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Load Matching Wind-Generated Electricity to Great Plains Agriculture

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SUMMARY:

The wind-assist electric system requires power from the utility during periods of low windspeeds and produces excess power during periods of high windspeeds when used with a constant load. The size of generator needed for a wind system should be based on the ability of the wind turbine to meet the demands of the load. Two wind systems with a 40 kW and a 60 kW induction generator but identical rotors were operated. The system with the 40 kW generator supplies 7% more energy to a 25 kW load than a system with the 60 kW generator in an average windspeed of 6.5 m/s.

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Load Matching Wind-generated Electricity to Great Plains Agriculture [1/]

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ABSTRACT

The interest in wind energy is increasing as conventional energy sources cost increase. Wind energy has been used for centuries to pump water and grind grain. Agriculture in the Great Plains of the United States has benefited in the past from wind produced electricity and can benefit in the future.

A wind turbine which produces electricity has lower overall efficiency than a mechanical system, but offers more flexibility in adapting to varying load demands and in site selection. The induction generator, which is normally excited by the electric utility, is the most popular wind turbine generator. A synchronous generator is normally used with a synchronous inverter to produce utility compatible power.

Performance characteristics of the modern wind turbine are presented. Data are supplied to develop the criteria to match the wind turbine size to the agricultural load. A wind system should be selected on its ability to supply the power needed, not on peak power output.

INTRODUCTION

The development of the modern wind turbine began in the 1970's. The transitition from prototype to production unit in the 1980's was rapid with over 10,000 units sold by 1985. The mass production of the modern wind turbine has been primarily for "wind farms" in California where hundreds of machines, grouped together, supplying power to the utility. Electrical wind machines took "root" in the United States with rural agriculture in the 1930's and have the potential to do so once again.

A machine which converts wind energy to electricity has a lower overall efficiency than a mechanical system, but offers more flexibility in adapting to varying load demands and in site selection. The induction

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generator, which is normally excited from the electric utility, is the most popular wind turbine generator. Wind machines that use a synchronous generator normally require a synchronous inverter to connect with the utility.

Farmers are now considering ways to produce power with renewable energy systems which will displace electricity purchased from the utility (Mullan and Gage, 1984). A wind turbine connected to a utility, operates in a wind-assist mode, supplying power to the loads with the excess being passed through the meters into the utility. If additional power is needed, it will be purchased from the utility. The wind-assist system advantages over a wind-alone system are: 1) power can be supplied to a load during the time it is needed regardless of windspeed, 2) constant power to a load should maintain good efficiency, 3) the system can be easily adapted to existing installations. Major disadvantages of the electrical wind-assist concept include: 1) it requires a connection to the electric utility which may not be practical due to the remote location and associated high cost, 2) the wind system may not reduce the peak demand on the utility.

The reliability of the modern wind turbine has increased where an availability of 95% is attainable (Clark and Vosper, 1984). Devices to control demand as described by Hiatt and Endahl (1984) can be used in combination with a renewable energy to provide load management.

SYSTEM FUNDAMENTALS

The induction generator is similar to an induction motor but operated above its synchronous speed. A gearbox is used to increase shaft speed between the rotor and the generator. The rotor essentially operates at a constant rotational speed while the generator output matches the voltage and frequency of the utility. Rotor efficiency is a function of the speed of the tip of the blade (tip-speed) to the windspeed (TS/WS), therefore its efficiency will vary with windspeed. Each blade airfoil has its own specific characteristic. Figure 1 is representative of a typical modern wind system. The ratio for the transmission is selected to achieve a peak rotor efficiency at a specific windspeed (Seale, 1983). Rotor diameter is most critical parameter is determining the capability of the system. Maximum return on investment calls for a more conservative design than maximum energy recovery criteria would dictate.

A Rayleigh probability distribution with the annual average windspeed is normally used to predict windspeed distribution unless candiadate site data are availiable. The Rayleigh distribution takes the form:

$$\text{Hours} = 8{,}760 \times (3.1416/2) \times (V/\bar{V}^{2}) \times e^{-k}$$

where V = windspeed

$\bar{V}$ = mean windspeed
e = 2.718

$$k = (3.1416/4) \times (V/\bar{V})^{2}$$

Figure 2 shows distribution of windspeeds with an average annual of 6.5 m/s, which could be a candidate site in the Great Plains. The windspeed with the highest occurence is 5.0 m/s which would occur 512 hours in a year for an average windspeed of 6.5 m/s.

Wind systems have been operated at the USDA Conservation and Production Laboratory, Bushland, Texas, with the same rotor but different sized induction generators. Table 1 contains the specifications of the wind systems operated. The wind turbines, with a 13.4 m rotor, have been operated with a 40 kW and a 60 kW three-phase induction generator at rotor rotational velocities of 56 and 67 r/min, respectively. The power curves for the two wind systems are shown in Figure 3. Peak system efficiency was 43.2% at 6.5 m/s for the 40 kW system and 46.8% at 8.5 m/s for the 60 kW system. System efficiency includes losses in the rotor, gearbox, and generator because of the higher rotational velocity. Cut-in windspeed is higher for the system with the larger generator. Both machines have been operated for extended periods of time to prove the validity of the power curve.

SYSTEM PERFORMANCE

The predicted energy from the 40 and 60 kW machines using a Rayleigh probability distribution is shown in Figure 4. The 60 kW machine will produce more energy than the 40 kW in windspeeds of 5.5 m/s and greater.

The distribution of the power output of the wind systems can be predicted by using the windspeed distribution and the power curves of the two units (Figure 5). For this example the power is to be output to a load which requires a continuous 25 kW of electrical power. A horizontal line is drawn at 25 kW in Figure 5 to represent the load. The percentage of time which the power is greater than the value given is represented by the curve. The 40 kW machine operates more often at low power outputs while the 60 kW machine operates more often at large power outputs.

The predicted performance of the systems, without load management, for an average windspeed of 6.5 m/s is summarized in Figure 6. The 40 kW system will supply 25 kW or more 23% of the time, provide a portion of the power 48% of the time, and not operate 29% of the time. The 60 kW system will supply 25 kW or more 27% of the time, provide a portion of the power 32% of the time, and not operate 41% of the time. The 60 kW system will produce 17% more energy than the 40 kW system but the 40 kW system will supply 7% more energy to the 25 kW load.

If the load was not operated continuously and load management was added, the wind systems would be capable of providing more of the overall energy needs of the system. At a lower average windspeed the difference between the two units to meet the energy requirements of the 25 kW would increase (Figure 7). At a average windspeed of 6.0 m/s the 40 kW system would provide 8.5% more energy then the 60 kW system to the 25 kW load.

Other factors that should be considered for load matching include the cost of each system, life of the components, and value of the excess energy, if any. A larger system with the same rotor must be designed with larger components. The larger the generator the more reactive power is required for the system to operate.

SUMMARY

The wind-assist electric system requires power from the utility during periods of low windspeeds and produces excess power during periods of high windspeeds. The size of wind turbine needed is based on the ability of the wind turbine to meet the power demands of the load. A wind system with a 40 kW generator can supply 7% more of the needed energy to a 25 kW load than a 60 kW generator in an average windspeed of 6.5 m/s. Load management is necessary if a wind turbine is to supply a large portion of the energy requirements of a load.

REFERENCES

1. Clark, R. N. and F. C. Vosper. 1984. Reliability of Wind Electric Generators. Proc. Wind Energy Expo 1984 and National Conference of AWEA, p. 307-318.

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3. Mullan W. and T. Gage. 1984. Impacts of Electric Pricing Structure on Farm Load Management. ASAE Paper No. 84-3539.

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Table 1. Specifications of the wind system with a 40 kW and 60 kW Induction Generator.

System:	
Type	Utility Interface
Axis of Rotor	Horizontal
Location of Rotor (with respect to tower)	Downwind
Number of Blades	3
Rotor Diameter	13.4 m
Centerline Hub Height	25.0 m
Wind Machine:	
Rotor	
Type	Fixed Pitch
Design Tip Speed Ratio	6
Operational Tip Speed Ratio Range	1.8/1 to 11/1
Rotor Solidity	0.085
Blade Material	Wood/Epoxy Laminated, Fiberglass covered
Generator:	
Type	Three Phase, Induction
Output Voltage and Frequency	480 VAC @ 60 Hz
Brake:	
Type	Electro-Mechanical
Actuation	Fail-Safe Spring
Release	Electromagnetically Released
Yaw System:	
Yaw Control	None, Rotates Freely 360 degrees
Rotor Speed Control:	
Rotor Overspeed (Normal Operation)	Blades stall in high winds
Rotor Overspeed (Emergency)	Control System Applied Brake
Rotor Overspeed (Emergency Back Up)	Blade Tip Brakes Deploy
Tower:	
Type	Galvanized Self-supporting
Height	24.4 m

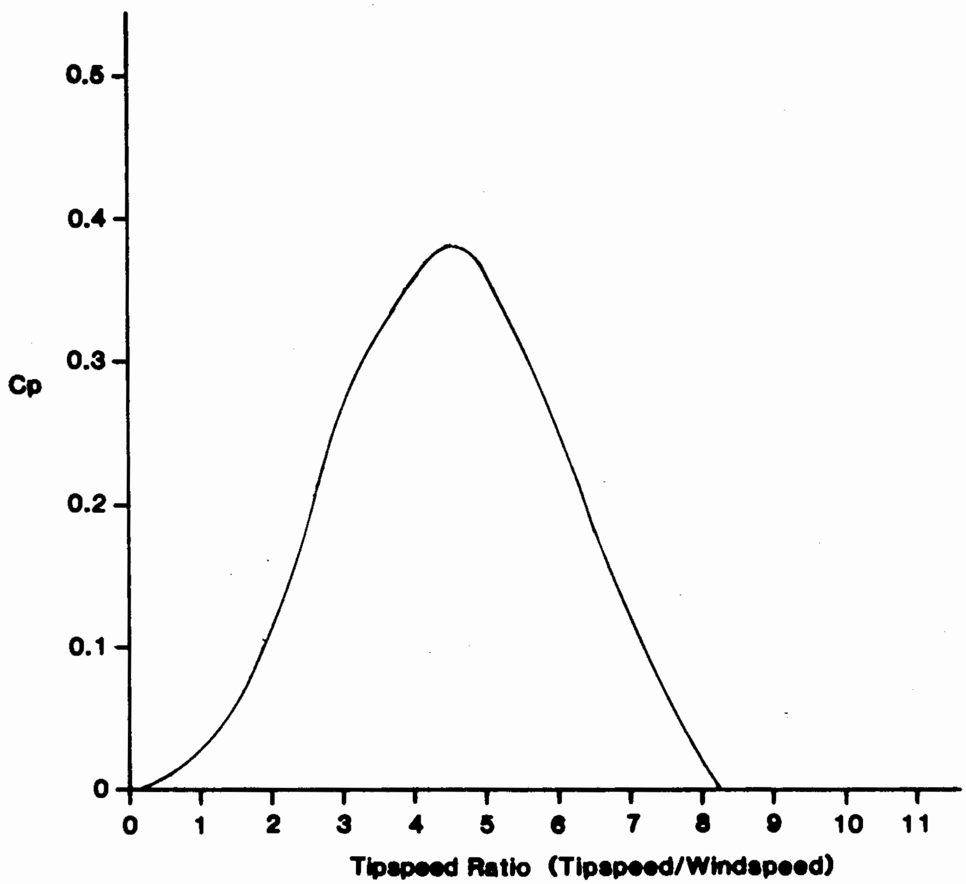

Fig. 1. Aerodynamic efficiency of a typical modern wind system.

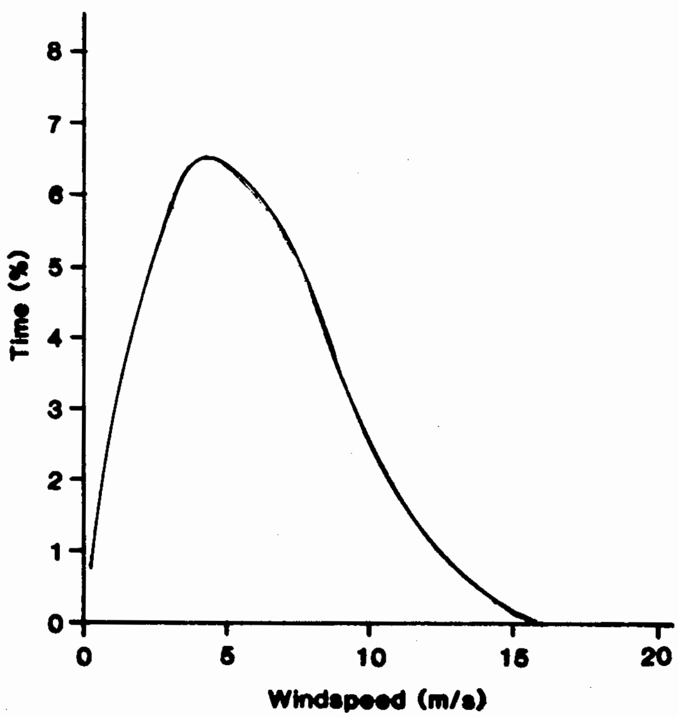

Fig. 2. Windspeed distribution for an average windspeed of 6.5 m/s using a Rayleigh probability distribution.

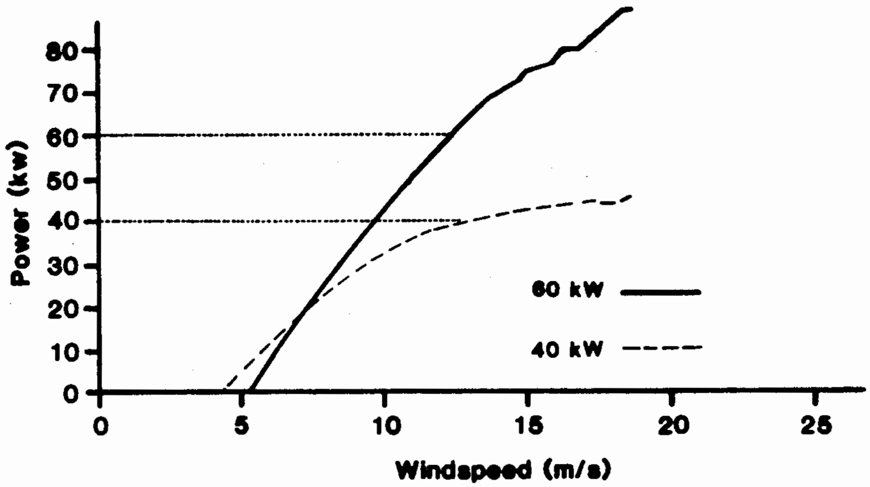

Fig. 3. Power curves, adjusted to standard air density, for a wind turbine, 13.4-m rotor with induction generator.

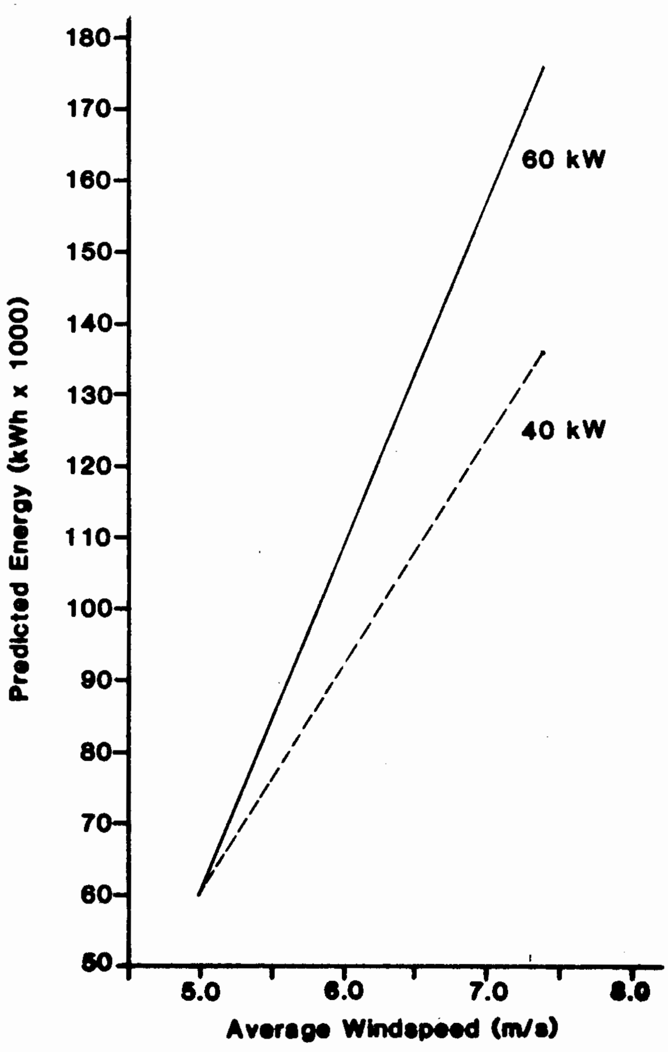

Fig. 4. Predicted energy production for a wind system with a 13.4-m diameter rotor.

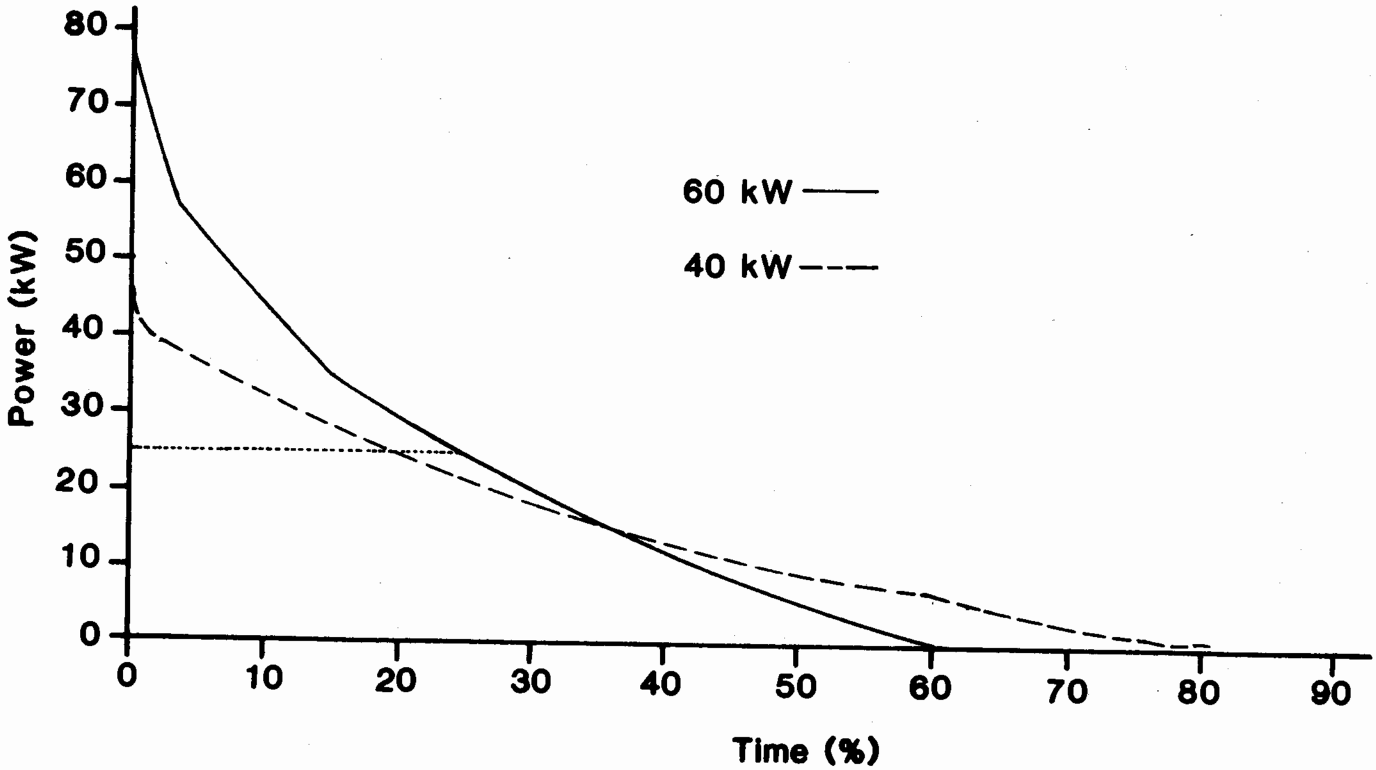

Fig. 5. Power duration of a 13.4-m rotor sized wind system with a 40 kW and a 60 kW induction generator for an average windspeed of 6.5 m/s.

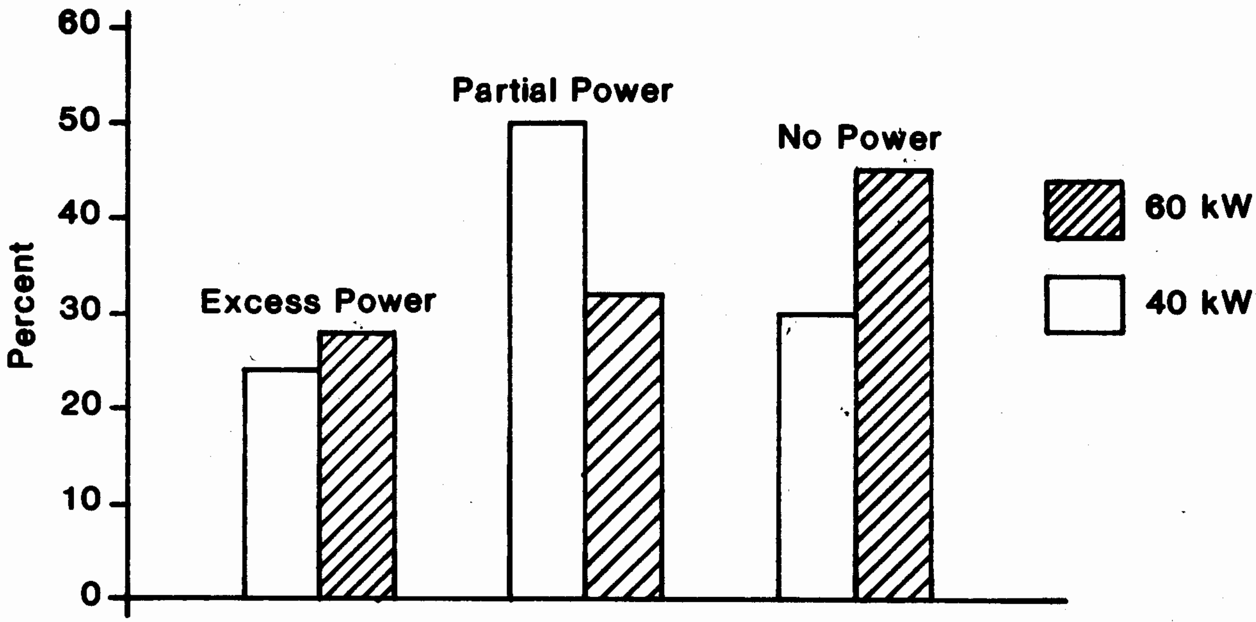

Fig. 6. Load matching of wind systems with a 25 kW continuous load and an average windspeed of 6.5 m/s.

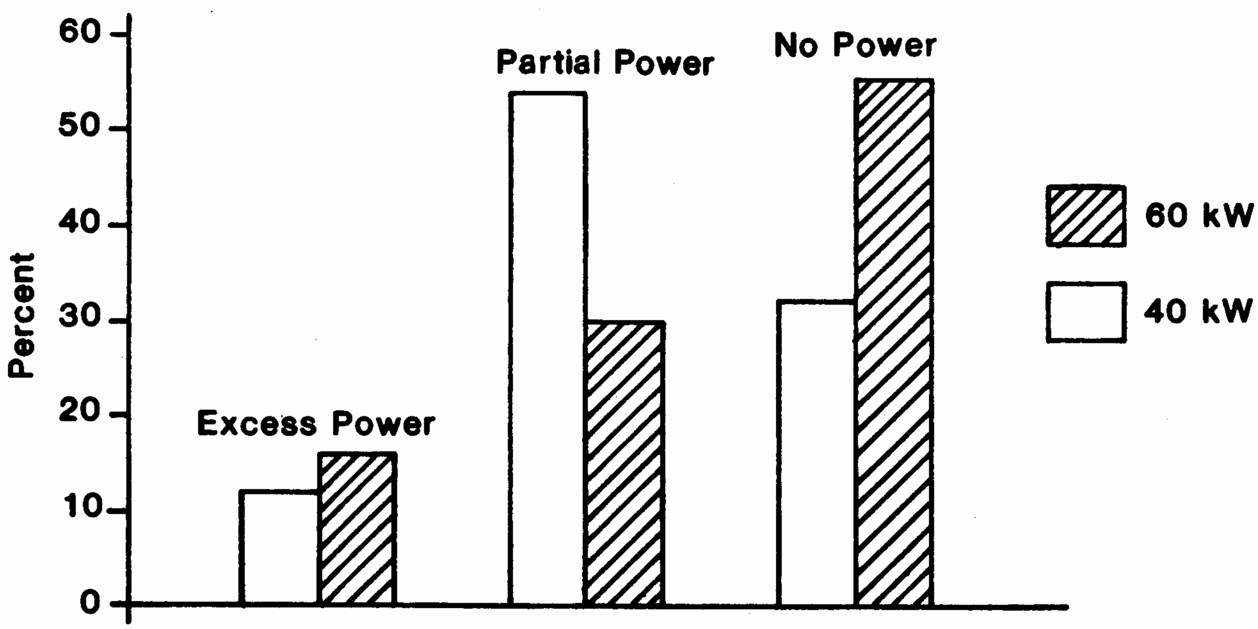

Fig. 7. Load matching of wind systems with a 25 kW continuous load and an average windspeed of 6.0 m/s.