Irrigation Pumping with Wind Energy—Electrical vs. Mechanical

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ABSTRACT

DURING the past few years, researchers have been examining new wind energy systems to pump the large volume of water needed for irrigation. One new system uses a vertical-axis wind turbine to generate electricity that is compatible with utility grid power, and the pump is powered by this electrical system using a conventional electric motor. Another new system uses a vertical-axis wind turbine to produce mechanical power, and the pump is powered directly with this mechanical power or in combination with a diesel engine or electric motor.

When the efficiency of converting wind energy to pumped water is compared for the two systems, the mechanical system provides 12% more energy than the electrical system. However, the electrical system is 2.5 times more profitable than the mechanical system because irrigation pumps are used seasonally. With the electrical system, energy generated in the non-irrigating season can be sold to the utility, but the mechanical system is only utilized when water is needed.

INTRODUCTION

Irrigation is a major energy user in on-farm agricultural production requiring an estimated 90 billion kWh of energy each year. Electricity, natural gas, and diesel fuel are the major forms of energy used in pumping irrigation water. Irrigation pumping energy accounts for 40 to 70% of the energy used on farms where irrigation is practiced. Irrigation pumps often lift water at least 50 m and require between 20 and 100 kW in the Great Plains region of the United States. Irrigation pumps in the Great Plains have flow rates between 30 and 50 L/s with wells in the northern areas having higher flow rates than wells to the south.

Windmills have been used since the 1870's to pump livestock and domestic water in the Great Plains, but are inadequate for the large water needs of irrigation. Pumping capacities of the multibladed windmills commonly range between 0.25 and 0.50 L/s (New Mexico Energy Institute, 1978), barely enough water for a vegetable garden. Because these old, proven, and reliable multiblade systems will not provide sufficient water for irrigation, researchers have selected new wind systems that utilize the aerodynamic lift principle.

Wind energy systems convert the kinetic energy in wind to mechanical power through a rotating rotor. This mechanical power can be either used directly to power irrigation pumps or can be converted to electrical energy and used to power electric motors. This study is a comparison between pumping water with a mechanical wind system and an electrical wind system.

MECHANICAL WINDPOWERED PUMP

An irrigation pumping system, using a high-speed vertical-axis wind turbine, was developed by USDA-ARS Engineers at Bushland, TX. Details of this design and performance of the system have been presented by Clark and Schneider (1980) and Clark et al. (1981B). The system consisted of a two-bladed vertical-axis wind turbine erected on a 9.1 m stand-alone tower. The blades were symmetrical airfoils with a 356 mm chord length, creating a rotor 16.7 m high with an equatorial diameter of 11.5 m. When the wind turbine was producing power, the rotor turned at a steady speed of 81 rpm. A right-angle speed increasing gearbox and timing belt were used to increase the shaft speed to 1780 rpm (Fig. 1). The pumping system consisted of a deep-well turbine pump and a 3-phase induction, vertical, hollow-shaft electric motor. A combination gear drive (Fig. 1) was used

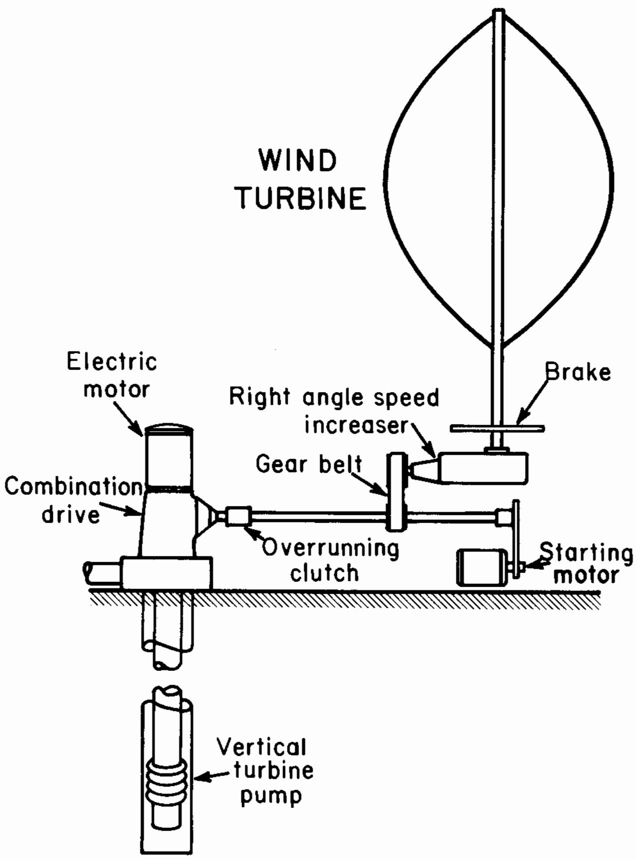

Fig. 1—Schematic of a mechanical drive vertical-axis pumping system.

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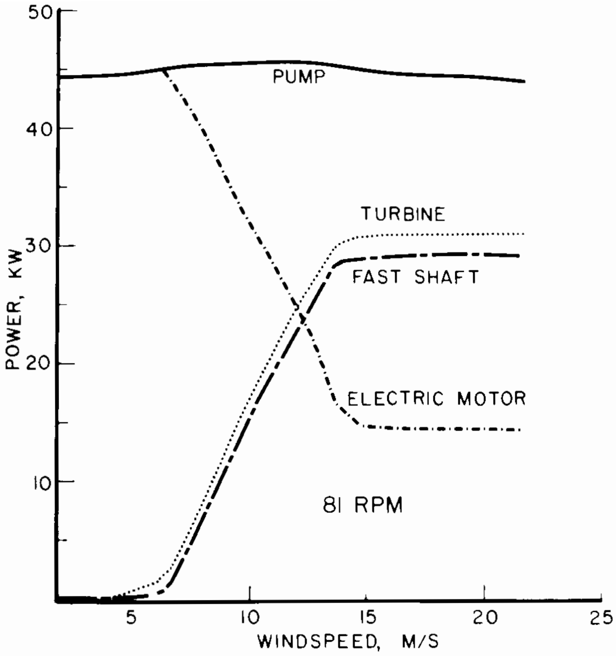

Fig. 2—Mechanical wind turbine system power, rotor power, electric motor power, and pump system power when rotor speed was 81 rpm (Clark et al., 1981B).

between the electric motor and pump, allowing power to be supplied from both the wind turbine and electric motor. Mechanical power from the wind turbine was supplied to the pump through an overrunning clutch to the combination gear drive. This mechanical power from the wind reduced the load on the electric motor, resulting in a saving of electrical energy.

Power measurements were made at several locations in the system. Mechanical power was measured at the base of the wind turbine rotor (turbine power) and in the high-speed wind turbine shaft (fast shaft). Electric power used by electric motor and water power applied by the pump were also recorded. Throughout all testing, the pumping lift remained fairly constant at 104 m and water flow averaged 21 L/s. Performance data was collected as 15-s averages and grouped by windspeeds for analysis by the method of bins.

Fig. 2 shows the power produced, transmitted, or consumed by each component of the pump system. Each curve contains over 50,000 data records collected over several months. The power produced by the wind turbine is shown both as low speed rotor power (turbine) and as high speed power transferred to the pump (fast shaft). The difference between these two curves represents the losses that occurred in the gearbox and timing belt drive. Losses averaged less than 10% over the whole operating range from 0 to 30 kW. Therefore, at least 90% of the power produced by the wind turbine rotor was utilized by the pump.

The electric motor power curve indicates the potential savings that are possible from using a wind turbine pumping system in a fuel saver mode. The pump power curve is the mechanical power input to the pump and indicates that the system did provide constant power to the pump.

ELECTRICAL WINDPOWERED PUMP

Electricity was provided to an irrigation pump from a vertical-axis wind turbine with an induction generator.

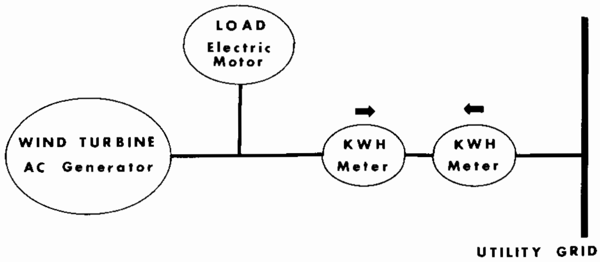

Fig. 3—Schematic of an electrical system for powering an irrigation pump (Clark et al., 1981A).

This wind turbine had a rated output of 100 kW at a windspeed of 15 m/s. Its two blades had a chord length of 610 mm, a height of 26 m, and an equatorial diameter of 17 m. The rotor operated at a near constant speed of 48 rpm in order to provide a near constant speed to the generator. A speed increasing gearbox with a ratio of 37:1 was used to increase the rotor shaft speed to synchronous generator speed.

The induction generator, which is an AC induction motor driven above its normal synchronous speed, required connection to the utility grid. The field of the generator is excited from the utility line, thus providing 60 cycle, AC electrical power that is in-phase with the utility power. The electrical irrigation pump motor was connected between the wind turbine generator and the utility power meters as shown in Fig. 3.

Data was collected similarly to that described for the mechanical pumping system except that individual samples were used rather than a 15-s average. Almost 400,000 data points were used in the data analysis to determine the performance of the electrical system. The power produced by the rotor was measured with a torque sensor located between the rotor and gearbox and is shown in Fig. 4 as rotor output. The power curves were similar for both wind turbines, but the electrical unit produced almost three times as much power because of its larger size. The electrical power delivered to the irrigation motor or to the utility grid from the wind turbine is also shown in Fig. 4. The difference between the two curves represents the power losses incurred in the speed increaser and induction generator. These losses averaged about 12% over the range from 0 to 100 kW, and were rather uniform above 50 kW. The total losses

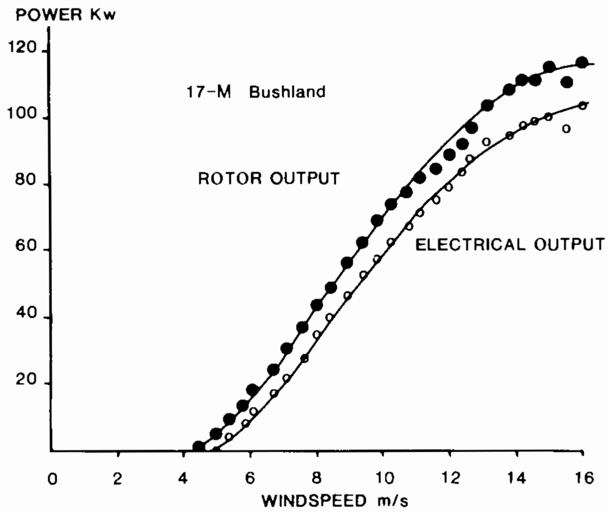

Fig. 4—Electrical power and rotor power from a vertical-axis wind turbine with induction generator.

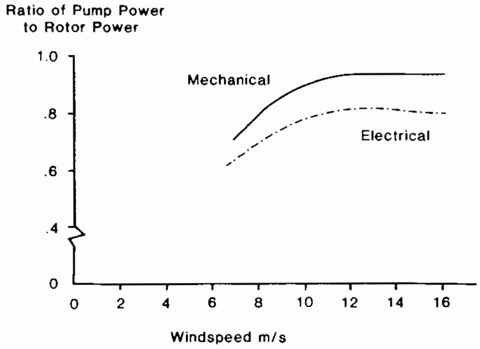

Fig. 5—Ratio of pump power to wind turbine rotor power for a mechanical and electrical wind powered pumping system.

between the wind turbine rotor and irrigation pump were calculated, assuming that a 3-phase electric motor has an efficiency of 90%. Thus, the power delivered to the irrigation pump was calculated to be 80% of the measured rotor power.

MECHANICAL vs. ELECTRICAL

The ratio of power delivered at the pump to power produced by the wind turbine rotor was compared for the mechanical and electrical systems (Fig. 5). The ratios of each system became constant after the wind units reached rated power; this provided the best comparison. The mechanical system provided approximately 92% of the wind turbine power to the pump, while the electrical system provided 80%. Therefore, when operating at rated power, a mechanical system provides 12% more power to the pump than an electrical system. When the systems operated at windspeeds below 8 m/s, they normally produced less than 30% of rated power and the relative efficiency of the system dropped rapidly. Even at the low windspeeds, the mechanical system maintained a higher transfer of power than did the electrical system.

The differences in power transfer cited in this experiment should be a minimum difference because of the use of the timing belt in the mechanical system. Gearbox efficiencies normally range between 95 and 98% while timing belts normally range between 90 and 95%. The gearboxes used on both wind turbines were similar and from the same manufacture. Gearboxes of the same model had a measured efficiency of 97.5% (H. F. Thibodeau, personal communication); therefore, most of the power loss in the mechanical system was in the timing belt.

Wind turbines have a high initial cost and low operating cost; therefore, it is necessary to operate the system as much as possible for maximum economic return. Irrigation pumping is a seasonal use depending on location and crops grown, but rarely exceeds 3000 h per year. A typical yearly irrigation pumping schedule is shown in Fig. 6 for the Southern Great Plains when winter wheat, grain sorghum, and cotton are irrigated. Total operational time in this example is 2000 h. Table 1 contains the monthly average windspeeds and wind power typically encountered in the Southern Great Plains. These data were determined from 17 years of NOAA data measured at a 7 m height. Windspeed and wind power would be greater at hubheight of the wind turbine.

A breakeven cost was determined for operating several wind-powered irrigation systems by Landsford et al. (1980). They determined the amount that one could afford to invest for average wind and pumping conditions under three energy price projections and two discount rates over a 20-year period. Fig. 7 shows the breakeven cost as determined by Landsford et al. (1980) for mechanical and electrical system, which are similar to those described in this paper. Energy price projects were based on a 4% per year increase compounded annually, and a discount rate of 10% was used. For the electrical system, a buy-back rate of 60% of retail was used for surplus electricity.

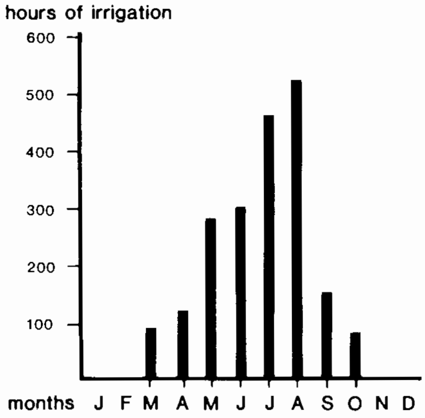

Fig. 6—Hours per month that an irrigation well is pumped on a typical Southern Great Plains farm.

TABLE 1. AVERAGE MONTHLY WINDSPEEDS AND AVERAGE POWER IN THE WIND STREAM AT 7 M FOR THE SOUTHERN GREAT PLAINS

Month	Average wind speed — m/s —	Average power W/m
January	6.4	400
February	6.8	430
March	7.9	530
April	8.0	520
May	7.3	460
June	7.1	410
July	6.2	260
August	6.3	230
September	6.3	280
October	6.6	320
November	6.5	320
December	6.6	330

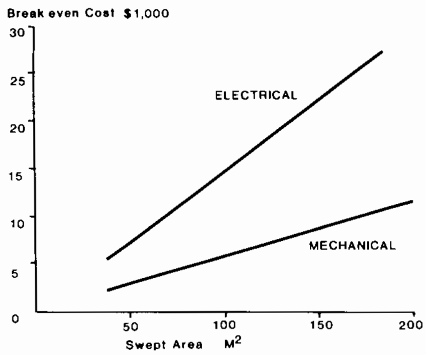

Fig. 7—The variation in breakeven cost of a wind powered pumping system with wind turbine rotor area (Landsford et al., 1980).

The electrical system has a higher breakeven cost because it operates not only during the irrigation season, but all year. Although the excess electricity is sold at a wholesale rate to the utility, the electrical system operates enough extra hours to make it more profitable than the mechanical system.

Assuming a rotor area of 150 m², one could afford to invest $9,000 for a mechanical system or $22,000 for an electrical system. The difference in breakeven cost would be reduced in areas where pumping times are greater or when other uses could be made of the mechanical wind power.

CONCLUSIONS

Irrigation water can be supplied satisfactorily by high-speed vertical-axis wind turbines. A mechanical wind-powered system provide about 12% more power to the pump than an electrical system in a given wind. Energy was lost in the conversion from mechanical power to electricity and electricity back to mechanical power. However, because irrigation pumps are used seasonally, usually less than one quarter of a year, mechanical wind systems may require as much as 2.5 times as long to pay for themselves as do electrical systems. Becuase of the high initial cost of wind systems and the relative low operating cost, wind systems must be operated as many hours as possible to provide a good economic return. Although the mechanical pumping system may be more energy-efficient than the electrical system; the electrical wind system appears to be more economically viable.

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