PERFORMANCE AND MAINTENANCE EXPERIENCES WITH A WIND TURBINE DURING 20 YEARS OF OPERATION

By

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ABSTRACT

A wind electric generator with a 13.4-m (44-ft) rotor diameter was installed in the Southern Great Plains at the USDA Conservation and Production Research Laboratory, Bushland, TX, in May 1982 and was operated to assist in providing electricity to a 23 kW (30 hp) irrigation pump motor. The original turbine was a 240 V, single-phase generator with a rated capacity of 25 kW. This prototype unit was changed to a three-phase, 40 kW generator production unit in 1984 and later that year, a three-phase, 480 V generator rated at 60 kW was installed. All three units used the same size rotor and design. The wind turbine has generated power for over 93,811 hours during the 20 years and produced almost 1,425,641 kWh of electricity. The wind turbine operated for 53.6% of the hours since installation and recorded a capacity factor of 20.4%. Although several component failures occurred during the testing period, the wind turbine had an availability of 90%.

KEYWORDS: Windmills, Wind turbines, Electric power, Energy, Generators

INTRODUCTION

The development of the modern wind turbine began in the late 1970's and the transition from prototypes to production units in the 1980's was rapid with over 10,000 units sold by 1985. Most early prototypes utilized either DC generators or an alternator using a synchronous inverter to make the electricity utility compatible. Machines that use either DC generators or alternators require an external mechanism to regulate rotor speed. This regulation is normally provided by a mechanism to vary the pitch of the rotor blades or to turn the rotor out of the wind. With increased machine size, the variable pitch mechanism became more complicated and costly. In 1978, two manufacturers began using induction motors, operated above synchronous speed, as generators in wind turbines. An induction generator operates essentially at a constant speed with a gearbox between the rotor and generator. The induction generator offered several advantages over the other systems; the main ones being that the pitch control system could be eliminated and that interfacing to the electric utility was greatly simplified (Park, 1981). A disadvantage of the induction generator is that it requires excitation from an external source, usually the utility line. Almost all medium size wind electric generators sold today use an induction generator.

The USDA-Agricultural Research Service began experimental studies with wind electric generating systems in 1976 and acquired several prototype machines in the 1978 to 1983 time period. In this paper, I report on the test results of a wind electric generator acquired in 1982 as a prototype and later converted to a production machine. Daily kWh meter records and a data logger have been maintained on this system since it was installed. Dates when the machine was modified are reported in Table 1. Continuous operation of the 25 kW prototype was started on July 1, 1982 and continued until February 27, 1984. The 25 kW prototype was changed to a 40 kW production model with the same rotor size. After 8 months of operation, the 40 kW unit was changed to a 60 kW. Even though the 60 kW unit was the first 60 kW built, only the generator and gearbox were different and all parts were interchangeable with the 40 kW unit. Since November 13, 1984, only three significant events required the turbine to be removed from the tower for repair. In October 1987, the up-wind tower leg cracked just below the turbine mounting plate. Three months were required to determine the proper corrective action and secure repair parts. Then in 1988, the front gearbox oil seal began leaking excessively and the turbine was again removed from the tower. At this time, we chose to replace the 60 kW gearbox with a 40 kW gearbox to reduce the rotor speed. The gearbox seals were again replaced in 1995. Each of these events are discussed under the reliability section. The turbine was operated without modification until 1997 when a soft-start system was installed to allow us to use the turbine as part of a wind/diesel hybrid generation system. Operating the turbine with the wind/diesel hybrid system produced a large number of emergency stops which created an unusually high number of brake repairs.

WIND TURBINE DESCRIPTION

The horizontal-axis wind turbine had a 13.4-m (44-ft) diameter, three-bladed, fixed pitch rotor mounted on a 24.4-m (80-ft) free-standing tower (Figure 1). The rotor blades were fabricated from laminated wood-epoxy and attached to a steel hub. The specifications of the wind electric generating system are listed in Table 2. The 25 kW prototype had a single-phase generator operating at 240 V, while the 40 and 60 kW units both had three-phase generators operating at 480 V. The unit was manufactured by Enertech Corporation[1] as a Model 44 (Enertech Corporation ceased operation about 1987).

The wind turbine start-up and shut-down was controlled by a signal from an anemometer located on the tower just below the blade tips. The parking brake held the rotor stationary until the control system determined that adequate wind was available to produce power, then the brake was released and the generator was utilized as a motor to accelerate the rotor to its operational speed. Normally this required about 15 sec to bring the system from a stopped position to full operational speed. The controller was set to have the wind turbine start when the wind speed averaged 5.4 m/s (12 mph) and to stop when the average wind speed dropped to 3.2 m/s (8 mph). A high wind speed shut-down occurred when the controller sensed an average wind speed of 22 m/s (50 mph) or higher for 45 sec. The controller would not restart the unit until the average wind speed dropped to less than 16 m/s (36 mph).

The data logger monitored the wind speed, wind direction, electrical power, air temperature, and barometric pressure at a rate of one Hertz and averaged the data over five minutes. Also, these data were averaged and recorded on an hourly and daily basis, thus producing three different data tables for each day. In addition to these computerized data, daily recordings were made each morning of the run-time hours, number of starts, electrical energy produced by the wind turbine, and electrical energy purchased from or sold to the utility. At other times during the 20-year period, data were recorded at 15-sec averaging intervals with data being sampled at 5 Hz. Power curves were developed using the high frequency data, while daily data were used to determine annual or monthly performance (Vosper and Clark, 1985).

PERFORMANCE DATA

The annual average wind speed during the 20 years was 5.71 m/s (13 mph) measured at the 10-m (33-ft) height. The wind speed at hub height (25 m (82 ft)) was calculated to average 7.1 m/s (16 mph), about 25% higher. The total run hours for each year are presented in Table 3. During the 20 years reported by these data, the turbine was in operation for 90% of the time. The accumulated energy produced is shown in Figure 2 along with the accumulated run hours. The turbine produced 1,425,641 kWh during the 20 years and averaged 71,300 kWh per year. The two years with the lowest production, 2001 and 2002, were caused by using the turbine in a wind/diesel hybrid experiment. The hybrid experiment was conducted to develop a new control system for integrating wind and diesel generation on a small independent grid with storage. The turbine was turned off while repairs or reprogramming was being conducted to the hybrid experimental system.

RELIABILITY

The wind turbine did experience several failures and problems during the testing period. Remembering that the 25 and 60 kW units were both prototypes and the 40 kW was an

[1]Mention of a manufacturer or product name does not constitute a recommendation or endorsement for use by the USDA-Agricultural Research Service, but is given for informational purposes only.

early production unit, these units performed well. Major maintenance and repairs are summarized in Figure 3. Similar items have been grouped for ease in describing events. Table 4 shows the complete list of down-times, the parts involved, the frequency of occurrence and a description what was performed. The six major causes of down time are described below.

Gearbox seals created the most lost run time because the repairs required the turbine to be removed from the tower, the hub removed and the shaft polished. The seals were replaced three times, but problems with the gearbox drain valve, vent and routine fluid checks were also included in the total of 3,271 hours or 1.7% of the 20 year period.

Close behind the gearbox repairs were repairs to the brakes. The unit had three braking systems, two of which required most of the repair. Out of the total time assigned to brakes, 2,669 hours were attributed to the parking brake and 563 hours to the tip brakes. Most of the parking brake problems were caused by the initial brake being too small and then several emergency stops during 2001-2002 when the unit was used to develop a wind/diesel hybrid control system. Repairing the parking brake required replacement of three disk pads and often times the metal spacers between the pads.

In October 1986, 4.5 years after installation, a 5-cm (2 in) long crack developed in the up-wind tower leg just below the top mounting plate. Similar cracks were found on this manufacturer's wind turbines located in the wind parks in California. After careful study by several groups, it was concluded that the crack was caused by loads translated from the free yaw movement of the rotor. Several "fixes" were suggested and we chose to replace the top tower section legs (schedule 40 pipe) with schedule 80 pipe. This was done and the turbine was returned to service resulting in 2611 hours of lost run time after locating the crack. There were 22,437 operating hours on the tower when failure occurred. This problem did not reoccur after the heaver tower leg was installed.

The yaw bearing was replaced 3 times during the 20 years resulting in lost run time of 2,534 hours. The turbine had to be completely removed from the tower for this repair. We determined that there were two contributing factors that caused excessive wear of the yaw bearing. The free yaw design allowed the turbine to waggle back and forth creating large moments on the bearing. Because of the prevailing wind direction at Bushland, significant wear occurred in a small portion of the bearing. The other contributing factor was the small diameter of the bearing, causing a large load on a small percentage of the bearing. A larger diameter bearing would have spread out the load, thus reducing the wear at the prevailing wind direction. Also included in this down time is the lubrication and inspection of the yaw bearing.

Accumulations of bugs, oil, and ice on the blades reduced power as much as 40%. Regular cleaning of the blades became a maintenance requirement. Included in the 1,705 hours of down time for cleaning the blades is several ice storms when the ice caused the airfoil shape to be changed and the turbine could not produce power. Results of the effect of dirty blades was reported by Yekuieli and Clark, 1987. Figure 4 shows the effect to performance of dirty blades and figure 5 shows that performance is easily restored after a rain.

The original machine had control system that use the rotational speed as an indicator of when to energize the generator. This control system was not reliable and was replaced after two years with one that used the average wind speed to energize the generator. Most of the 1,578 hours of lost time were caused by the early controller; however, six failures of components on the wind speed cards resulted in 393 hours of lost time during the last 18 years of operation.

All other down time was assigned to a general category of inspections and system upgrades. These included changing the system from 25 kW to 40 kW to 60 kW and then back to 40 kW. A soft-start controller was added in 1997 as part of the upgrade to begin the wind hybrid experimental work. These activities resulted in 2.2% of the total lost time.

Overall availability for the wind turbine has been 90% during the total period. Six major repair items were identified as contributing to 8% of the lost time. Performance results from this turbine have resulted in new and improved components which are now being used in new production units. New machines show availability of 98 to 99%. Dirty blades caused by icing and accumulation of bugs create the greatest lost run time on current production wind machines and with new airfoil designs, much of that lost time is minimized.

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TABLE 1. SIGNIFICANT EVENTS DURING THE TESTING OF ENERTECH 44, BUSHLAND, TX, 1982 - 2003

DATE	MONTH	ACTIVITY
May 28, 1982	0	Installed 25 kW
July 1, 1982	1	Began performance testing
February 27, 1984	20	Removed 25 kW
March 20, 1984	21	Installed 40 kW
November 5, 1984	29	Removed 40 kW
November 13, 1984	29	Installed 60 kW
May 13, 1988	71	Removed 60 kW Gearbox (Leaking seal)
July 19, 1988	73	Installed 40 kW Gearbox with 60 kW Generator
August 19, 1997	182	Installed a soft-start controller system
April 20, 1999	202	Operated the system in a wind/diesel hybrid test

TABLE 2. SPECIFICATIONS OF ENERTECH 44 WIND TURBINE INSTALLED AT BUSHLAND, TX, 1982 - 2003

SYSTEM	
Type	Utility interface
Axis of rotor	Horizontal
Location of rotor (with respect to tower)	Downwind
Number of blades	Three
Centerline hub height	25 m (82 ft)
ROTOR	
Rotor diameter	13.4 m (44 ft)
Rotor type	Fixed pitch
Rotor speed at rated power	57 rpm (40 kW) and 67 rpm (60 kW)
Blade material	Wood/epoxy laminate, fiberglass coat
GENERATOR	
Type	Induction, three-phase (40 & 60 kW)
Output voltage	480 V (40 & 60 kW)
Frequency	60 Hz
TRANSMISSION	
Type	Double reduction, Planetary
Ratio	1:32 (40 kW) and 1:27 (60 kW)
YAW SYSTEM	
Yaw control	None, rotates freely 360 degrees
BRAKES	
Normal stops	Dynamic brake
Parking brake	Electro-mechanical, fail safe spring
ROTOR SPEED CONTROL	
Rotor overspeed (Normal operation)	Blades stall in high winds
Rotor overspeed (Emergency)	Control system applied braking
Rotor overspeed (Emergency back up)	Blade tip brakes deploy
TOWER	
Type	Galvanized self-supporting
Height	24.4 m (80 ft)
PERFORMANCE	
Rated wind speed	13.4 m/s (30 mph)
Start-up wind speed	5.4 m/s (12 mph)
Shut-down wind speed	3.2 m/s (8 mph)
Cut-out wind speed	22.3 m/s (50 mph)

Table 3. Enertech 44, 20 yr operating history 1983-2002

Year	Connected Time hrs	Connected Time %	Energy Produced kWh	Availability %	Wind Speed m/s	Atmos. Dens kg/m3
1983	5567	63.6	63710	92.6	6.0	1.08
1984	4611	52.6	72295	86.3	5.9	1.08
1985	4862	55.5	91732	94.9	5.6	1.08
1986	4121	47.1	77522	82.1	5.7	1.08
1987	3850	44.0	65638	81.0	5.6	1.08
1988	3971	45.3	71643	77.0	5.6	1.08
1989	5893	67.3	83452	99.4	5.3	1.08
1990	5831	66.6	86592	97.5	5.6	1.08
1991	5705	65.1	82390	96.6	5.9	1.08
1992	5641	64.6	73510	98.0	5.4	1.08
1993	5754	65.9	88363	96.4	5.7	1.08
1994	5769	66.4	79392	95.7	5.6	1.08
1995	4099	46.8	51931	72.8	5.7	1.08
1996	4991	56.8	76470	86.8	5.8	1.08
1997	4608	52.6	56958	75.4	5.5	1.08
1998	4944	56.4	68885	93.2	5.5	1.07
1999	4487	51.2	65147	93.3	5.7	1.08
2000	4241	48.3	66589	85.3	5.7	1.07
2001	2745	31.3	43750	81.2	5.2	1.08
2002	2121	24.0	59672	64.1	6.3	1.08
	93811	53.6	1425641	87.5	5.7	1.08

TABLE 4. Total downtime, frequency of occurrence and notes describing corrective action.

Total Downtime (hours)	Frequency	Parts repaired	Notes
2669	11	Parking brake	Pad failure and removal/replacement
2611	2	tower	Crack discovered in a leg in the top section, replaced with larger schedule tubing, 1986
2527	3	gearbox seal	Replacement of leaking seals (requires removing turbine from tower)
2534	6	yaw bearings	Lubrication and replacement when worn (requires removing turbine from tower)
1944	1	soft start controller	Upgrade of start-up controller, problems with installation 1997
1705	36	blades	Cleaning blades, changing pitch, and off for icing
834	2	installation of turbine modification	Upgrading 25 kW to 40 kW in 1984 and 40 kW to 60 kW in 1987
720	1	gearbox drain valve	replaced leaking valve on 60 kW prototype, 1988
625	18	external causes	Interrupted power supply for rewiring to a different application. Switched off to avoid affecting other experiments.
564	14	tip brakes	Replacement of tip brakes after redesign in 1985, changed release mechanism in 1991
536	1	electrical frequency sensor	Monitors line frequency and sensor failed requiring replacement
530	1	shaft failure	Main shaft failure on 25 kW prototype because of improper lathe cut, 1984
393	6	wind speed cards	Control system sensor; chip failures or shorted connections
370	2	rpm sensor	Failure of sensor and replacement. Used only on 25 kW unit.
244	5	inspections	Routine inspections or inspections after unexpected noises.
202	3	relay	Relay malfunction and replacement, occurred during holiday periods
60	1	control system component	electrical component failure requiring replacement
35	6	twist cable	time required to untwist cable and repair broken wire
25	9	gearbox	Oil level checks and oil changes
24	3	spinner	replacement of nose spinner, 1985 and 1988
17	2	slip-ring assembly	Repair to slip-ring assembly used on 25 kW unit
1	1	power factor capacitor	Failure and replacement of a component

Fig. 1. The Enertech 44 was installed in 1982. The hub height was 25-m and the system supplied power to a 480 V irrigation pump connected to the utility grid.

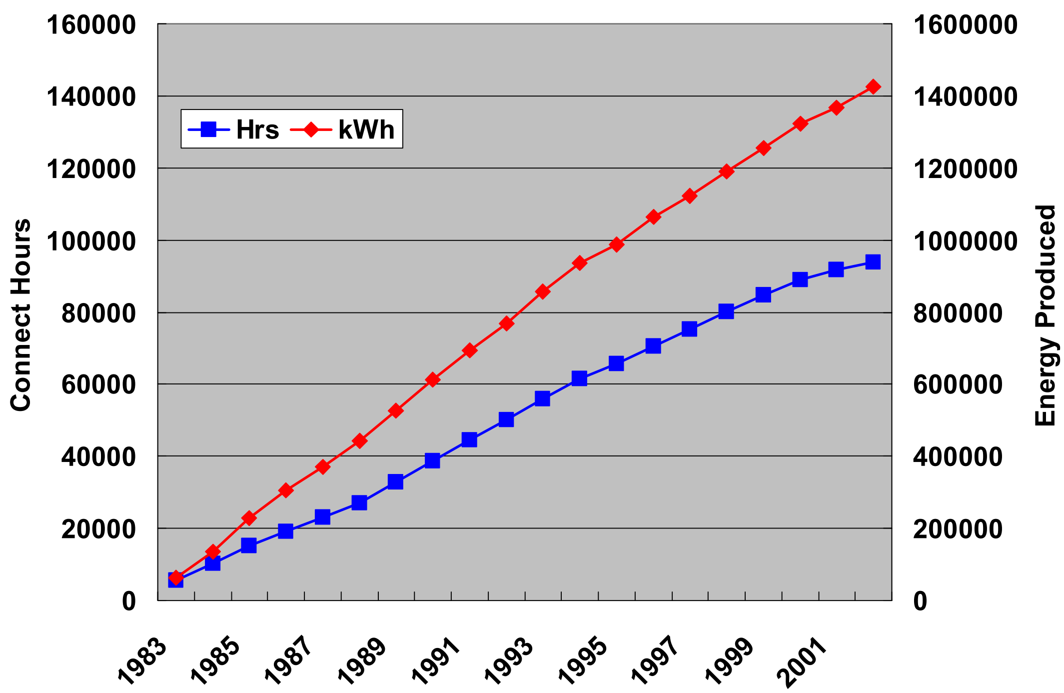

Fig. 2. The turbine averaged 71,280 kWh per year for a capacity factor of 20.4%. The turbine averaged 4690 hours of on-line operation per year.

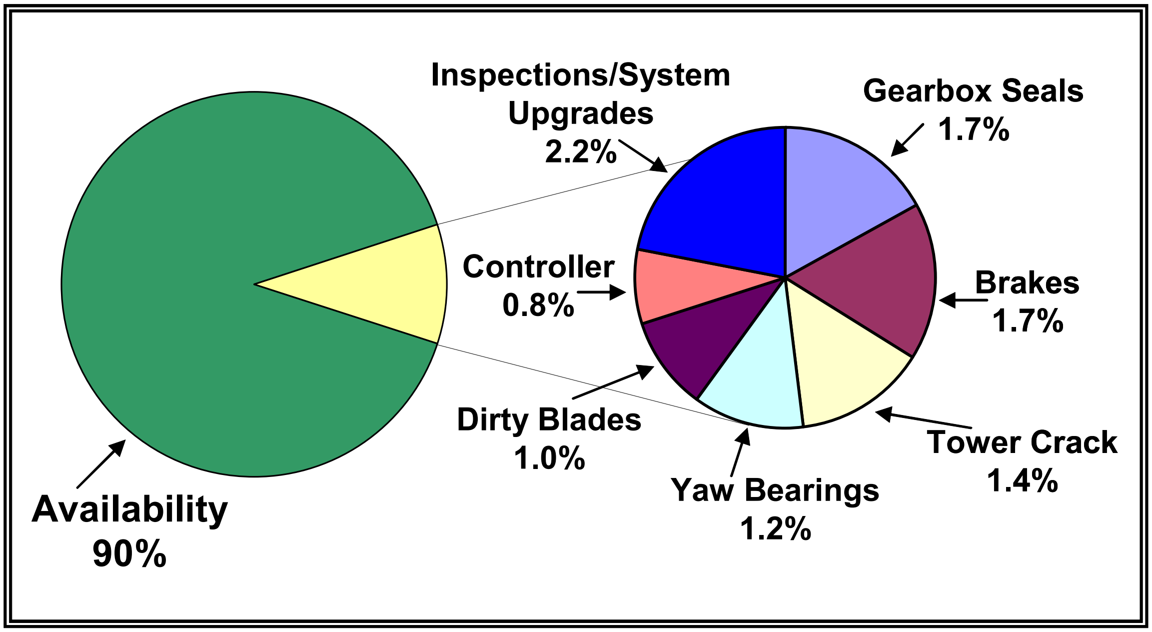

Fig. 3. Major repair and maintenance times.

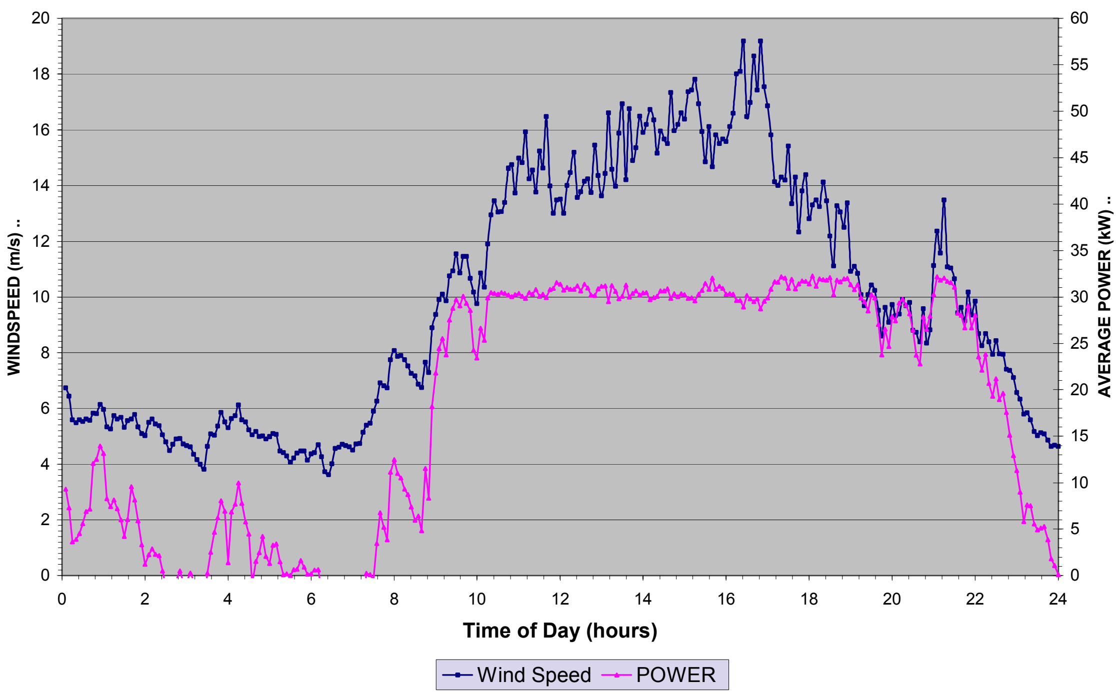

Fig. 4. Dirty blades from leaky oil, bugs, and ice reduced power by as much as 40% at rated wind speed. Regular cleaning of the blades became a maintenance requirement.

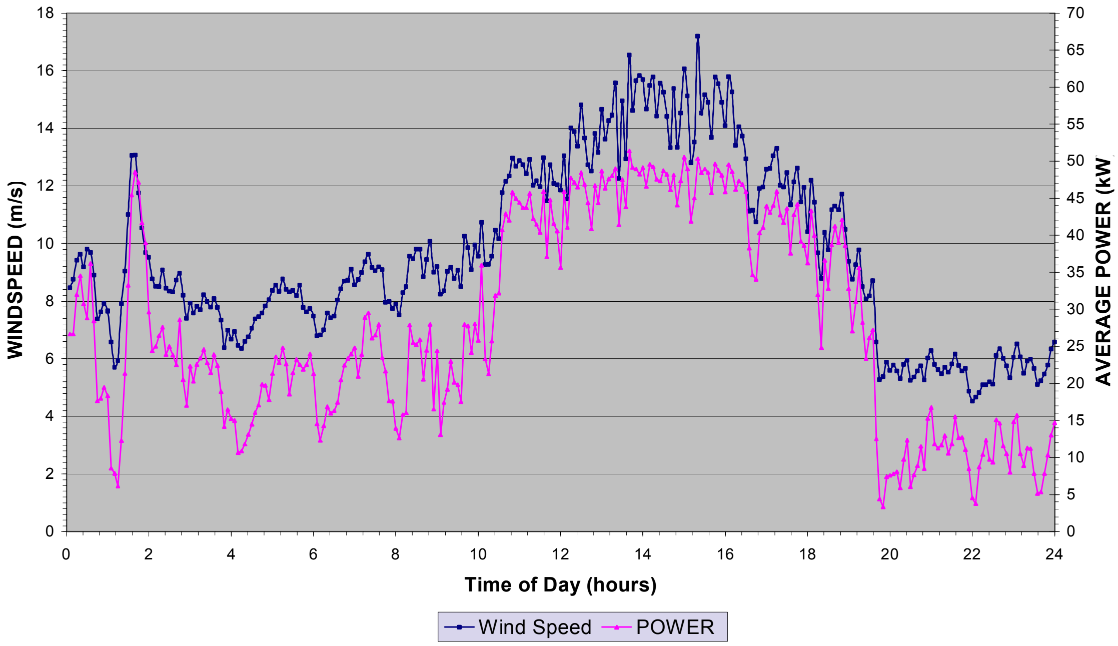

Fig. 5. Power was restored after blades were washed; either by rain or water spray.