ONE AND A HALF YEARS OF FIELD TESTING A WIND-ELECTRIC SYSTEM FOR WATERING CATTLE IN THE TEXAS PANHANDLE

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ABSTRACT

A wind-electric water pumping system was used to replace a multi-bladed mechanical windmill for watering cattle on USDA-ARS range land near Bushland, TX. The multi-bladed windmill had 15 blades with a rotor diameter of 3.05 m, and powered a 4.8 cm diameter piston pump. The wind turbine (3 blades, 3.05 m rotor diameter) used for the wind-electric system had a 1.5 kW rating at a 12.5 m/s wind speed and used a permanent magnet alternator to power a submersible motor with a 10 cm centrifugal pump. Over the past 1.5 years the wind-electric system has been able to pump enough water from a 73 m well to satisfy the water requirements for 80 head of cattle during the fall, winter and spring. However, only about half the water needed for the 80 head of cattle was pumped by the wind-electric system in the summer (July and August). An estimate of the mechanical windmill showed it would have pumped enough water to satisfy the water requirements of 80 head of cattle during the entire year. Theoretical analysis of the wind-electric system suggests that the water volume should be high enough for summer if the tower height is increased from 18.3 m to 30.5 m -- this will also add an additional $1000 to the cost of wind-electric system.

INTRODUCTION

For about the past two decades the renewable energy research team at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX, has examined using wind or solar energy for pumping water for livestock watering or domestic uses. If utility power is available it is more cost effective to use this electricity (at least for the 48 contiguous states in the U.S.) than purchasing a wind or solar powered system. From 1988 to the present, wind-electric systems have been tested in the Hydraulic Laboratory. In the laboratory, the water is pumped in a controlled environment from underground sumps and pumping depth is simulated by using a back pressure valve to simulate the pumping head. Utility power at the laboratory site not only accommodates needed power for instrumentation but makes it easier to diagnose problems with the wind turbine, controller, motor or pump by switching to utility power for testing. However, this laboratory testing is different from field testing as we discovered when we installed some 10 kW wind turbines at actual water wells near Garden City, TX (Vick et. al, 1997). Problems occurred while testing at this Garden City, TX location where utility power was not available, and it was difficult to determine which pumping system component was at fault. In the laboratory the motor and pump could be connected to utility power and tested independent of the turbine to see if the flow rate agreed with the manufacturer's specifications without pulling the pump and motor from the underground sump. Based on the experience at the Garden City, TX location, we felt it was important that we conduct a test of a smaller wind-electric system at a remote location (no utility intertie) at an actual water well site. A Bergey[1] 1500 was installed at a remote well on the south section of the USDA property replacing a 3.05 m, Dempster[1] mechanical windmill that had been installed in 1938 when the Conservation and Production Research Laboratory was built. Our objective was to see if the Bergey 1500 could provide sufficient water for the cattle that grazed in this pasture. Results of the first six months of pumping with this Bergey 1500 (Oct'97 to Mar'98) were reported in Windpower '98 (Vick et. al, 1998b). For the first six months of testing, sufficient water was provided to water the 80 head of cattle placed in this pasture. However, during the summer months (Jul-Aug 1998) insufficient water was pumped by the Bergey 1500 to water 80 head of cattle.

WIND-ELECTRIC WATER PUMPING SYSTEM

The initial requirements for the project were to pump sufficient water from a static water depth of 73 m to maintain sufficient water in a 40 m^3 capacity stock tank for 40 head of cattle. Several years of testing the Bergey Windpower[1] 1500-PD wind turbine showed it to be very reliable (Vick et. al, 1998a) and past data indicated it could satisfy the requirements if an 18.3 m tower was used. The rotor diameter was 3.05 m and the generator was a permanent magnet alternator. Over speed protection in high winds was provided by horizontal furling -- similar to a conventional mechanical windmill. This wind turbine can also be manually furled from the ground using a winch attached at the bottom of the tower. The turbine has three fiberglass blades which are made using a pultrusion process and therefore they have a constant chord and no static twist. The blades do have pitch weights located near the tip which provide some dynamic twist. The turbine was mounted on an 18.3 m guyed Rohn[1] 25G lattice tower. The controller used was developed by a cooperative effort between the USDA-ARS and West Texas A&M University - Alternative Energy Institute (WTAMU-AEI) and was similar to the one developed for a Bergey 850 (Ling and Clark, 1997). The submersible motor was an off-the-shelf Franklin Electric[1] 1.1 kW, 230 V, 3ϕ, AC submersible motor. The pump was an off-the-shelf Grundfos[1] 0.75 kW, 19-stage centrifugal pump. Both pumps and motors of this type are readily available worldwide. The static water level of the well was at 73 m, the bottom of the well was at 90 m, and the pump was located at 87.8 m. The cylindrical stock tank was 9.2 m in diameter, 0.6 m deep, and had a capacity of 40 m^3. An overflow drain pipe was mounted in the tank that carried excess water to an area in the field approximately 100 m north of the tank.

REMOTE POWER SYSTEM FOR INSTRUMENTATION AND DATA ACQUISITION SYSTEM

Because of the remote location of this well, a stand-alone power system was needed for the instrumentation and data acquisition system. From Oct'97 until Jan'99 the hybrid power system consisted of the following:

1) 12 V (80 A-hr @ 2 A/hr) lead-acid deep cycle battery
2) 300 W Southwest Windpower[1] DC output wind turbine (Air Module 303)
3) 25 W crystalline silicone photovoltaic solar panel

On Jan. 27, 1999 the 300 W wind turbine and 25 W solar panel were replaced with two 53 W crystalline silicone photovoltaic solar panels. Prior to the replacement data had been lost due to low battery voltage and the voltage on the battery sometimes exceeded 14 Volts. Since the replacement we have not lost any more data, and the battery voltage has stayed between 12 and 14 Volts. On cloudy days the Bergey 1500 is used to charge the battery.

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[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA - Agricultural Research Service.

INSTRUMENTATION AND DATA ACQUISITION SYSTEM

The data collected on the wind-electric system included:

1) Wind speeds at 10 and 16.2 m heights (m/s)
2) Voltage (V)
3) Current (A)
4) Frequency (Hz)
5) Power (W)
6) Flow rate (l/min)
7) Instrumentation and data acquisition system battery voltage (V)
8) Outside air temperature (deg F)
9) Inside air temperature (deg C).

One minute averages of these variables were collected using a Campbell Scientific Instruments[1] CR21X micrologger. The wind speeds were measured using model 014 Met-One[1] anemometers that produced two pulses per revolution. Two anemometers were mounted at heights of 10 and 16.2 m on the same tower as the wind turbine. Both anemometers were extended 1.5 m west of the tower on telescoping pipes. The prevailing wind is from the southwest with little wind from the east, resulting in little data being affected by tower shadow. Using the 16.2 m anemometer height rather than the hub height (18.5 m) results in an error in wind speed of less than 0.25 m/s based on extrapolations of the wind speeds at 10 m and 16.2 m. Water flow was measured using a JLC[1] IR-Opflow Type 6 flow meter and this data was recorded on the Campbell micrologger. A Hersey[1] model MVR-30 dial type totalizing flow meter was also used to check the flow rate measured and it was read each time the micrologger data was retrieved -- about twice a week. Both inside and outside temperatures were measured using copper-constantan thermocouples. The inside air temperature is the temperature inside the building where the instrumentation, data acquisition system, and controller were kept and was monitored to help determine if temperature had an effect on the controller operation.

RESULTS

Figure 1 presents over a 19 month period the actual daily water volume pumped by the Bergey 1500 and the daily water that could have been pumped assuming no down time on the Bergey 1500. The main reasons for the down time were:

1) icing of the blades during the winter
2) intensional manual furling of the wind turbine or letting the wind turbine run offline due to a full stock tank or no cattle in the pasture
3) controller problems.

The controller problems were corrected and simply required increasing the amperage of the fuses and reprogramming the logic in the CPU chip. Originally it was assumed only 40 head of cattle would be grazed in the South Section pasture, but about 80 head have been placed there during various times of the year. Enough water could have been provided for 80 head of cattle during all months of the year except July and August. There was very little down time during the months of July and August, so eliminating the down time would not have helped during these months.

The daily supply and demand of water during the summer months are presented in Figure 2. On June 29, 1999 the number of cattle was increased from 4 to 79. Also, there was a severe drought occurring during these months which not only caused a substantial decrease in water in the stock tank due to evaporation, but resulted in high temperatures and low water content in the grass which caused the cattle to drink

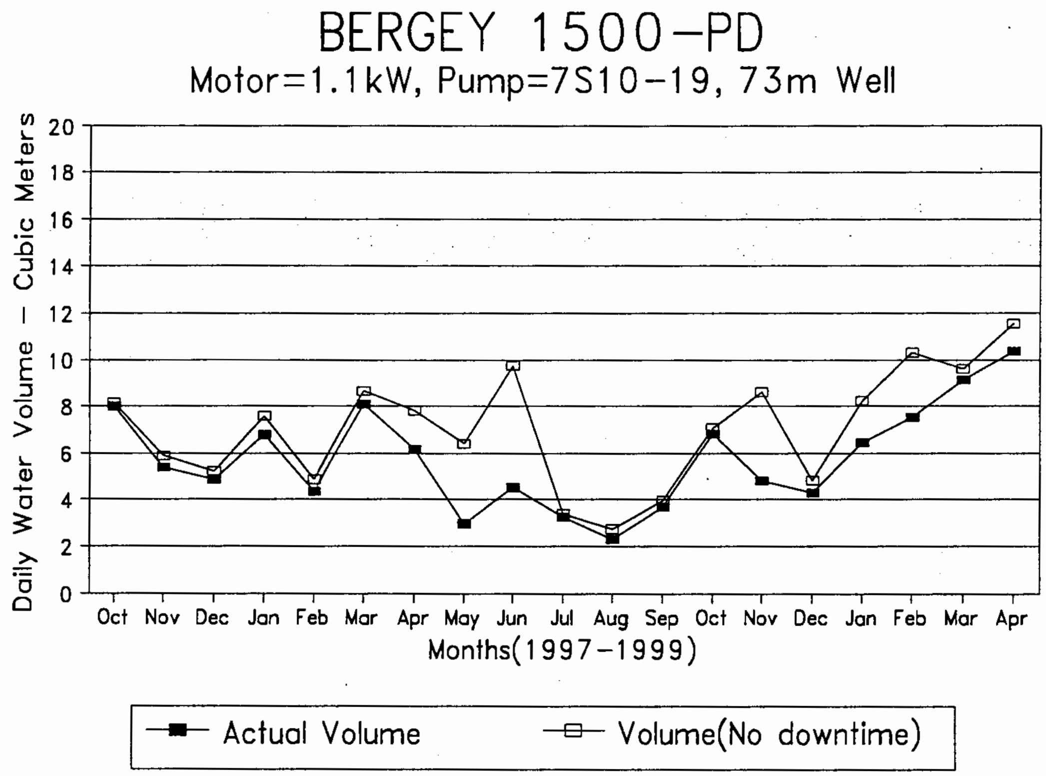

Figure 1. Daily Water Volume for Bergey 1500 (Actual & Predicted with no downtime).

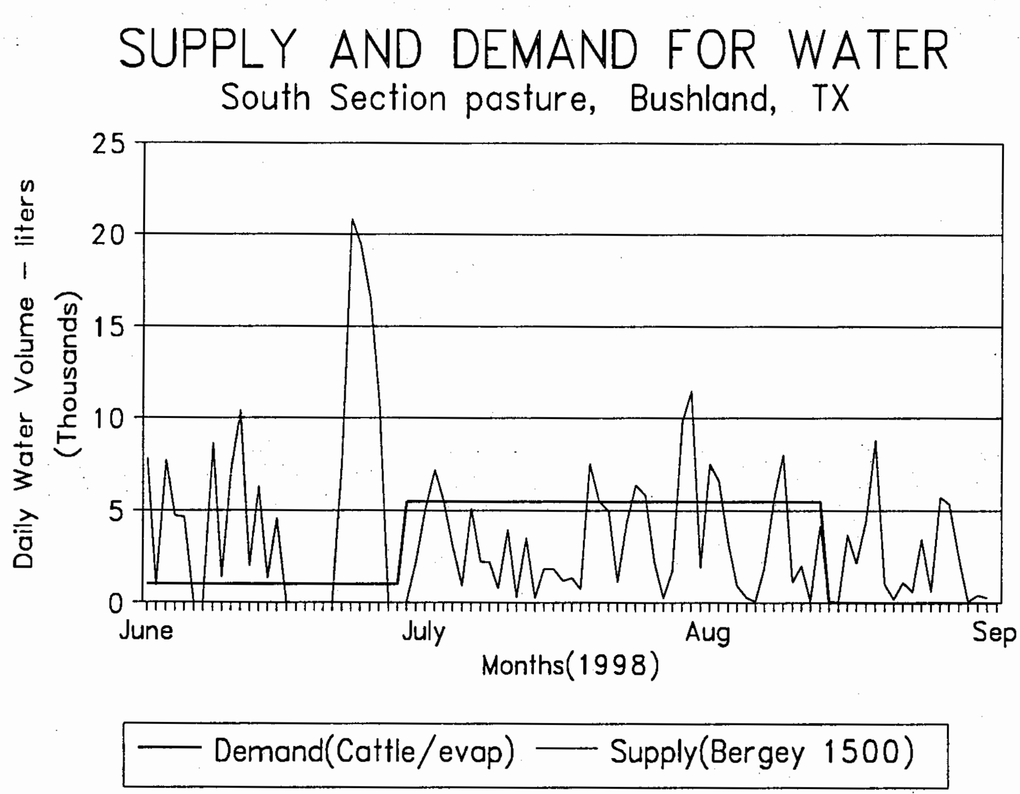

Figure 2. Supply and Demand for Water in the South Section During the Summer of 1998.

more water. We estimated that the demand in water for the cattle and evaporation from the stock tank was 5500 liters/day. Since the average daily water provided by the Bergey 1500 during July and August was only 3250 liters/day; the volume deficit was 2250 liters/day. If water had been stored in a storage tank during the windier months of May and June, the size of the storage tank would need to hold at least 139500 liters (37000 gallons) to supplement the water supply during July and August. Having to get such a large storage tank would make this wind-electric system uneconomical. The water deficit was made up during the first part of July by hauling water to the stock tank, and during the last part of July and the month of August by tapping into an irrigation well near another part of the pasture. On August 13 all the cattle were moved to another pasture which decreased the demand for water to zero. Hauling water to the stock tank is not an attractive option to most farmers and ranchers, so it is desirable to improve the daily water volume of the wind-electric system in the summer.

When the water deficit was first discovered in July, an analysis of the data revealed the flow rate at moderate wind speeds was significantly decreased by increasing the capacitance in the controller (Figure 3). Since no inverter is used to convert the variable voltage/frequency 3-phase electricity generated by the permanent magnet alternator of the wind turbine into constant voltage/frequency, capacitance is added in parallel to the inductive motor/generator to bring the power factor close to unity. If no capacitance is used, very little water would be pumped because the current and voltage would be so out of phase with each other. An additional 15 µF of capacitance was added at the end of March in order to increase the amount of water pumped at high wind speeds above 10 m/s. While it is evident that additional capacitance improved the flow rate at those higher wind speeds (Figure 3), it also resulted in a decrease in flow rate in the 7 to 10 m/s wind speed range. When the capacitance was decreased from 70 µF back to 55 µF at the end of July, there was a noticeable improvement in flow rate in the wind speed range of 7 to 13 m/s. The reason the flow rate is higher for wind speeds above 10 m/s in July and August than February and April is due to less amount of time at the higher wind speeds (Figure 4) which means the wind turbine is less likely to lose synchronization and go offline (Figure 5). Although this improvement in flow rate due to lower capacitance would have improved the water volume, it still is not enough to keep the farmer or rancher from hauling a significant amount of water during the summer . On Dec. 2, 1998 variable capacitance was included in the controller such that 55 µF would be used at moderate wind speeds and 75 µF would be applied at higher wind speeds. The flow rate improvement at wind speeds above 10 m/s in 1999 compared to 1998 can be attributed to applying the variable capacitance (Figure 6). The improvement in flow rate in 1999 compared to 1998 at low wind speeds is not understood and has nothing to do with the variable capacitance. Figures 7 and 8 present the wind distributions and online time for February and April

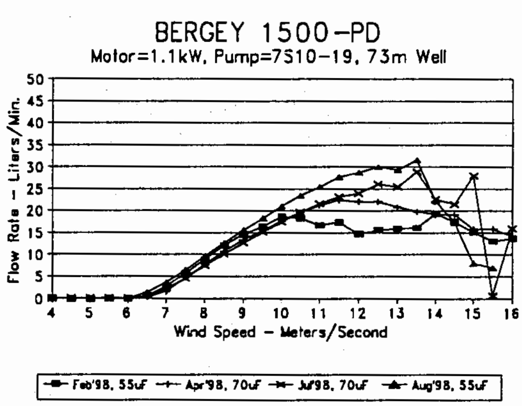

Figure 3. Effect of Capacitance on Flow Rate.

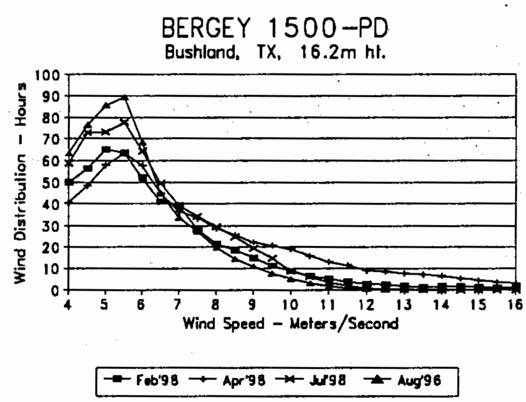

Figure 4. Wind Distributions for Constant Capacitance Comparison.

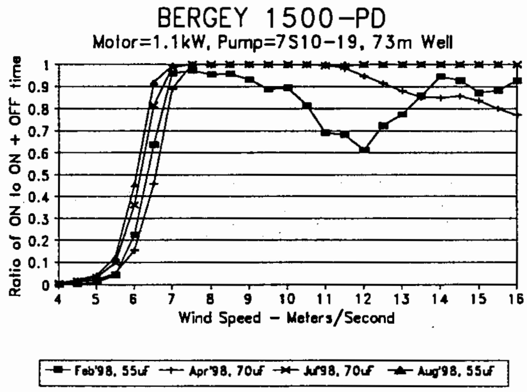

Figure 5. Effect of Capacitance and Month on Online Time.

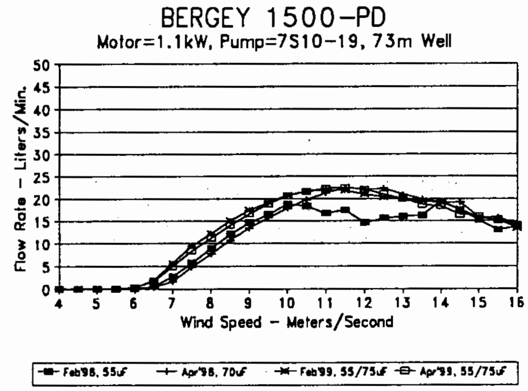

Figure 6. Effect of Varying the Capacitance with Wind Speed on Water Flow Rate.

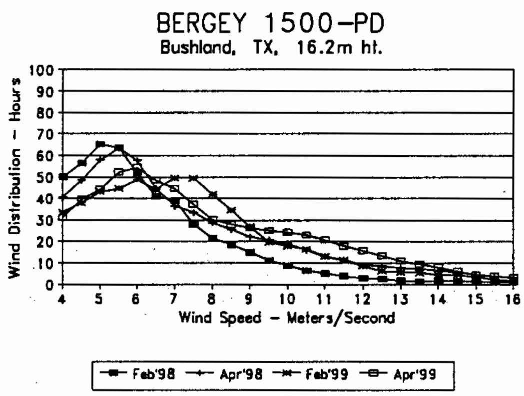

Figure 7. Wind Distributions for Variable Capacitance Comparison.

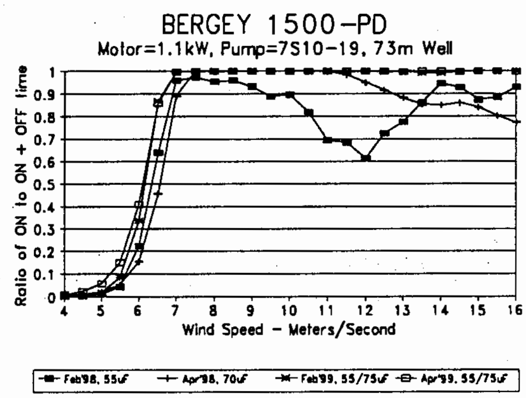

Figure 8. Effect of Varying Capacitance with Wind Speed on Online Time.

in 1998 and 1999. Figure 8 demonstrates that there was a significant decrease in down time at high wind speeds by varying the capacitance with wind speed.

The livestock manager could not remember having to haul water during the past 15 years when the 3.05 m Dempster mechanical windmill pumped water into the stock tank in the south section. During this time period however, no data was collected on this mechanical windmill and the most cattle that ever grazed in this pasture were 50. However, using data collected on a 2.44 m Dempster at Bushland and using information published by another mechanical windmill manufacturer, we estimated a flow rate versus wind speed curve for the 3.05 m Dempster with a 4.8 cm diameter pump at a pumping depth of 73 m (Figure 9). The high blade solidity of the mechanical windmill and the fact that the wind energy is directly converted into mechanical power (i.e. no mechanical to electrical to mechanical conversion) resulted in a low cut-in wind speed of 3 m/s compared to a 6 m/s cut-in wind speed on the Bergey 1500. However, at higher wind speeds the Bergey 1500 dramatically outperforms the Dempster windmill. Figure 10 presents the average wind speed at hub heights of the Bergey 1500 and the Dempster: 18.5 m and 10 m, respectively. Figure 11 presents the daily water volume for the Bergey 1500 and the Dempster from Jan.'98 to Apr.'99. The

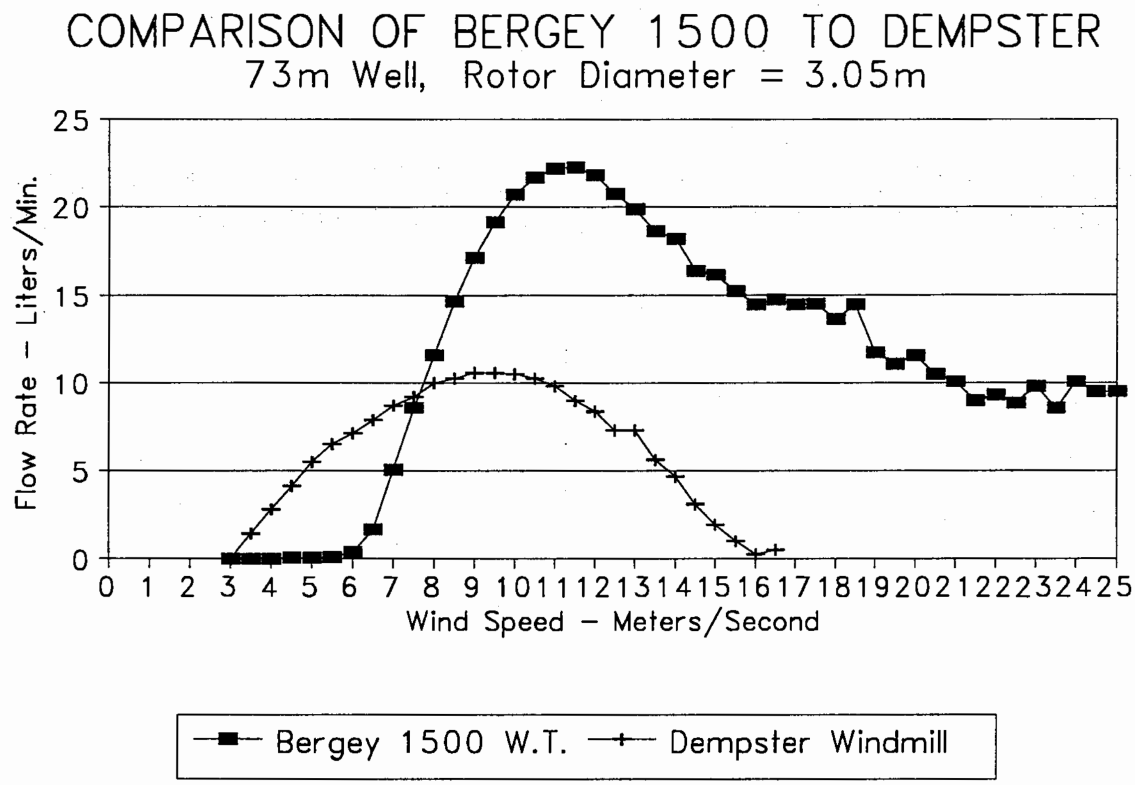

Figure 9. Comparison of Flow Rates of Bergey 1500 Wind Turbine and Dempster Windmill.

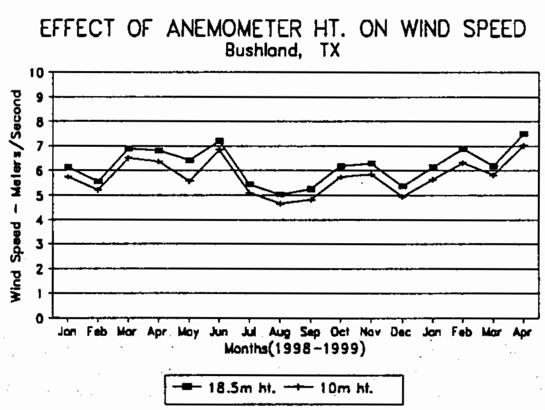

Figure 10. Comparisons of Average Monthly Wind Speeds at 18.5 m and 10 m Heights in Bushland, TX.

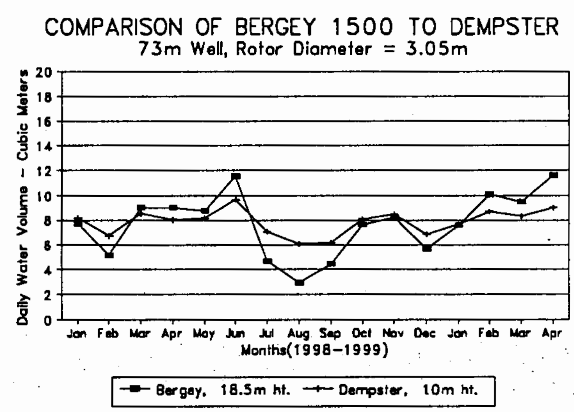

Figure 11. Comparison of Daily Water Volume of Bergey 1500 to that Calculated for Dempster Windmill.

Bergey 1500 outperforms the Dempster in the spring, and both perform about the same in fall and winter. The Dempster outperforms the Bergey in the summer. In fact, the Dempster 3.05 m windmill is predicted to have supplied the water needed by the 80 head of cattle for all months of the year including summer.

Figure 12 presents the effect of height on wind speed at various heights for two different locations in the Texas Panhandle – White Deer and Bushland. White Deer is a town located about 100 km (60 miles) East-Northeast of Bushland, and the closest place to Bushland where complete wind speed data was recorded at several heights. Gaps in the White Deer data are due to insufficient data being recorded. The most important months to look at are July and August where the average wind speeds at the 10 m height for Bushland and White Deer are very similar. For these two months the average wind speed increased significantly in White Deer from the 10 m height to the 25 m height and then again from 25 m to 40 m height. Figure 13 presents the water volume predicted for the Bergey 1500 pumping from the 73 m well given the wind distributions at White Deer and Bushland for the various heights. According to the White Deer data, increasing the height of the wind turbine from 18.5 m to 25 m will double the daily water volume in August to 6000 liters/day which means the daily water volume should be high enough to water 80 head of cattle in August (water demand is 5500 liters/day).

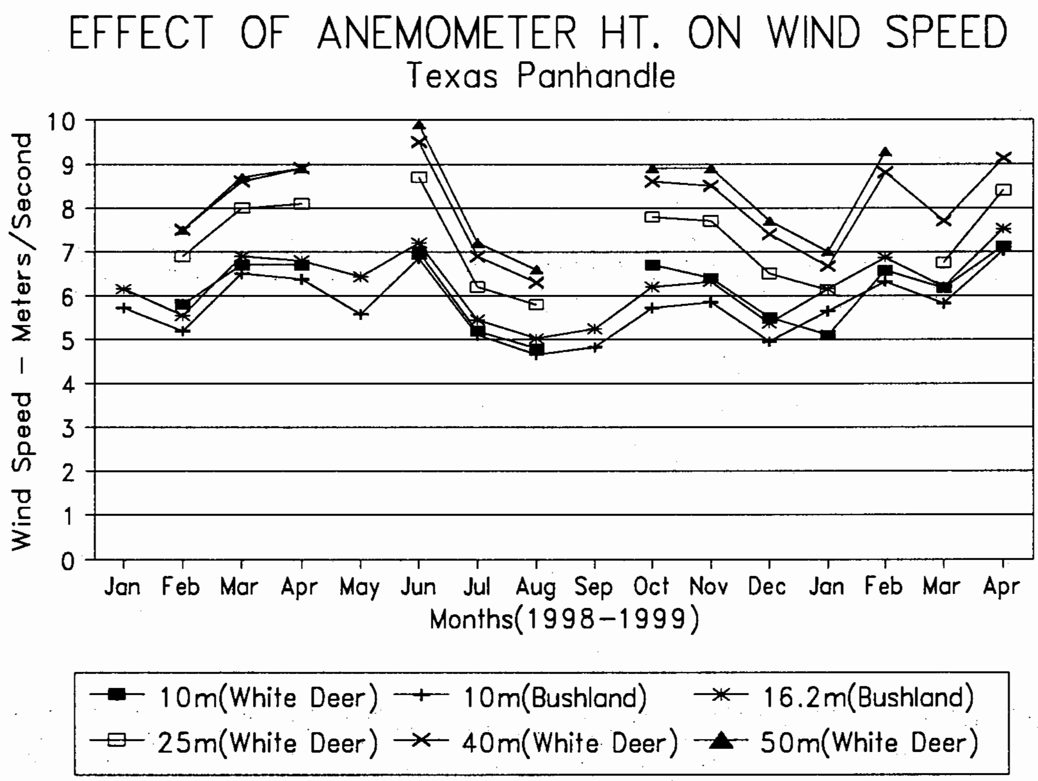

Figure 12. Effect of Anemometer Height on Wind speed for Two Locations in Texas Panhandle.

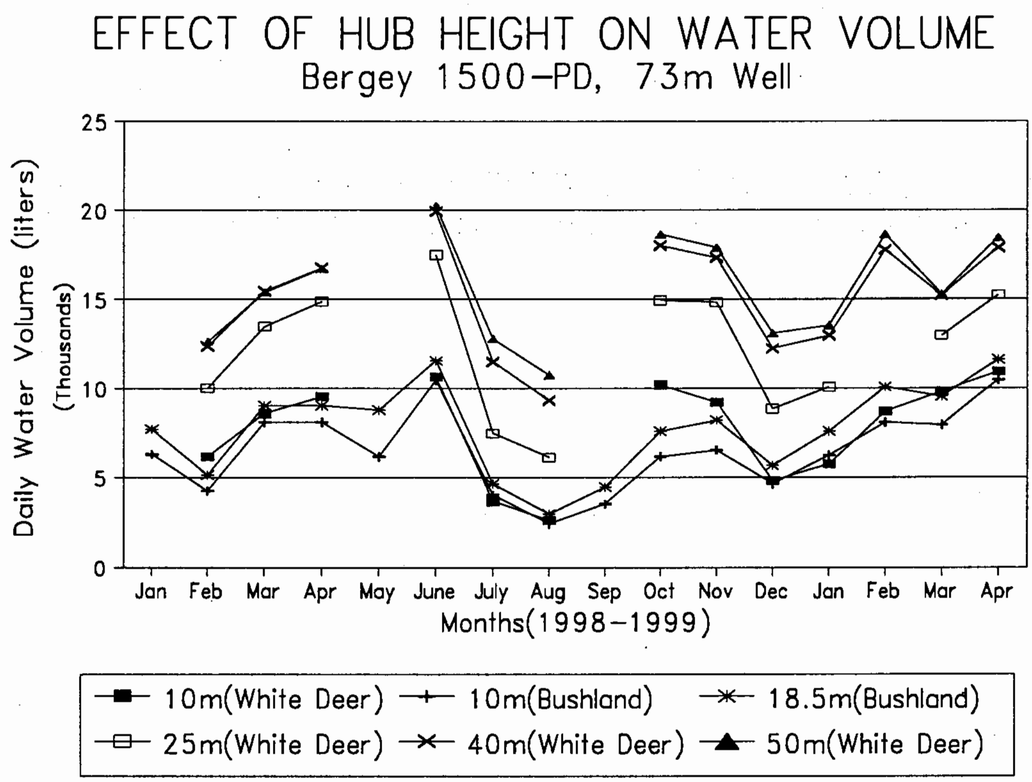

Figure 13. Effect of Wind Turbine Hub Height on Daily Water Volume for Bushland, TX and White Deer, TX.

CONCLUSIONS

A 1.5 kW wind-electric water pumping system was shown to provide enough water for 80 head of cattle from a 73m well during the fall, winter, and spring for a wind regime similar to that of the western half of the Texas Panhandle. During the summer months of July and August the wind-electric system could only provide a little over half the water required. It is estimated that a mechanical windmill with the same rotor diameter could have provided enough water from the same well for 80 head of cattle during all months of the year. The majority of the down time for the wind-electric system was caused by some problems with the ARS/AEI controller, but all those problems have been fixed. The performance of the wind-electric system was improved significantly by varying the capacitance with wind speed using the ARS/AEI controller. We were also surprised that increasing the capacitance from 55 µF to 70 µF resulted in a significant decrease in flow rate in the 7 to 10 m/s wind speed range. No down time was caused by the wind turbine or submersible motor and pump.

The most important discovery of the field testing of this wind-electric system was that not enough water was pumped in the low wind months during the summer. Ways of increasing the amount of water pumped during the summer for the wind-electric system included:

1) Pumping water in a storage tank during the higher wind months of spring and using this water to supplement the water supply during the summer
2) Increasing the height of the wind turbine in order to take advantage of the higher winds

3) Using a small 3ϕ gasoline generator to pump water whenever the water gets too low.

As for (1), the size of the storage tank would have been too expensive to supplement the water supply in the summer. Increasing the tower height to 31 m (100 ft) from 18.3 m (60 ft) would appear to solve the low water volume problem in the summer. The increased tower cost is $1100 from $1900 to $3000. Another option is to use a small 3ϕ gas generator to provide water during the low wind months. We estimate the cost of the 3ϕ gas generator to be $2600. Of course, if the wind turbine could be modified to have a lower cut-in wind speed, this would obviously be the best solution.

ACKNOWLEDGMENTS

We would like to thank the Alternative Energy Institute at West Texas A&M for supplying us the wind distribution data they gathered at White Deer, TX.

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