-01	112.9	98.2%	Oct-02	112.4	97.7%
May-01	113.4	98.6%	Nov-02	112.6	97.9%
Jun-01	113.2	98.2%	Dec-02	112.9	98.2%
Jul-01	113.0	98.3%	Jan-03	112.7	98.0%
Aug-01	112.4	97.7%	Feb-03	113.1	98.3%
Sep-01	113.1	98.4%	Mar-03	112.9	98.2%
Oct-01	113.2	98.4%	Apr-03	112.7	98.0%
Nov-01	113.3	98.5%	May-03	113.4	98.6%
Dec-01	113.4	98.6%	Jun-03	113.0	98.3%
Jan-02	112.7	98.0%	Jul-03	113.3	98.5%
Feb-02	113.1	98.3%	Aug-03	113.0	98.3%
Mar-02	112.7	98.0%	Sep-03	113.1	98.3%
Mean	**112.9**	**98.2%**			

Voltage imbalance is defined as the maximum deviation from the average of the three phase voltages divided by the average of the three phase voltages, expressed as a percentage. Manufacturers of electric motors and generators typically recommend that users not exceed 1% voltage imbalance. Figure 5-11 shows that the voltage imbalance averaged about 0.4% over the past three years. Voltage imbalance at the Madison site exceeded this 1% threshold only twice during the monitoring period. The voltage imbalance shows a seasonal dependency with the average value varying between 0.2% in winter and 0.5% in summer. The cause of this trend is unclear but indicates that there is a large seasonal load to one or two phases of the NYSEG line. NYSEG may wish to correct this problem to prevent damage to equipment on their system.

OUTAGES

Outages are characterized as being major or minor in nature. A major outage occurs when the entire plant is shut down for more than a day or when one turbine is shut down for more than a week. A minor outage occurs when the entire plant is shut down for more than one hour, or one turbine is shut down for more than a day. During these three years of plant operation, there were 17 major outages and 49 minor outages. Outages that do not meet these definitions have not been analyzed for this report.

Table 5-6 lists the summary of the outages by cause. Plant and turbine outages are treated separately in this table so that they are not double-counted. The plant totals have been translated into equivalent turbine totals in order to compare the plant and turbine outages equally. The turbine total is the sum of the individual turbine outages. Grid outages refer to problems that are not on the plant's side of the grid connection point. Most grid outages are due to low voltage on the 115 kV power line, which trips the substation breaker and requires a manual reset. Natural Causes are typically weather-related problems such as lightning and icing. Equipment and grid malfunctions caused by natural causes are included in this category. Most of the natural outages were due to icing during the unusually harsh winter of 2002-2003. Internal Mechanical & Electrical outages are unscheduled repairs. Most of these repairs were for defective bearings in the gearboxes. Consequently a replacement schedule had to be arranged for all of the generator gearboxes. This malfunction shut down the turbines for an unexpectedly long amount of time. Scheduled maintenance refers to regular inspections and preventative repairs. Scheduled maintenance was a small fraction of the outage downtime. Individual turbine maintenance operations always lasted less than a day, so they do not meet the minor turbine outage criteria.

Table 5-6: Outage Summary by Cause

	Plant Outages			**Turbine Outages**	
Classification	Plant Total (hrs)	Equivalent Turbine Total (hrs)	Fraction of Plant Total (%)	Turbine Total (hrs)	Fraction of Turbine Total (%)
Grid	120	840	37%	177	2%
Natural Causes	150	1050	46%	1298	15%
Internal Mechanical & Electrical	26	182	8%	7403	83%
Scheduled Maintenance	29	203	9%	0	0%
Total	**325**	**2275**		**8878**	

Table 5-7 lists the summary of the outages by the affected turbine component or system. Lightning and icing refer to incidents in which the affected turbine component is not known. In this analysis, generator gearbox problems were the most significant source of outages. The individual outages (categorized by both cause and affected turbine component) are listed in Appendix C.

Table 5-7: Outage Summary by Affected Turbine Component

	Plant Outages			Turbine Outages	
Classification	Plant Total (hrs)	Equivalent Turbine Total (hrs)	Fraction of Plant Total (%)	Turbine Total (hrs)	Fraction of Turbine Total (%)
Blade	0	0	0%	414	5%
Brake	0	0	0%	148	2%
Generator Gearbox	0	0	0%	6203	69%
Generator	0	0	0%	134	1%
Grid	120	840	69%	0	0%
Icing	0	0	0%	150	2%
Lightning	0	0	0%	695	8%
Rotor	0	0	0%	429	5%
Yaw System	0	0	0%	387	4%
Scheduled Maintenance	23	161	13%	0	0%
Miscellaneous	32	224	18%	468	5%

Table 5-8 shows the major and minor outages for the plant and each turbine. Most of the outage time was due to major outages at the turbines. Major plant outages were rare. Turbine 7 experienced a longer period of outages than the other turbines because a replacement gearbox was not readily available when needed.

Table 5-8: Major and Minor Outages

Outage Breakdown	Major (hrs)	Minor (hrs)	Total
Plant	108	217	325
Turbine 1	1058	193	1251
Turbine 2	678	43	721
Turbine 3	459	259	718
Turbine 4	243	304	547
Turbine 5	652	202	854
Turbine 6	1512	105	1617
Turbine 7	2910	260	3170

The electricity produced by the Madison plant is sold through the New York Independent System Operator (NYISO). The price for the sale of power is set in real time and reflects the need for power on the system. At times of low demand, the NYISO attempts to reduce the output of power plants to match the low demand by reducing the price of power. However, some plants, such as nuclear or coal cannot easily reduce production and would rather pay. Thus the real time price of wholesale power can go negative. Plants that can easily curtail production should do so in order to avoid paying to supply power to the grid.

Madison Windpower shuts down the plant whenever the price for power goes negative. Negative pricing has occurred 62 times since the inception of the plant, for a total of 57.5 hours as detailed in Appendix D. It typically occurs in the middle of the night during spring and summer, when demand is lowest.

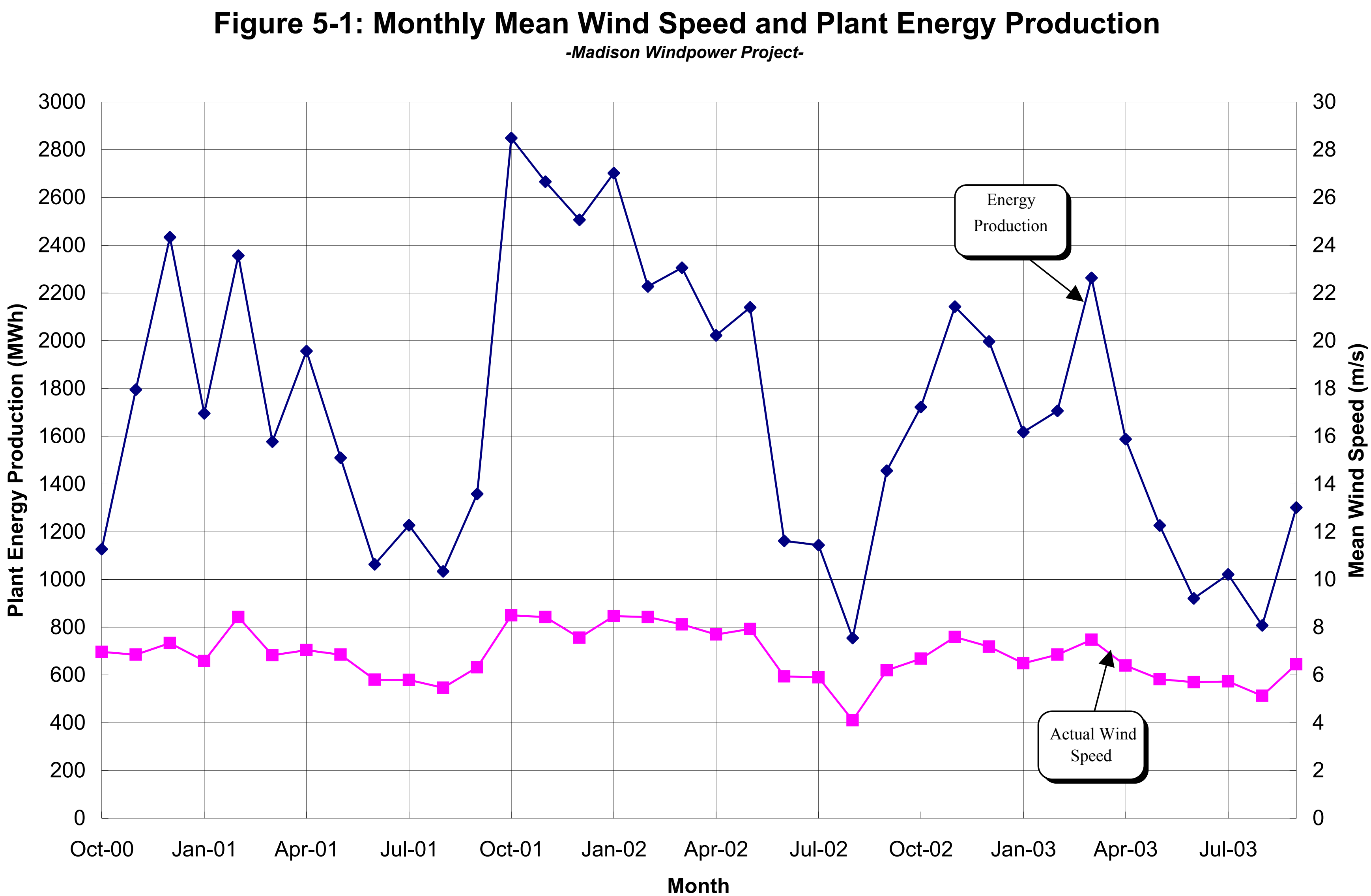
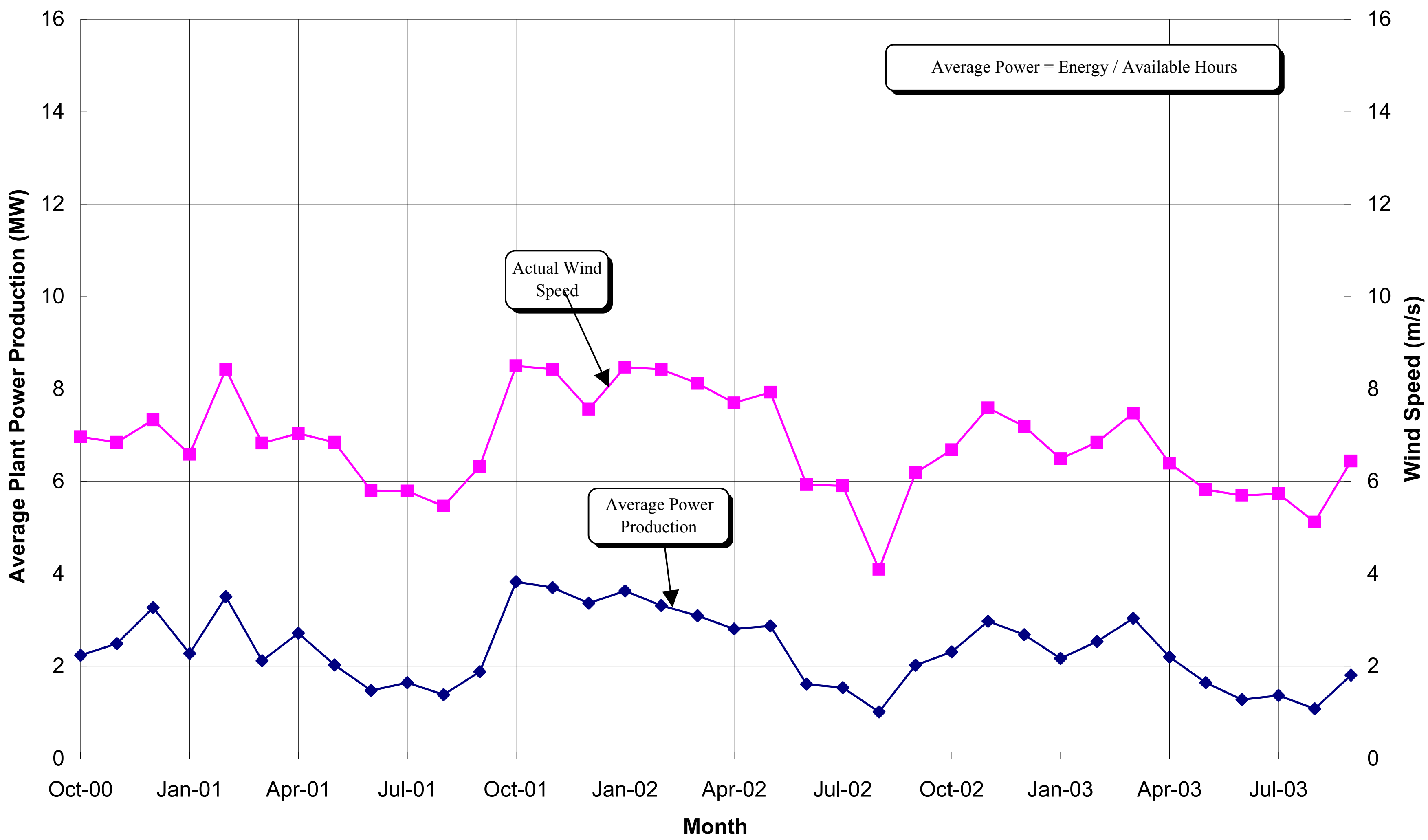


Figure 5-1: Monthly Mean Wind Speed and Plant Energy Production
-Madison Windpower Project-
Plant Energy Production (MWh)
Mean Wind Speed (m/s)
Month
Energy Production
Actual Wind Speed
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03

Figure 5-1

Figure 5-2: Monthly Mean Wind Speed and Average Plant Power Production

-Madison Windpower Project-



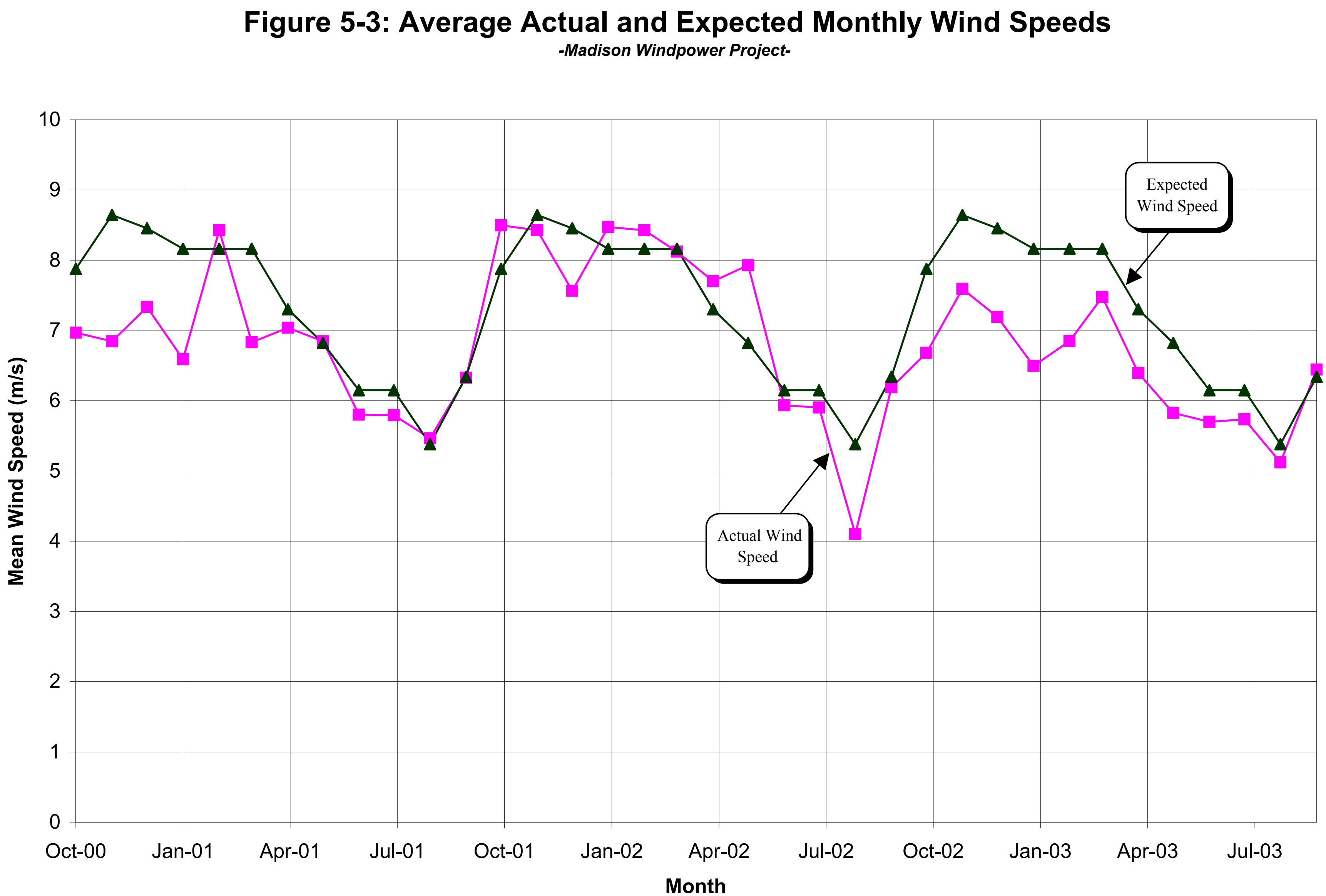


Figure 5-3: Average Actual and Expected Monthly Wind Speeds
-Madison Windpower Project-
Mean Wind Speed (m/s)
Month
Expected Wind Speed
Actual Wind Speed
0
1
2
3
4
5
6
7
8
9
10
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03

Figure 5-3

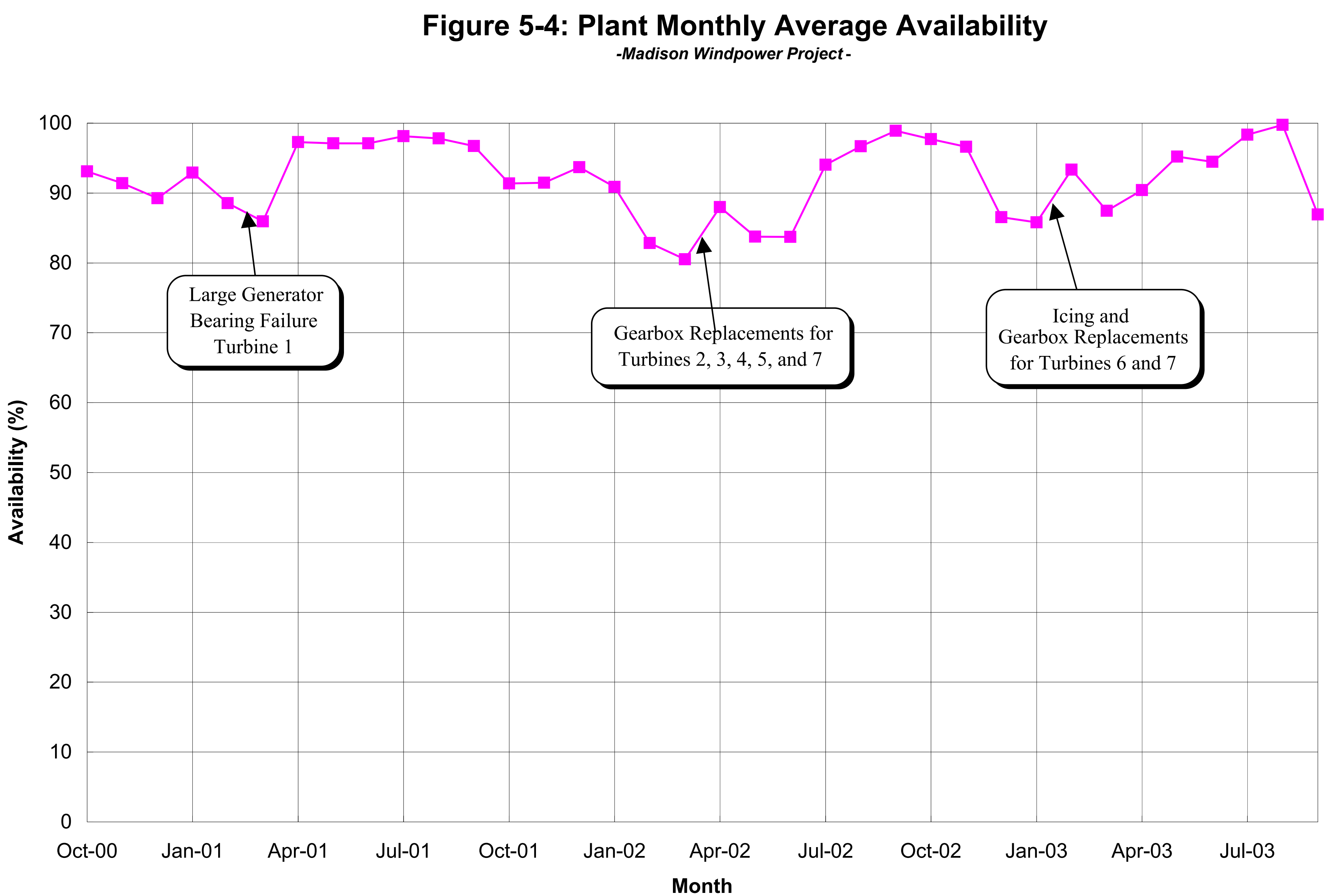
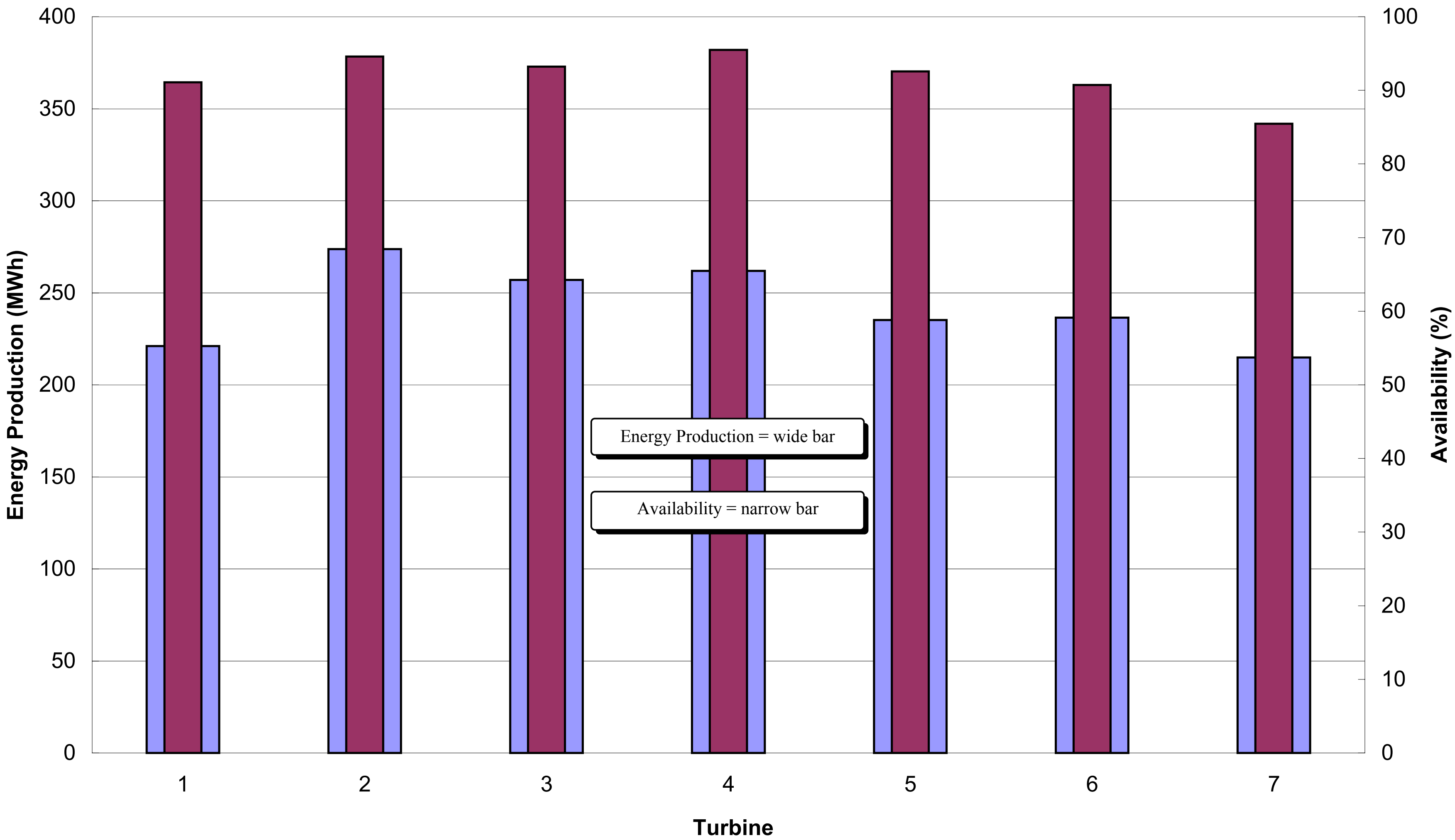


Figure 5-4: Plant Monthly Average Availability
-Madison Windpower Project-
Availability (%)
100
90
80
70
60
50
40
30
20
10
0
Large Generator Bearing Failure Turbine 1
Gearbox Replacements for Turbines 2, 3, 4, 5, and 7
Icing and Gearbox Replacements for Turbines 6 and 7
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Month

Figure 5-4

Figure 5-6: Average Monthly Turbine Energy Production and Availability

-Madison Windpower Project-



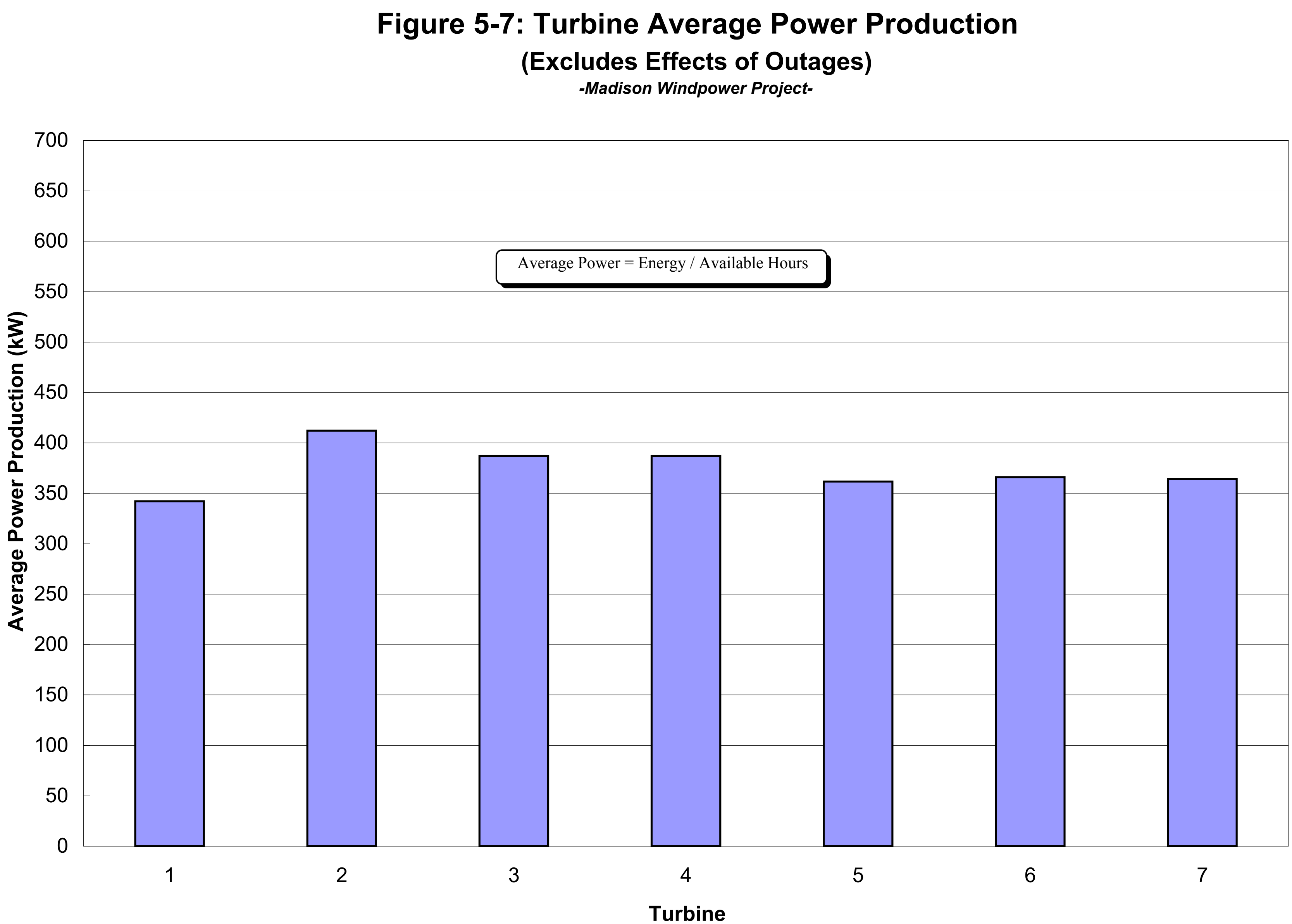


Figure 5-7: Turbine Average Power Production
(Excludes Effects of Outages)
-Madison Windpower Project-
Average Power = Energy / Available Hours
Average Power Production (kW)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
Turbine

Figure 5-7

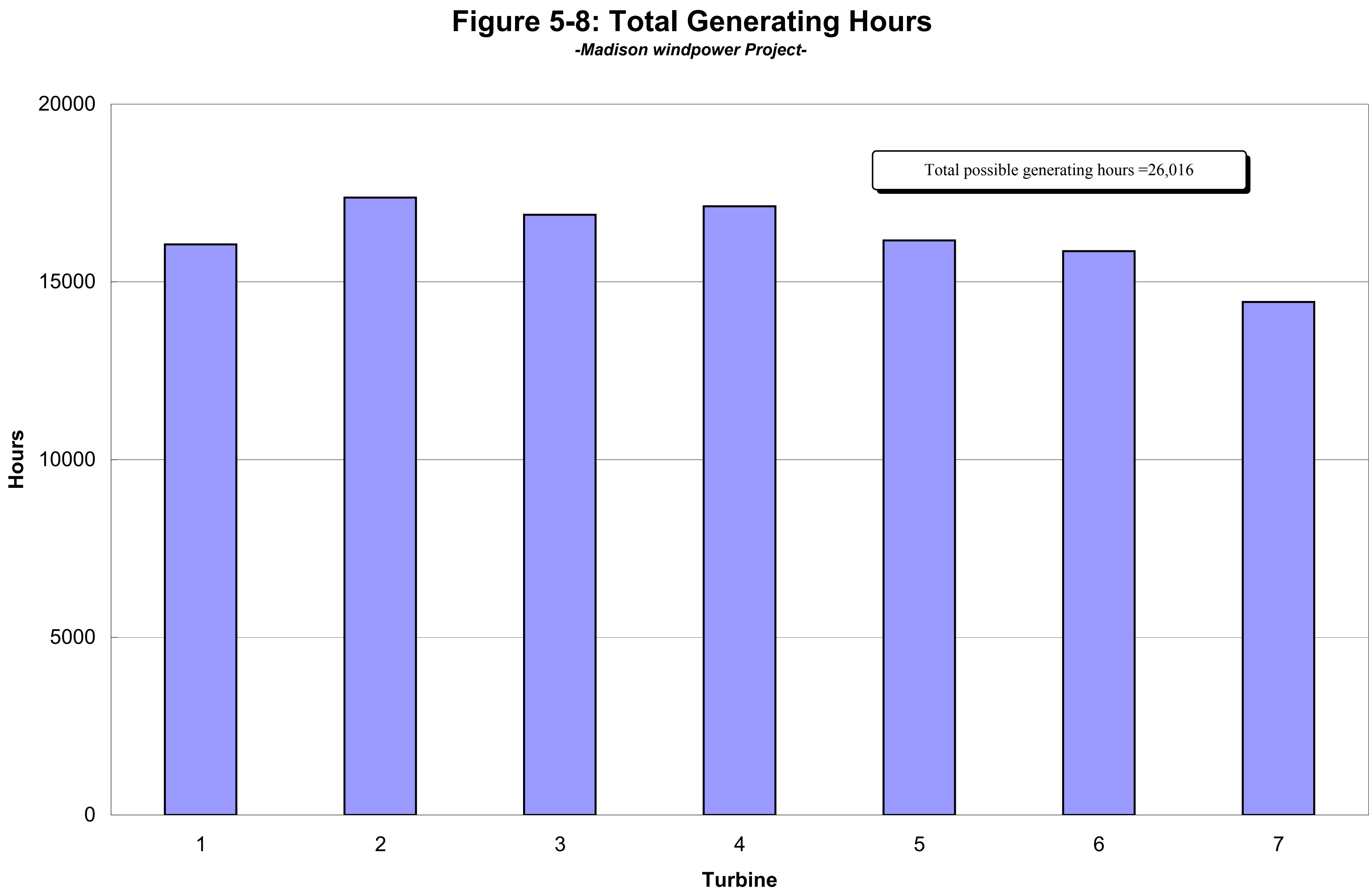


Figure 5-8: Total Generating Hours
-Madison windpower Project-
Total possible generating hours =26,016
20000
15000
10000
5000
0
Hours
1
2
3
4
5
6
7
Turbine

Figure 5-8

Figure 5-9: Power Factor

-Madison Windpower Project-

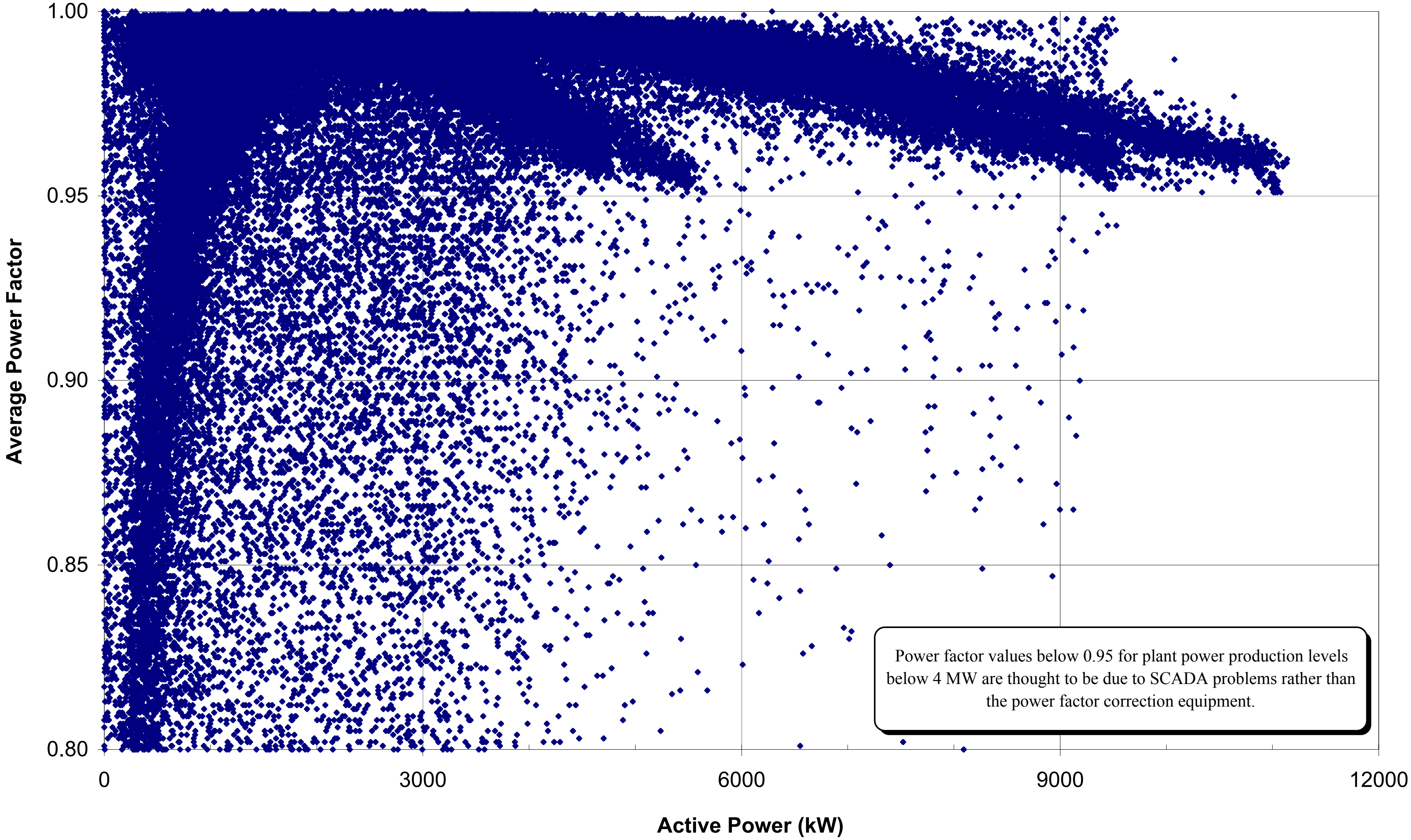


Figure 5-9

Figure 5-10: Average Grid Voltage

-Madison Windpower Project-

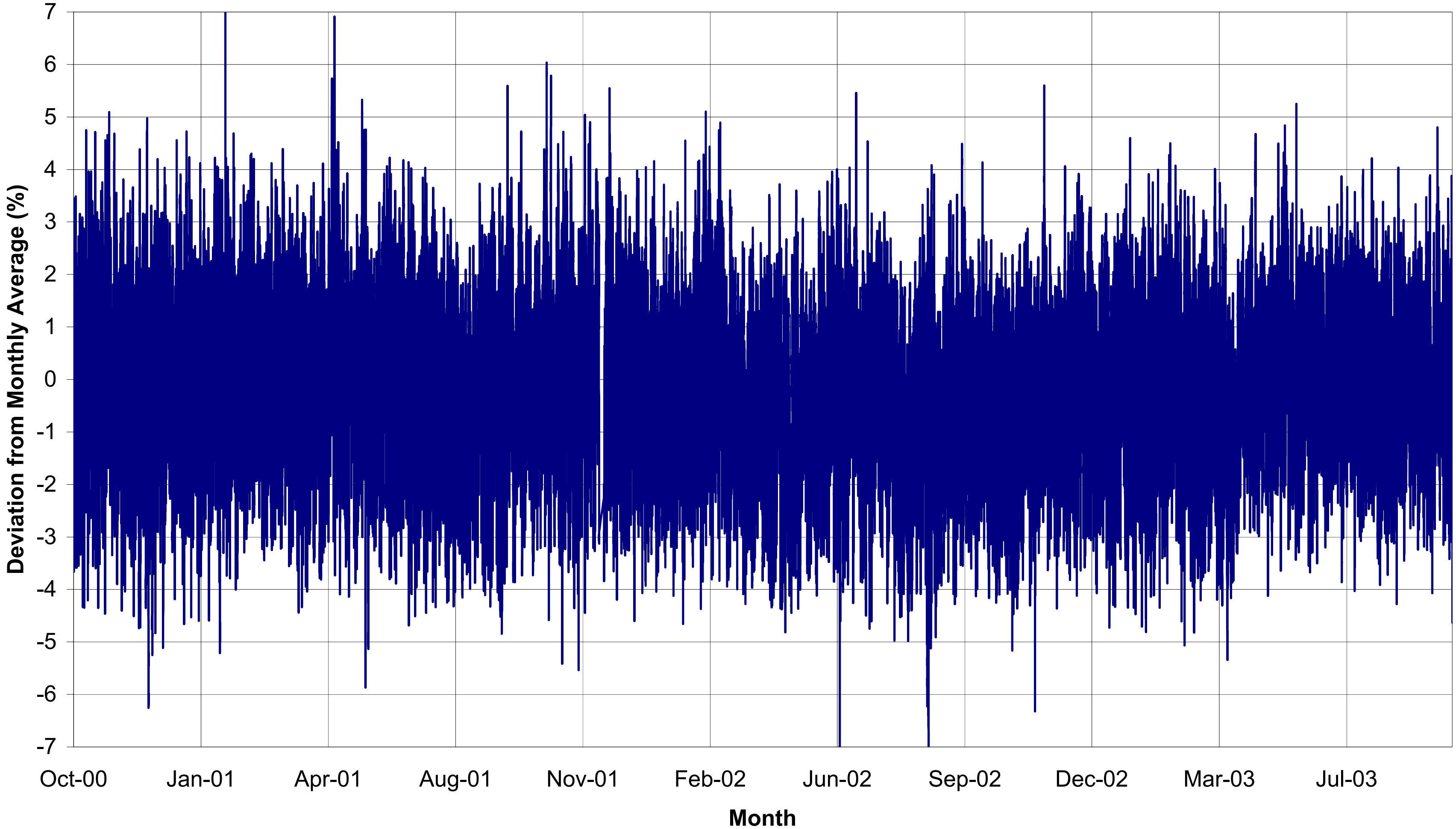
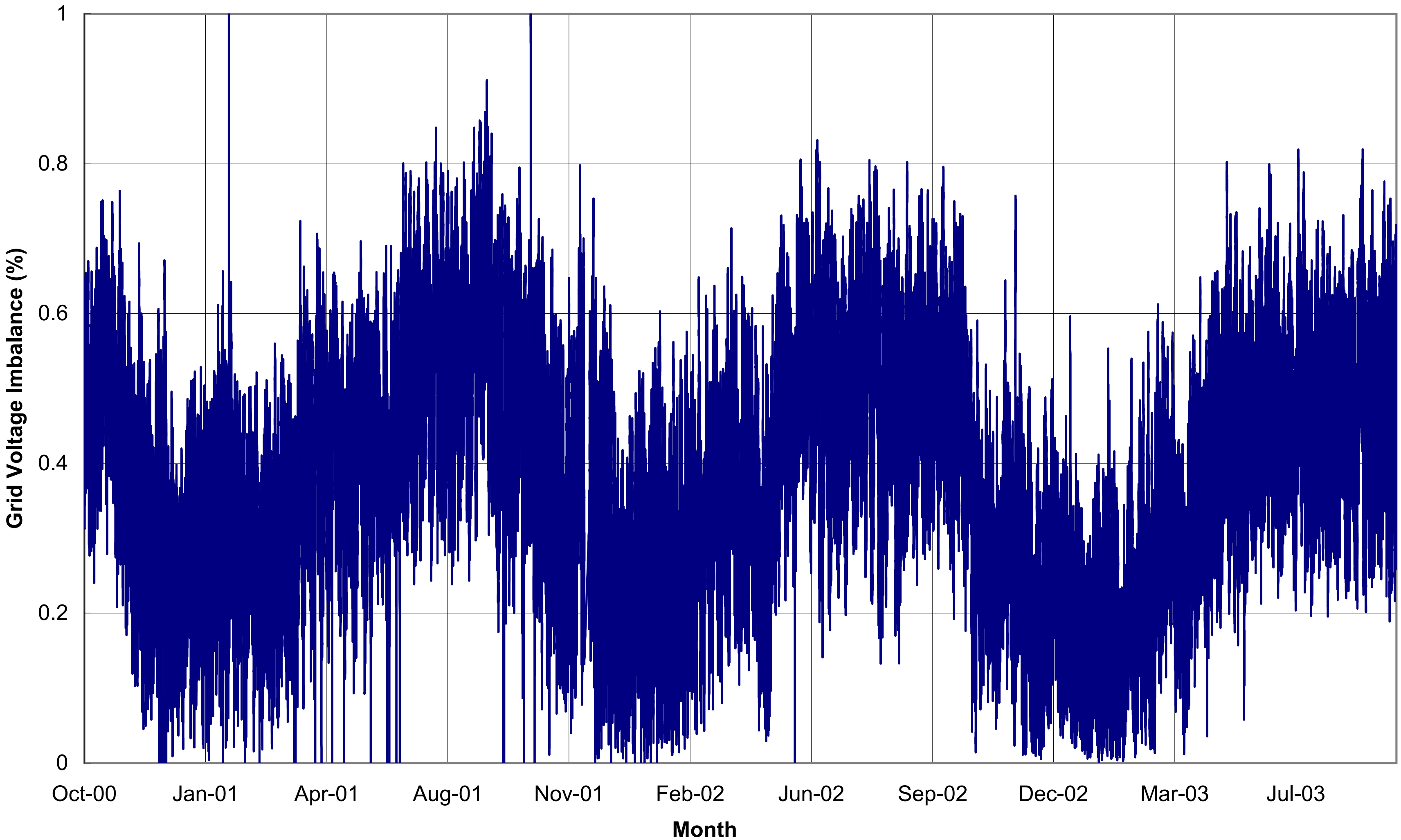


Figure 5-11: Grid Voltage Imbalance

-Madison Windpower Project-



CONCLUSIONS

Section 6

The Madison Windpower Project has been a successful demonstration of large-scale wind development in New York State. Since the installation of the Madison facility, other windfarms have been developed in New York using lessons learned from Madison. In fact, the data gained from Madison is being used to facilitate the integration of large quantities of wind energy from the many windfarms that are being planned all over the state. For example, a NYSERDA-sponsored study by GE Power Systems, *Effects of Integrating Wind Power on Transmission System Planning, Reliability and Operations*, uses data from Madison.

The experience at Madison shows that the energy production from a wind facility is primarily dependent on the actual wind experienced and the performance and reliability of the turbines. The Vestas V66 turbines performed well when they were online because they produced the expected amount of energy for a given windspeed. However, the actual wind speeds experienced during the period and the reliability of the turbines were both lower than expected.

The wind speeds were lower than expected due to the incomplete meteorological record used to predict the wind resource, the lower-than-average wind speeds in this region of the state during plant operation, and the difference in elevation of the project met towers. This experience demonstrates the need to have sufficient long-term meteorological data in order to predict a wind plant's energy production accurately. Continued evaluation of the projected wind speeds during plant operation can clarify trends and enhance understanding of the site's wind resource. As such, it is expected that the overall wind resource at Madison will be more favorable during the lifetime of the plant.

The reliability of the machines was lower than expected due to the gearbox failures and other component difficulties discussed earlier in the report. These failures highlight the need for robust turbine reliability warrantees to protect turbine owners against loss of revenue in the case of such unexpected turbine component failures. On the positive side, excellent lightning protection in the V66 resulted in fewer outages due to static discharge than have been observed at other sites.

Valuable knowledge and information has been gained from the Madison Windplant that will improve the quality and cost-effectiveness of windfarms being planned throughout New York. The experience at Madison has enabled state and local governments, community organizations and individuals, independent developers, and wind energy consultants to gain experience with large-scale wind development and turbine technology. The data gathered in this project will be used to educate the public and decision makers regarding the characteristics of wind energy facilities, investigate the impacts on the grid of large-scale wind energy development, and improve models to predict energy production of wind plants. These efforts will help to remove barriers to large-scale wind energy development in New York State.

Appendix A: Definition of Terms

Actual Wind Speed: the validated wind speed measured by the 67 m anemometer on the site meteorological tower

Availability: the amount of time that a turbine is available to operate in a given period divided by the total time in the period

Capacity Factor: the energy production divided by the product of the total time period and the rated power output

Expected Wind Speed: the predicted wind speed at the site as calculated in the energy production estimate completed in December 1999

Grid-Adjusted Availability: the amount of time that a turbine is available to operate in a given period divided by the total time that the grid is available to support turbine operation (excludes grid outages)

Normalized Capacity Factor: the capacity factor divided by the availability (excludes lost capacity due to outages)

Appendix B: Monthly Turbine Performance

Month	Turbine #	1	2	3	4	5	6	7
Oct-00[7]	Availability	68%	99%	93%	100%	94%	100%	98%
	Energy (MWh)	91	189	166	185	159	184	153
	Capacity Factor	11%	24%	21%	23%	20%	23%	19%
	Normalized Capacity Factor	16%	24%	23%	23%	21%	23%	19%
Nov-00	Availability	83%	97%	86%	98%	89%	95%	92%
	Energy (MWh)	195	303	252	277	250	275	242
	Capacity Factor	16%	26%	21%	23%	21%	23%	20%
	Normalized Capacity Factor	19%	27%	24%	23%	24%	24%	22%
Dec-00	Availability	90%	98%	82%	99%	86%	88%	80%
	Energy (MWh)	301	402	343	394	337	370	287
	Capacity Factor	25%	33%	28%	32%	27%	30%	23%
	Normalized Capacity Factor	27%	33%	34%	32%	32%	34%	29%
Jan-01	Availability	95%	96%	90%	96%	93%	94%	86%
	Energy (MWh)	214	280	236	254	245	254	213
	Capacity Factor	17%	23%	19%	21%	20%	21%	17%
	Normalized Capacity Factor	18%	24%	21%	22%	21%	22%	20%
Feb-01	Availability	79%	98%	90%	100%	76%	95%	81%
	Energy (MWh)	301	350	273	453	286	378	317
	Capacity Factor	27%	32%	25%	41%	26%	34%	29%
	Normalized Capacity Factor	34%	32%	27%	41%	34%	36%	35%
Mar-01	Availability	36%	93%	88%	97%	96%	98%	94%
	Energy (MWh)	90	271	234	252	244	245	241
	Capacity Factor	7%	22%	19%	21%	20%	20%	20%
	Normalized Capacity Factor	20%	24%	22%	21%	21%	20%	21%
Apr-01	Availability	97%	99%	98%	97%	98%	93%	98%
	Energy (MWh)	256	316	296	289	275	265	258
	Capacity Factor	22%	27%	25%	24%	23%	22%	22%
	Normalized Capacity Factor	22%	27%	26%	25%	24%	24%	22%
May-01	Availability	91%	95%	98%	100%	100%	97%	100%
	Energy (MWh)	173	260	238	224	211	201	203
	Capacity Factor	14%	21%	19%	18%	17%	16%	17%
	Normalized Capacity Factor	15%	22%	20%	18%	17%	17%	17%
Jun-01	Availability	99%	97%	97%	96%	96%	98%	97%
	Energy (MWh)	133	177	165	156	149	142	141
	Capacity Factor	11%	15%	14%	13%	13%	12%	12%
	Normalized Capacity Factor	11%	15%	14%	14%	13%	12%	12%

[7] Partial month (began October 12, 2000)

Month	Turbine #	1	2	3	4	5	6	7
Jul-01	Availability	96%	100%	97%	99%	100%	98%	97%
	Energy (MWh)	143	198	193	184	167	181	161
	Capacity Factor	12%	16%	16%	15%	14%	15%	13%
	Normalized Capacity Factor	12%	16%	16%	15%	14%	15%	13%
Aug-01	Availability	100%	99%	95%	95%	97%	99%	100%
	Energy (MWh)	135	162	151	153	151	152	130
	Capacity Factor	11%	13%	12%	12%	12%	12%	11%
	Normalized Capacity Factor	11%	13%	13%	13%	13%	12%	11%
Sep-01	Availability	92%	95%	98%	99%	99%	98%	96%
	Energy (MWh)	180	213	193	211	196	193	171
	Capacity Factor	15%	18%	16%	18%	17%	16%	14%
	Normalized Capacity Factor	17%	19%	17%	18%	17%	17%	15%
Oct-01	Availability	68%	91%	98%	94%	97%	97%	96%
	Energy (MWh)	298	446	449	425	430	412	389
	Capacity Factor	24%	36%	37%	35%	35%	34%	32%
	Normalized Capacity Factor	36%	40%	37%	37%	36%	35%	33%
Nov-01	Availability	95%	98%	97%	87%	97%	85%	82%
	Energy (MWh)	360	448	434	349	408	353	315
	Capacity Factor	30%	38%	36%	29%	34%	30%	27%
	Normalized Capacity Factor	32%	39%	37%	34%	36%	35%	32%
Dec-01	Availability	99%	98%	94%	100%	97%	90%	78%
	Energy (MWh)	346	387	384	371	381	355	285
	Capacity Factor	28%	32%	31%	30%	31%	29%	23%
	Normalized Capacity Factor	28%	32%	33%	30%	32%	32%	30%
Jan-02	Availability	97%	66%	97%	99%	88%	93%	96%
	Energy (MWh)	369	290	453	428	368	416	377
	Capacity Factor	30%	24%	37%	35%	30%	34%	31%
	Normalized Capacity Factor	31%	36%	38%	35%	34%	36%	32%
Feb-02	Availability	98%	80%	98%	96%	33%	85%	90%
	Energy (MWh)	356	327	402	384	107	343	308
	Capacity Factor	32%	30%	36%	35%	10%	31%	28%
	Normalized Capacity Factor	33%	37%	37%	36%	29%	36%	31%
Mar-02	Availability	90%	63%	92%	63%	59%	98%	98%
	Energy (MWh)	354	326	383	281	174	398	390
	Capacity Factor	29%	27%	31%	23%	14%	32%	32%
	Normalized Capacity Factor	32%	42%	34%	36%	24%	33%	32%
Apr-02	Availability	100%	86%	64%	97%	87%	98%	83%
	Energy (MWh)	299	301	260	316	254	314	278
	Capacity Factor	25%	25%	22%	27%	21%	26%	23%
	Normalized Capacity Factor	25%	30%	34%	27%	25%	27%	28%

Month	Turbine #	1	2	3	4	5	6	7
May-02	Availability	100%	98%	92%	99%	99%	98%	0%
	Energy (MWh)	325	398	344	363	348	362	-1
	Capacity Factor	27%	32%	28%	30%	28%	30%	0%
	Normalized Capacity Factor	27%	33%	30%	30%	29%	30%	N/A
Jun-02	Availability	99%	92%	100%	96%	99%	99%	0%
	Energy (MWh)	178	187	216	187	193	201	-1
	Capacity Factor	15%	16%	18%	16%	16%	17%	0%
	Normalized Capacity Factor	15%	17%	18%	16%	16%	17%	N/A
Jul-02	Availability	98%	99%	100%	100%	100%	100%	61%
	Energy (MWh)	141	195	193	180	164	168	102
	Capacity Factor	11%	16%	16%	15%	13%	14%	8%
	Normalized Capacity Factor	12%	16%	16%	15%	13%	14%	14%
Aug-02	Availability	94%	100%	100%	89%	95%	99%	99%
	Energy (MWh)	91	126	122	107	105	108	96
	Capacity Factor	7%	10%	10%	9%	9%	9%	8%
	Normalized Capacity Factor	8%	10%	10%	10%	9%	9%	8%
Sep-02	Availability	97%	100%	97%	100%	100%	99%	100%
	Energy (MWh)	193	239	231	221	216	156	199
	Capacity Factor	16%	20%	19%	19%	18%	13%	17%
	Normalized Capacity Factor	17%	20%	20%	19%	18%	13%	17%
Oct-02	Availability	100%	97%	97%	97%	98%	95%	100%
	Energy (MWh)	239	274	268	257	248	193	243
	Capacity Factor	19%	22%	22%	21%	20%	16%	20%
	Normalized Capacity Factor	20%	23%	22%	21%	21%	17%	20%
Nov-02	Availability	100%	98%	96%	97%	97%	98%	91%
	Energy (MWh)	308	349	329	327	312	239	279
	Capacity Factor	26%	29%	28%	27%	26%	20%	24%
	Normalized Capacity Factor	26%	30%	29%	28%	27%	21%	26%
Dec-02	Availability	95%	94%	86%	97%	92%	27%	94%
	Energy (MWh)	308	368	247	361	313	76	324
	Capacity Factor	25%	30%	20%	29%	25%	6%	26%
	Normalized Capacity Factor	26%	32%	23%	30%	28%	23%	28%
Jan-03	Availability	73%	84%	51%	89%	84%	73%	88%
	Energy (MWh)	187	282	80	317	258	223	270
	Capacity Factor	15%	23%	7%	26%	21%	18%	22%
	Normalized Capacity Factor	21%	27%	13%	29%	25%	25%	25%
Feb-03	Availability	90%	97%	96%	75%	88%	96%	98%
	Energy (MWh)	225	290	286	179	204	271	251
	Capacity Factor	20%	26%	26%	16%	18%	24%	23%
	Normalized Capacity Factor	23%	27%	27%	22%	21%	26%	23%

Month	Turbine #	1	2	3	4	5	6	7
Mar-03	Availability	89%	98%	92%	99%	99%	99%	36%
	Energy (MWh)	260	389	347	370	354	364	180
	Capacity Factor	21%	32%	28%	30%	29%	30%	15%
	Normalized Capacity Factor	24%	32%	31%	31%	29%	30%	40%
Apr-03	Availability	95%	94%	94%	84%	93%	94%	55%
	Energy (MWh)	226	270	251	196	238	225	182
	Capacity Factor	19%	23%	21%	16%	20%	19%	15%
	Normalized Capacity Factor	20%	24%	23%	20%	22%	20%	28%
May-03	Availability	100%	96%	100%	99%	98%	73%	100%
	Energy (MWh)	168	198	198	180	175	132	175
	Capacity Factor	14%	16%	16%	15%	14%	11%	14%
	Normalized Capacity Factor	14%	17%	16%	15%	15%	15%	14%
Jun-03	Availability	67%	92%	93%	96%	96%	96%	96%
	Energy (MWh)	74	155	143	147	134	135	133
	Capacity Factor	6%	13%	12%	12%	11%	11%	11%
	Normalized Capacity Factor	9%	14%	13%	13%	12%	12%	12%
Jul-03	Availability	99%	97%	95%	97%	100%	100%	100%
	Energy (MWh)	145	149	150	155	142	144	137
	Capacity Factor	12%	12%	12%	13%	12%	12%	11%
	Normalized Capacity Factor	12%	13%	13%	13%	12%	12%	11%
Aug-03	Availability	98%	97%	98%	98%	98%	98%	98%
	Energy (MWh)	106	130	129	117	110	108	107
	Capacity Factor	9%	11%	11%	10%	9%	9%	9%
	Normalized Capacity Factor	9%	11%	11%	10%	9%	9%	9%
Sep-03	Availability	100%	100%	99%	100%	99%	11%	100%
	Energy (MWh)	195	247	219	218	197	18	207
	Capacity Factor	16%	21%	18%	18%	17%	2%	17%
	Normalized Capacity Factor	16%	21%	19%	18%	17%	14%	17%

Appendix C: Plant and Turbine Outage Hours

Cause

Grid		Gr
Natural Causes		N
Internal Mechanical & Electrical	-	I
Scheduled Maintenance	-	S

Effect

Blade		B
Brake		Br
Generator Gearbox	-	Gx
Generator		G
Grid		Gr
Icing		I
Lightning		L
Rotor		R
Yaw System		Y
Scheduled Maintenance	-	S
Miscellaneous		M

Start Date	End Date	Cause	Effect	Description	Plant	Turbine 1	Turbine 2	Turbine 3	Turbine 4	Turbine 5	Turbine 6	Turbine 7
10/21/00	10/22/00	**I**	**M**	communications failure on communcation lines used by Pittsfield operation center to control turbines	20							
10/27/00	10/30/00	**I**	**G**	generator realignment		81						
11/23/00	11/25/00	**N**	**M**	transmission fluid too cold because turbine stopped turning in ambient temp <-10C								45
12/9/00	12/9/00	**Gr**	**Gr**	grid low voltage	1							
12/12/00	12/13/00	**Gr**	**Gr**	grid low voltage	13							
12/15/00	12/15/00	**Gr**	**Gr**	grid low voltage	6							
12/20/00	12/20/00	**Gr**	**Gr**	grid low voltage	5							
12/29/00	1/3/01	**N**	**Br**	high speed brake malfunction due to snow				105				

Start Date	End Date	Cause	Effect	Description	Plant	Turbine 1	Turbine 2	Turbine 3	Turbine 4	Turbine 5	Turbine 6	Turbine 7
12/30/00	1/3/01	**I**	**M**	oil leak in relief valve in hydraulic system								109
2/2/01	2/3/01	**Gr**	**Gr**	grid low voltage	15							
2/10/01	2/14/01	**I**	**Y**	yaw gearbox failure								106
2/23/01	3/19/01	**I**	**Gx**	large generator - gearbox bearing failure		585						
4/25/01	4/25/01	**Gr**	**Gr**	grid low voltage	10							
5/20/01	5/22/01	**I**	**M**	oil leak in oil hose in hub		55						
8/14/01	8/14/01	**S**	**S**	uptower transformer inspection in response to uptower transformer fire in V-66 turbines in Texas	2							
8/30/01	9/1/01	**I**	**M**	code 161 that would not restart				45				
9/6/01	9/6/01	**S**	**M**	retro-fit 25kV cable bus	6							
9/29/01	10/10/01	**I**	**Y**	yaw motor developed more torque than yaw gearboxes could handle, waiting for replacement gearbox		281						
11/23/01	11/27/01	**Gr**	**M**	damage due to power quality problems on grid - electrical components damaged (3 capacitors and contactors, 10 100amp fuses)							105	
11/26/01	12/7/01	**I**	**Gx**	replacement of 300 kW auxiliary generator gearbox								275
11/28/01	11/30/01	**Gr**	**M**	damage due to power quality problems on grid - electrical components damaged (capacitor banks)					72			
1/6/02	1/9/02	**I**	**Gx**	gearbox bearing failure						67		
1/22/02	1/22/02	**I**	**M**	VGCS lost communication and data	4							
1/22/02	2/6/02	**I**	**Gx**	gearbox replacement			360					
2/4/02	2/4/02	**I**	**M**	25 kV breaker open	2							
2/10/02	3/9/02	**I**	**Gx**	gearbox replacement						652		
3/5/02	3/5/02	**Gr**	**Gr**	grid low voltage	5							
3/9/02	3/11/02	**N**	**L**	lightning						53		

Start Date	End Date	Cause	Effect	Description	Plant	Turbine 1	Turbine 2	Turbine 3	Turbine 4	Turbine 5	Turbine 6	Turbine 7
3/12/02	3/22/02	**I**	**Gx**	gearbox replacement					243			
3/22/02	4/4/02	**I**	**R**	Rotor Current Controller (RCC) replacement			318					
4/15/02	4/25/02	**I**	**Gx**	gearbox replacement				241				
4/26/02	7/11/02	**I**	**Gx**	gearbox replacement								1835
6/5/02	6/6/02	**Gr**	**Gr**	grid low voltage	11							
6/7/02	6/7/02	**Gr**	**Gr**	grid low voltage	7							
6/15/02	6/17/02	**I**	**Br**	high temperature brake disc (loose wire on brake disc sensor)			43					
6/26/02	6/27/02	**Gr**	**Gr**	grid low voltage	12							
8/9/02	8/11/02	**I**	**B**	blade repairs					52			
8/14/02	8/14/02	**Gr**	**Gr**	grid low voltage	6							
8/16/02	8/18/02	**I**	**M**	external shaft speed sensor malfunction						37		
9/11/02	9/11/02	**Gr**	**Gr**	grid low voltage	3							
12/1/02	12/3/02	**N**	**B**	icing - caused blade pitching problems				56				
12/3/02	12/3/02	**N**	**I**	icing	3							
12/10/02	1/7/03	**I**	**Gx**	gearbox replacement and waiting for vibration analysis favorable conditions							682	
12/25/02	12/25/02	**N**	**I**	icing	21							
1/3/03	1/6/03	**N**	**I**	icing	77							
1/8/03	1/10/03	**I**	**Gx**	generator gearbox bearing work				53				
1/11/03	1/13/03	**N**	**R**	icing - caused rotor to spin too fast, which triggered the shut-down of the external rpm guard		57						
1/16/03	1/25/03	**I**	**Gx**	gearbox bearing replacement				218				
1/29/03	1/29/03	**Gr**	**Gr**	grid low voltage	2							
2/2/03	2/3/03	**N**	**I**	icing	16							
2/3/03	2/5/03	**N**	**R**	icing - caused rotor to spin too fast, which triggered the shut-down of the external rpm guard					54			

Start Date	End Date	Cause	Effect	Description	Plant	Turbine 1	Turbine 2	Turbine 3	Turbine 4	Turbine 5	Turbine 6	Turbine 7
2/15/03	2/17/03	**N**	**G**	icing - caused vents to be iced shut, which raised the temperature in large generator					53			
2/22/03	2/24/03	**N**	**B**	icing - caused a turbine blade to pitch too sharply						45		
3/12/03	4/14/03	**I**	**Gx**	gearbox replacement - due to oil leak caused by manufacturer defect								800
3/17/03	3/17/03	**N**	**I**	icing - shut down 25 kV power line to turbines	1							
3/21/03	3/21/03	**N**	**I**	icing - shut down 25 kV power line to turbines	1							
4/5/03	4/6/03	**N**	**I**	icing - shut down 115 kV power line	31							
4/16/03	4/19/03	**I**	**B**	blade crack repairs					73			
5/1/03	5/9/03	**N**	**B**	lightning - blade tip repair							188	
6/3/03	6/4/03	**Gr**	**Gr**	grid low voltage	7							
6/3/03	6/11/03	**I**	**Gx**	gearbox replacement		192						
6/23/03	6/23/03	**S**	**S**	scheduled substation maintenance	8							
6/25/03	6/26/03	**S**	**S**	scheduled substation maintenance	13							
7/21/03	7/21/03	**Gr**	**Gr**	grid low voltage	2							
8/14/03	8/15/03	**Gr**	**Gr**	Northeast Blackout	15							
9/4/03	9/30/03	**N**	**L**	lightning							642	
				Totals	**325**	**1251**	**721**	**718**	**547**	**854**	**1617**	**3170**

Appendix D: Negative Pricing Periods[8]

Date	Start Time	End Time	Duration (min)	Turbines Taken Offline
5/7/01	23:50	5:30	340	All WTs
5/8/01	6:49	7:19	30	All WTs
5/11/01	5:09	5:20	11	All WTs
5/17/01	23:58			All WTs
5/18/01	12:50	13:05	15	All WTs
5/18/01	23:47	0:15	28	All WTs
5/19/01	22:56	4:12	316	All WTs
5/20/01	4:27	5:11	44	All WTs
5/21/01	2:02	2:30	28	All WTs
5/21/01	4:15	4:45	30	All WTs
5/24/01	3:20	3:25	5	All WTs
5/27/01	0:15	1:12	57	All WTs
5/29/01	0:18	1:23	65	All WTs
5/30/01	2:44	6:15	221	All WTs
5/31/01	3:00	4:20	80	All WTs
6/2/01	0:02	7:15	433	All WTs
6/3/01	3:00	5:30	150	All WTs
6/3/01	6:50	7:51	61	All WTs
6/3/01	23:40	0:00	20	All WTs
6/5/01	1:30	4:25	175	All WTs
6/9/01	1:45	2:04	19	All WTs
6/19/01	3:20	3:28	8	All WTs
6/19/01	5:45	6:00	15	WT01 & WT03
7/2/01	5:20	5:58	38	WT01 & WT02 starting at 5:20, all WTs starting at 5:30
7/3/01	5:40	6:10	30	All WTs
9/3/01	6:31	7:10	39	All WTs
11/23/01	7:45			All WTs
5/18/02	11:24			All WTs except WT07 (was already down for repair)
5/19/02	23:59			All WTs except WT07 (was already down for repair)
5/25/02	5:35	5:54	19	None (no wind)
5/26/02	5:36	7:04	88	All WTs except WT07 (was already down for repair)
6/3/02	0:00	2:15 - 2:35	155	All WTs except WT07 (was already down for repair)
6/3/02	5:40	6:07	27	All WTs except WT07 (was already down for repair)
6/4/02	1:30	2:35	65	All WTs except WT07 (was already down for repair)
6/15/02	3:08	3:38	30	None
6/16/02	2:10	3:08	58	All WTs except WT02 and WT07 (already down for repair)
6/21/02	5:38	6:34	56	All WTs except WT07 (was already down for repair)
7/12/02	0:43	0:58	15	None - also occurred several times during the night without shutdown
7/13/02				None (no wind)
7/19/02	14:33	14:48	15	None

[8] Negative pricing information comes from the operator's logbook. Gaps occur when the operator does not record all of the information. Incomplete records are not included in the total.

Date	Start Time	End Time	Duration (min)	Turbines Taken Offline
7/25/02	1:24	2:26	62	All WTs
7/30/02	8:09	8:17	8	All WTs
7/30/02	9:19	9:25	6	All WTs
5/1/03	12:27	12:32	5	None
5/20/03	23:45	23:55	10	None
5/21/03	0:38	0:43	5	None
5/21/03	1:10	1:45	35	All WTs
5/24/03	6:22	6:25	3	None
5/25/03	6:16	7:27	71	All WTs
5/26/03	23:44	23:59	15	All WTs
5/27/03	0:00	1:10	70	All WTs - would not restart no wind
5/27/03	1:34			All WTs - would not restart no wind
5/27/03	3:40			All WTs - would not restart no wind
5/27/03	5:30	7:00	90	All WTs
5/28/03	2:00	2:30	30	None
5/28/03	3:00	3:05	5	All WTs except WT04 (would not pause but production in the red anyway - low wind)
6/8/03	2:00	2:11	11	All WTs paused except WT02 & WT04
6/8/03	2:11	4:00	109	All WTs paused except WT02 & WT05
6/13/03	4:54	5:20	26	All WTs paused except WT02, WT04 & WT06
6/15/03	4:28			All WTs paused (down <1 hour)
6/22/03	3:55	4:05	10	All WTs paused
6/22/03	4:25	6:00	95	All WTs paused
		Total (min)	**3452**	
		Total (hrs)	**57.5**	