PERFORMANCE OF A SMALL WIND POWERED WATER PUMPING SYSTEM

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ABSTRACT

Lorentz[1] helical pumps (Henstedt-Ulzburg, Germany) have been powered by solar energy for remote water pumping applications for many years, but from Oct. 2005 to Mar. 2008 a Lorentz helical pump was powered by wind energy at the USDA-ARS Conservation and Production Research Laboratory (CPRL) near Bushland, TX. The wind turbine used was a Southwest Windpower (Flagstaff, AZ) Whisper 100 (2.1 m or 7 ft rotor diameter) which generated 3-phase variable voltage, variable frequency AC electricity. The wind powered version required an additional controller manufactured by Lorentz to rectify the electricity to DC before entering the primary controller. For the Bushland, TX site, the wind powered helical pump system demonstrated the ability to pump enough water at a 50 m (164 ft) pumping depth to meet the daily requirements of 120 beef cattle and 60 beef cattle at a 100 m (328 ft) pumping depth. Modifications of the controller(s) are still needed to make the wind powered system comparable to the reliability and durability of the solar powered units.

INTRODUCTION

Conergy (U.S. office in Santa Fe, NM) and Southwest Windpower asked USDA-ARS CPRL to evaluate a Lorentz helical pump for pumping water with a Southwest Windpower (www.windenergy.com) Whisper 100 wind turbine. The appropriate helical pump for the Bushland site (static water level 75 meters or 246 ft) was the HR07 helical pump. The requested pumping depths to be tested in the first year of testing were: 50, 75, 100, and 150 meters (different pumping depths were simulated with a back pressure valve). Using a variac (this allows the 3-phase AC voltage to be varied), the pump could be powered off 230 V 3-phase electricity from the utility grid to produce pump curves. Figure 1 shows pump curves collected during the helical pump testing at USDA-ARS CPRL. After approximately one year of testing, the pumping performance degraded significantly (compare pump curves labeled 10/24/2005 and 10/16/2006). At that time, Conergy decided that they did not want to continue the testing. When the technical specifications were evaluated for the helical pump on Lorentz website (www.Lorentz.de), and we realized the pumping design limit (120 m) of this helical pump had been exceeded, Bernt Lorentz (owner and designer of Lorentz helical pumps) was contacted to see if he wanted to continue with the testing. He did want to continue the testing, so Bernt Lorentz sent us another helical pump, pump motor, and updated PS1200 controller circuit

[1] The mention of trade or commercial products in this article is solely for the purpose of providing specific information, and does not imply a recommendation or endorsement by the U.S. Department of Agriculture.

boards. Lorentz sent a HR07-1 instead of a HR07-2 helical pump because they expected the performance would be better for the underground sump water temperature of 13°C (55°F) at Bushland. After approximately one year, another pump curve was collected and a slight degradation was observed; but then after 1.3 years the pump performance on this pump had also degraded significantly. This time we did not exceed the pumping depth design limit of 120 m and we are unsure why the wind powered Lorentz helical pumps degraded much faster than the solar powered Lorentz helical pumps, but we believe modifications of controller(s) could correct the deficiency.

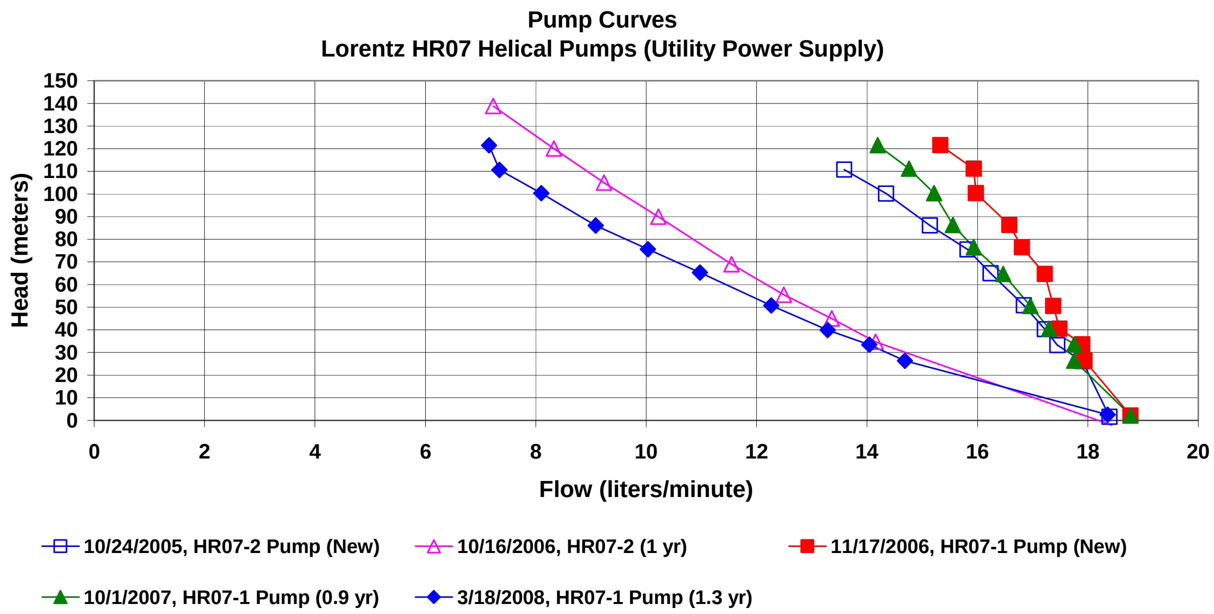

Fig. 1. Pump Curves of Lorentz Helical Pump Testing at USDA-ARS CPRL (Bushland, TX).

<u>Test Set Up and Instrumentation</u>

The Southwest Windpower (SWWP) Whisper 100 wind turbine was installed on a 15.2 m (50 ft) tower (see Fig. 2 and 3). The anemometer for wind measurement was located at the hub height of the wind turbine on a 30 m (100 ft) tower which was located 30 meters west of the wind turbine(WT) tower (tower with anemometer can be seen on right side of Fig. 3). A 3-way switch located in building at base of wind turbine tower could:

1. disconnect wind turbine from any electrical load
2. short phases of wind turbine to electrically brake the wind turbine
3. connect wind turbine electricity to 3-way switch in Wind Lab.

Fig.4 shows the 3-way switch in the Wind Lab and the controllers positioned between the wind turbine and the helical pump motor. This 3-way switch could do the following:

1. disconnect pump motor from any power source
2. connect pump motor to wind turbine
3. connect pump motor to utility via a variac

Fig.2. SWWP Whisper 100 Wind Turbine. (Bushland, TX).

Fig. 3. SWWP Whisper 100 Wind Turbine, WT Tower, and Met Tower (Bushland, TX).

The WSP600 controller rectifies the 3-phase AC electricity from the wind turbine or utility into DC. The PS1200 converts the DC electricity into a "Modified" AC before connecting to helical pump motor. The PS1200 controller is currently being used on the solar-PV water pumping systems (DC electricity is generated from a solar-PV array). There is a switch on this PS1200 controller for disconnecting the pump motor from the power source. There are also error codes displayed on PS1200 for trouble-shooting. Figure 5 shows the Lorentz helical pump and motor with helical pump shaft to the side. The helical pump motor turns the pump shaft in the rubber insert of the pump which produces a progressive cavity for the water.

The data collected on this water pumping system included:

1. Julian Day
2. Time (hour, minute, second)
3. Water flow rate (gallons/minute)
4. Water pressure (psig)
5. Hub height wind speed (m/s)
6. Wind turbine power (W)
7. Wind turbine electrical frequency (Hz)
8. DC Voltage from WSP600 to PS1200 (V)
9. DC Current from WSP600 to PS1200 (A)

The data were sampled every second and the average value over a one-minute period was stored. The data were then binned with wind speed (0.5 m/s wind speed bins) and the mean and standard deviation of each measured parameter was calculated. Other values calculated included highest daily wind speed, total daily water volume, etc. which were recorded in a log book. At least 500 one-minute samples were obtained in each 0.5 m/s wind speed bin over the wind speed range of 4 to 10 m/s for each pumping depth. Occasionally, one-second data were recorded to evaluate the controller operation. Noise data were also collected for a few days, but not enough data were collected to display a graph. However, the noise coming from wind turbine was not excessive (didn't exceed 70 dB) unless the PS1200 controller unloaded the wind turbine.

Fig.4. 3-Way Switch and Controllers Used on Wind Powered Water Pumping System. (Bushland, TX).

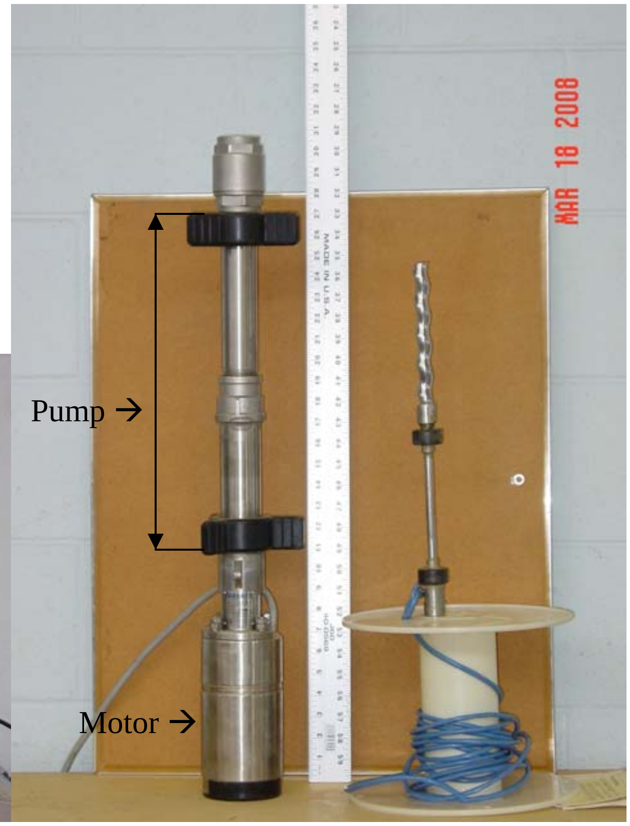

Fig. 5. Lorentz Helical Pump and Motor with Pump Shaft on Right (Bushland, TX).

RESULTS

Pumping Performance of Wind Powered Helical Pump System

All wind turbines have some type of aerodynamic and/or electrical loading capability to prevent the wind turbine from going into overspeed. The yaw axis is offset from the tower axis of the Whisper 100 which allows the wind turbine to furl (i.e. yaw out of the wind) at some wind speed. According to Fig.6, the wind turbine is furling (evident by decrease in rotor speed) at a wind speed of 12 to 13 m/s for pumping depths of 50 to 100 m. For a 150 m pumping depth the Whisper 100 furls at a higher wind speed (13 to 14 m/s) which is expected (higher electrical loading usually results in a higher furling wind speed).

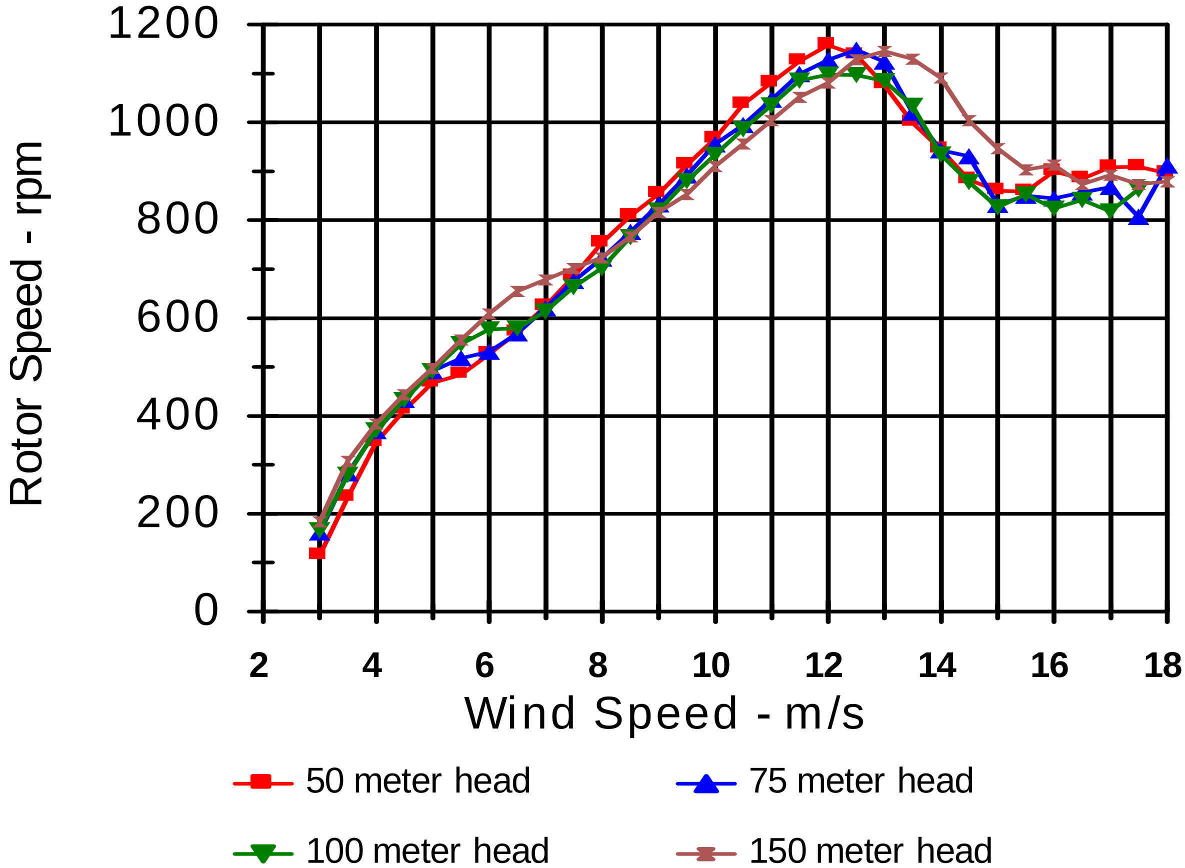

Fig.6. Measured Wind Turbine Rotor Speed of SWWP Whisper 100 Wind Turbine Connected to Lorentz HR07-2 Pump Motor (Bushland, TX).

The DC voltage and current measured between the WSP600 and PS1200 controllers are shown in Fig.7 and 8, respectively. The DC voltage curve shape with respect to wind speed is very close to that of the rotor speed except for the 150 meter pumping depth at high wind speeds. The DC current begins a rapid rise at a higher wind speed for deeper pumping depths (later we will see that these wind speeds correspond to cut-in wind speeds for when water is pumped). As the pumping depth increases the peak maximum current also increases and occurs at a higher wind speed.

Figure 9 shows the DC power as a function of wind speed and pumping depth. The amount of DC power required for each pumping depth increases until either the controller regulates the input power to the motor or the wind turbine begins to furl which causes the power to remain constant or decrease with increasing wind speed. The amount of DC power regulated by the controller to the pump motor varies from 300 to 500 W (50 to 150 pumping depths, respectively). Figure 10 shows the measured power of the Whisper 100 wind turbine as a function of wind speed and pumping depth. The peak power generated by the Whisper 100 wind turbine varies from 400 to 700 W (50 to 150 m pumping depths, respectively). It is evident from a comparison of Fig. 9 and 10 that there is a significant loss in power across the WSP600 controller.

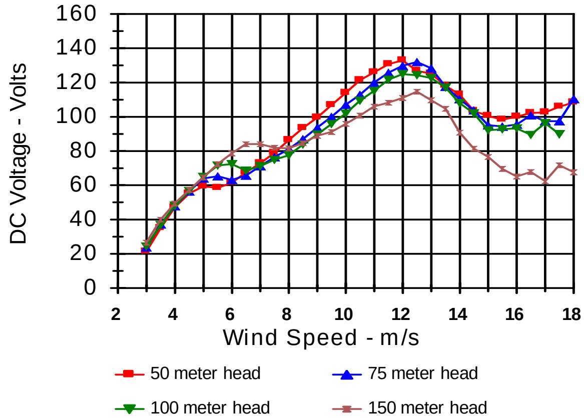

Fig. 7. Measured DC Voltage between WSP600 and PS1200 Controllers (Bushland, TX).

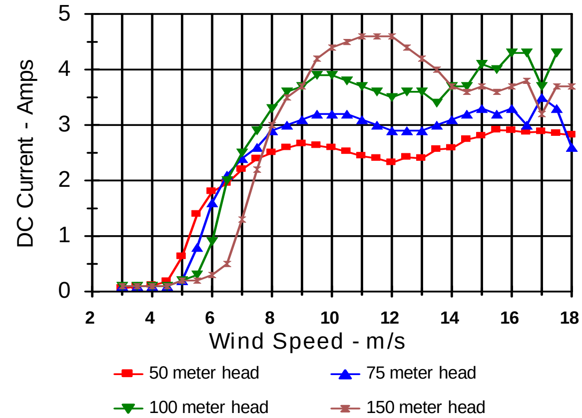

Fig. 8. Measured DC Current between WSP600 and PS1200 Controllers (Bushland, TX).

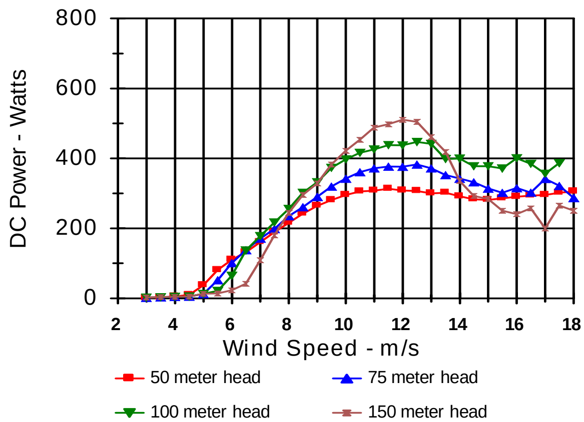

Fig. 9. Measured DC Power between WSP600 and PS1200 Controllers (Bushland, TX).

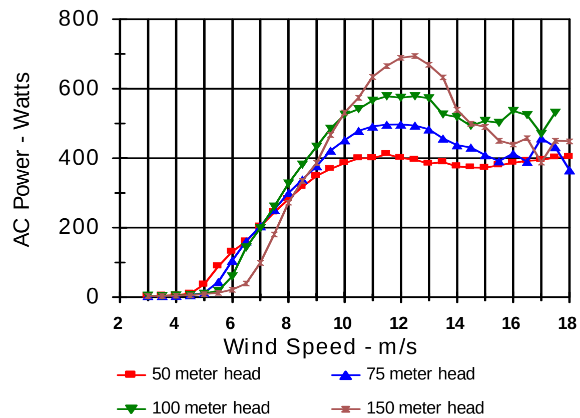

Fig. 10. Measured AC Power of SWWP Whisper 100 Wind Turbine (Bushland, TX).

Figure 11 shows the flow rate of the Lorentz HR07-2 helical pump with the SWWP Whisper 100 wind turbine. The flow rate with respect to wind speed and pumping depth appears well behaved up to the furling wind speed (12 to 14 m/s), but for higher wind speeds the flow rate does not appear to be predictable. Since most of the time the wind speed is below the furling wind speed then estimations of daily water volume should be accurate. For Bushland, TX (a class 4 wind site), the average percentage of time exceeding this furling wind speed at a 18.5 m (60 ft) height is only 3%. It should also be noted that off time was removed for the 75 m pumping depth above a wind speed of 10 m/s since the controller (s) were disconnecting wind turbine from helical pump more of the time then when data were collected at the other pumping depths. Additional discussion on this topic can be found in the section labeled “Lorentz Controller Analysis”. Figure 12 shows the predicted monthly daily volume for Bushland, TX for the SWWP Whisper 100 wind turbine at an 18.5 m (60 ft) hub height with the Lorentz HR07-2 helical pump. This monthly distribution of daily volumes is fairly typical of the Great Plains (i.e. highest water volumes in the spring and lowest in the summer). The number of cattle that can be watered is defined by the minimum daily water volume which occurs in August. Assuming each beef cow requires 50 liters (13.5 gallons) of water per day, the number of cattle that can be watered varies from 60 (100 m pumping depth) to 120 (50 m pumping depth). To estimate daily volumes at other locations with other hourly wind speed distributions, below is a table showing the wind speed and flow rate.

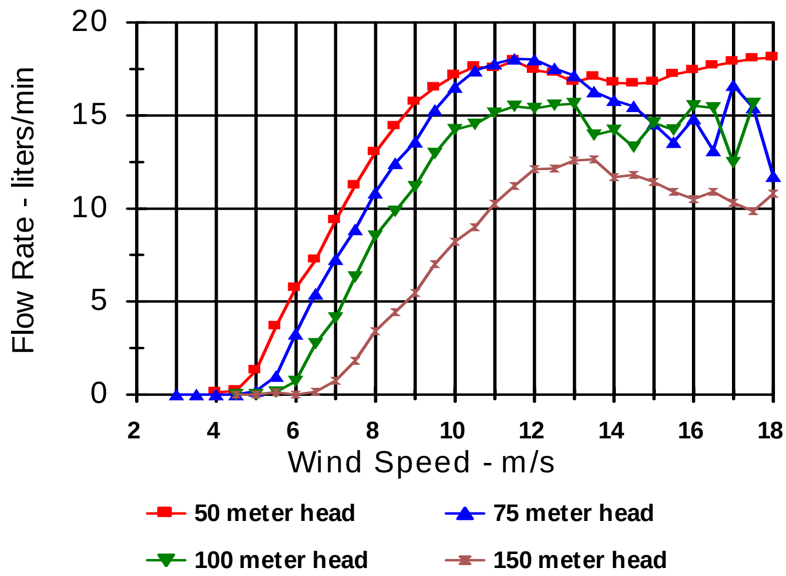

Fig. 11. Flow Rate of Lorentz HR07-2 Helical Pump Powered by SWWP Whisper 100.

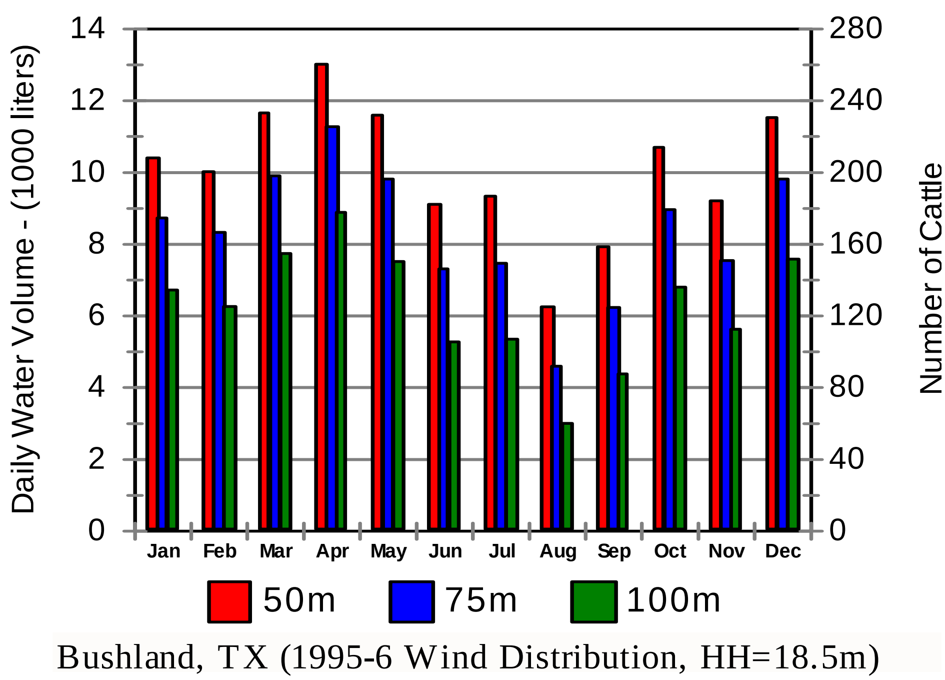

Fig. 12. Daily Water Volume of Lorentz HR07-2 Helical Pump Powered by SWWP Whisper 100.

Table 1. Flow Rate of Lorentz HR07-2 Helical Pump Powered by SWWP Whisper 100.

	50 m	75 m	100 m		50 m	75 m	100 m
Wind	Flow	Flow	Flow	Wind	Flow	Flow	Flow
Speed	Rate	Rate	Rate	Speed	Rate	Rate	Rate
(m/s)	(lpm)	(lpm)	(lpm)	(m/s)	(lpm)	(lpm)	(lpm)
4	0.1	0.0	0.0	10.5	17.6	17.4	14.5
4.5	0.2	0.2	0.0	11	17.5	17.8	15.1
5	1.3	0.2	0.0	11.5	18.0	18.1	15.5
5.5	3.7	1.0	0.1	12	17.4	18.0	15.4
6	5.7	3.3	0.7	12.5	17.3	17.5	15.6
6.5	7.2	5.5	2.7	13	16.8	17.2	15.6
7	9.4	7.4	4.1	13.5	17.1	16.3	14.0
7.5	11.2	8.9	6.3	14	16.8	15.8	14.2
8	13.0	10.9	8.5	14.5	16.7	15.5	13.3
8.5	14.4	12.4	9.9	15	16.8	14.6	14.6
9	15.7	13.5	11.2	15.5	17.2	13.6	14.2
9.5	16.5	15.3	13.0	16	17.4	14.8	15.5
10	17.2	16.5	14.2				

Efficiency

It is important to evaluate the efficiency of the components of the system in order to determine where improvements can be made. Figure 13 shows the power coefficient of Whisper 100 wind turbine when connected to Lorentz helical pump. The peak power coefficient varies from 0.29 to 0.33 over a wind speed range of 6 to 9.5 m/s for the different pumping depths. These peak measured power coefficients are fairly typical of those measured on small wind turbines (Vick, 1998 – ASAE & ASME, and Vick, 2003, Clark, 2008). Possibly improvement in wind turbine efficiency could be obtained with additional electrical loading (Neal, 2007). Figure 14 shows the ratio of DC power to AC power. The accuracy of the AC power transducer below 200 W appears questionable since below this level this ratio exceeds 1. However it appears that at most wind speeds above 8 m/s there is a 20 to 25 % conversion loss from 3-phase AC power to DC power. Other rectifiers (Vick, 2003) measured on other small stand-alone systems have shown better conversion efficiency. Obviously higher conversion efficiency from AC to DC would result in better pumping performance.

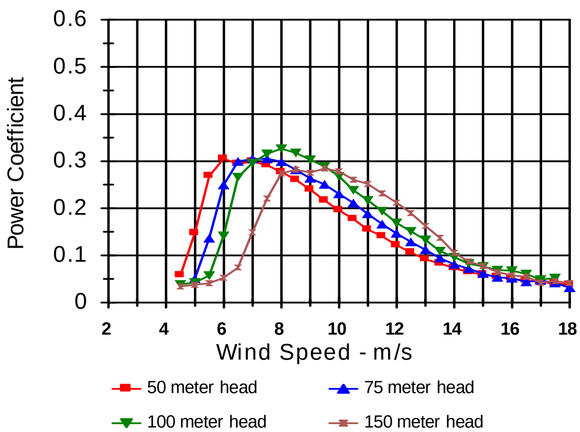

Fig. 13. Power Coefficient (Cp) of SWWP Whisper 100 with Electrical Loading of Lorentz HR07-2 Helical Pump.

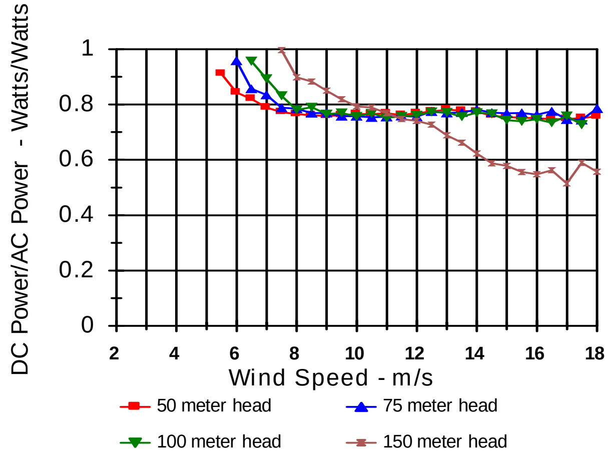

Fig. 14. Ratio of DC to AC Power for Lorentz Controller Efficiency Estimation.

The pump efficiencies of the Lorentz helical pump varied between 40 and 70% for most wind speeds at pumping depths of 50 to 100 m. This level of pump efficiency was about the same as that measured on similar size/type pumps (Vick, 2005). The peak pumping efficiency occurred at higher wind speeds as the pumping depth increased. Interestingly, as the pumping depth increased, the pumping efficiency continued to increase with wind speed (we are unsure why). System efficiency is a measure of the total efficiency from wind energy to water pumped. Figure 16 shows the system efficiency for all the pumping depths measured. This water pumping system was most efficient in the 75 to 100 m pumping depth range. The peak system efficiency was 12% in this pumping depth range which was very good, but this water pumping system should be able to achieve higher values with improvements in the controller(s).

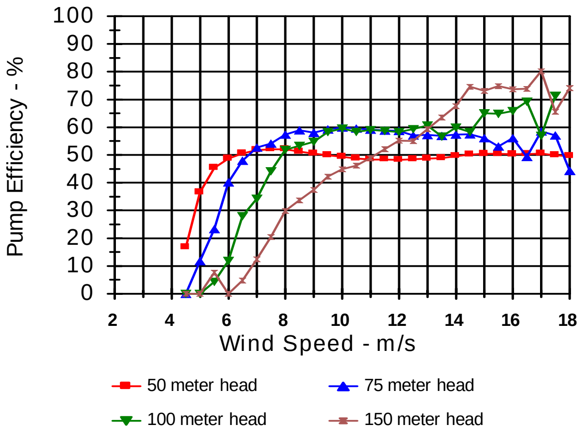

Fig.15. Pump Efficiency of Lorentz HR07-2 Helical Pump.

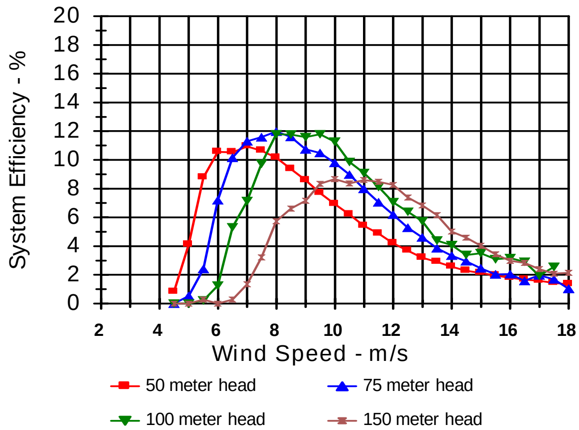

Fig. 16. System Efficiency of Lorentz HR07-2 Helical Pump with SWWP Whisper 100 Wind Turbine.

Lorentz Controller Analysis

After testing the HR07-2 Lorentz helical pump, additional testing was performed on another Lorentz helical pump (HR07-1). Both these pumps were similar and should perform about the same. Fig.17 shows a comparison of flow rates for a 50 m pumping depth for these two pumps during different time periods. During the period Nov.2006 to Jan.2007 the HR07-1 pump performance varied significantly from that measured on the HR07-2 pump for wind speeds above 10 m/s. Additional data collected on the HR07-1 pump from Feb.2007 to Apr.2007 closely approached the data measured on the HR07-2 pump. In Fig.18 the same data in Fig.16 were binned with wind speed except flow rate data below 4 lpm were excluded. All of the data now (both HR07-1 and HR07-2) approximated the same flow rate curve. This coalescence of the data indicated there were data collected when the helical pump wasn't pumping.

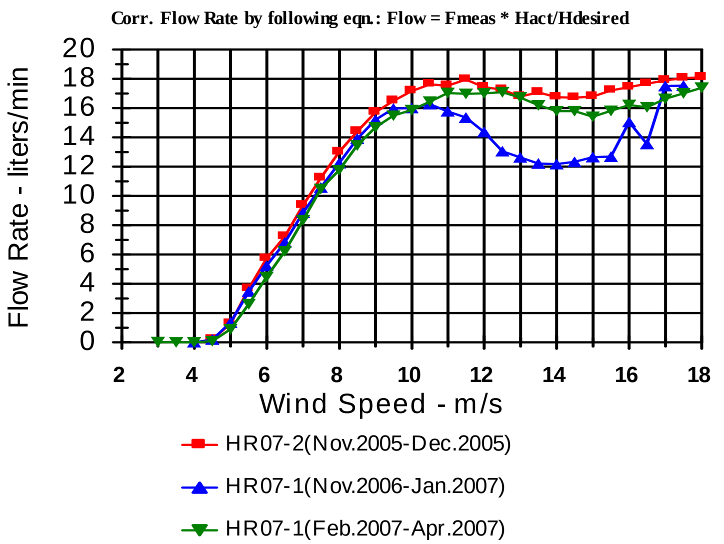

Fig. 17. Flow Rate of Lorentz HR07-2 & HR07-1 Pumps at 50 m Head.

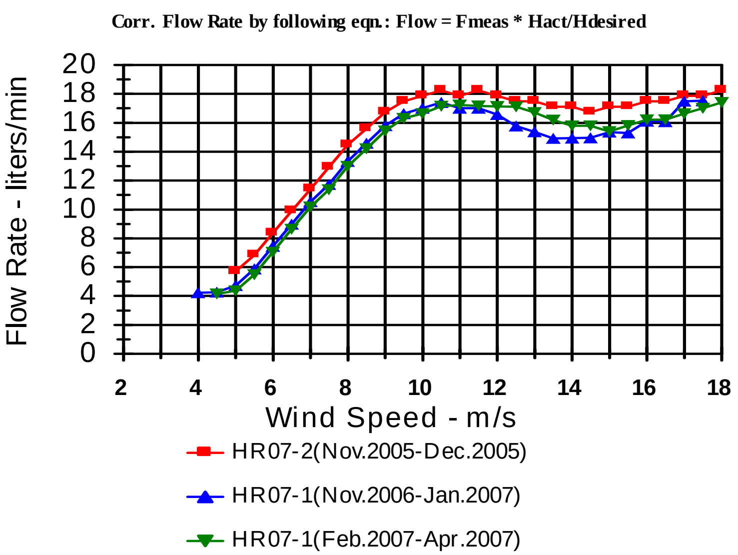

Fig. 18. Flow Rate of Lorentz HR07-2 & HR07-1 Pumps at 50 m Head, only Flow Rate > 4 lpm.

Fig.19 shows a time series of flow rate and wind speed on New Years Day in 2006. The water pumping system behaved very well from midnight to noon. However, from noon to 2 p.m., 3 p.m. to 3:30 p.m., and 4:10 p.m. to 5 p.m. there are periods when the helical pump is not pumping although at these same wind speeds earlier in the day the helical pump performed well. The PS1200 controller is responsible for disconnecting the wind turbine from the helical pump motor. There was no particular wind speed range that the controller would disconnect the pump motor, but generally the controller disconnected the wind turbine more often in the afternoon (possibly due to more turbulent winds). We also believe that the switching on and off of the helical pump and motor may be the cause of the pump and/or motor damage. We believe this is causing damage because switching any motor on and off repeatedly will result in shortening its lifetime.

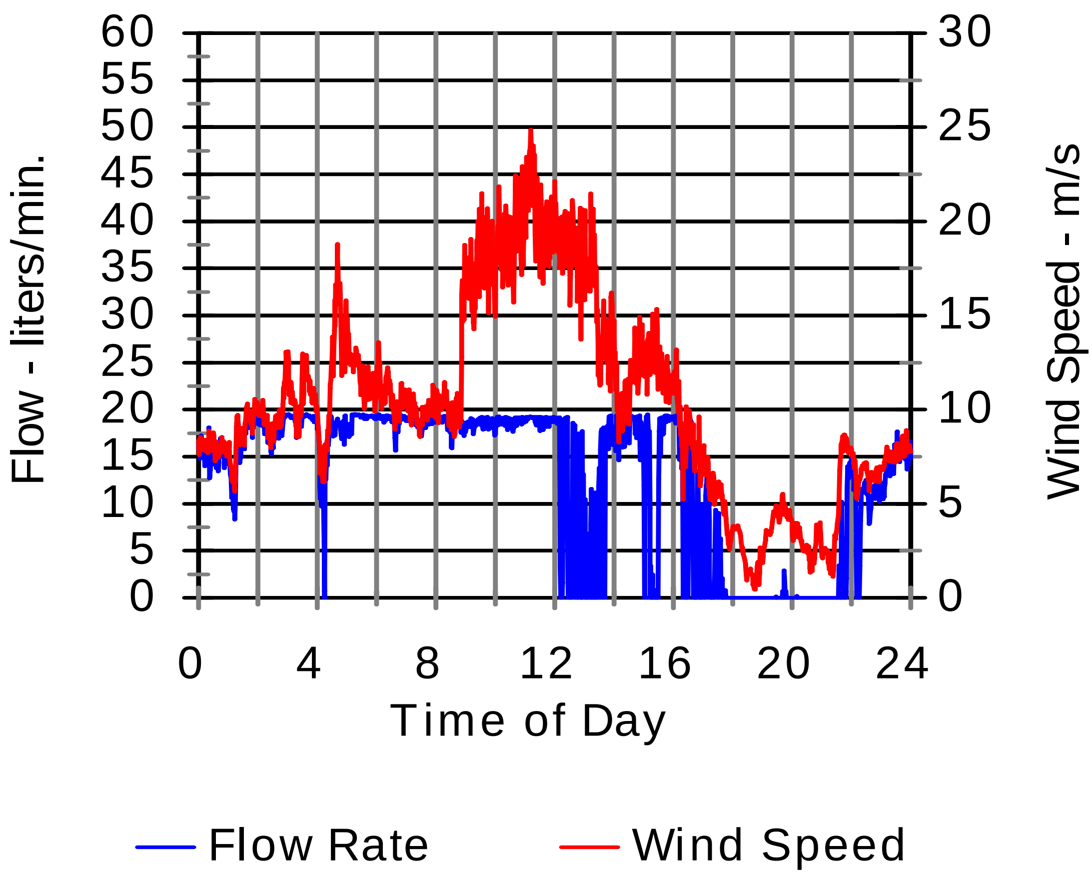

Fig. 19. Time Series of Wind Powered Lorentz HR07-2 Helical Pump (Jan. 1, 2006).

CONCLUSIONS

A helical pump which has been powered by solar-PV modules was powered by a small (2.1 m or 7 ft blade rotor diameter) wind turbine over a 2.3 year period. The pumping performance measured was very good at demonstrating an ability to pump enough water at a 50 m pumping depth to water 120 cattle and at a 100 m pumping depth to water 60 cattle. The peak power coefficient measured of the wind turbine was 0.33 (typical of a small wind turbine). The pump efficiency varied between 40 and 80% depending on the pumping depth. The peak total system efficiency was 12% for pumping depths of 75 and 100 m. Additional system efficiency improvement is probable with modifications to the controller. Although measured performance was good for this wind powered water pumping system, the longevity of this system is still unknown.

ACKNOWLEDGEMENTS

We would like to thank Adam Holman and Donny Cagle (West Texas A&M University - Alternative Energy Institute) for helping with the installation, instrumentation, maintenance, and data processing of this system.

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