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SMALL WIND POWER MACHINE
FOR RURAL AND FARM USE IN THE STATE OF MISSOURI

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Abstract

This paper describes work in progress to develop a prototype wind power generator for use by small farms, rural and isolated homes. It is anticipated that the wind power generator may supply power (1 to 10 kw) as base electric power (including energy storage), supplemental power, or in other forms (e.g. water pumping, nitrogen or hydrogen manufacture, and direct mechanical drive). The objective of this study is to produce a system(s) of high efficiency, low construction cost, and minimum maintenance requirement. Preliminary wind tunnel tests have been completed on several blade designs. A tower system is under construction on campus that will provide for the continuous testing of the full size prototype wind power generators.

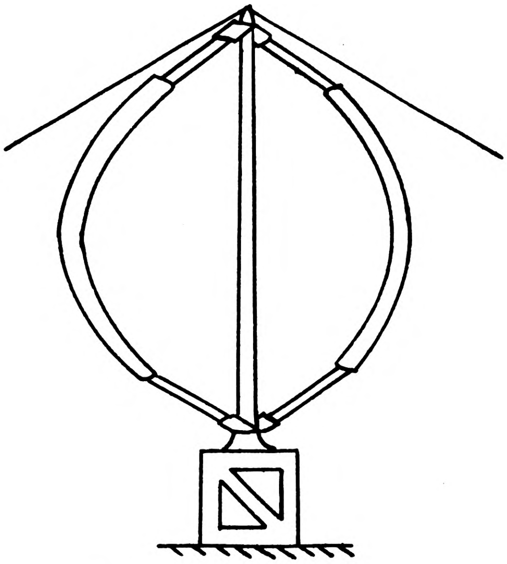
1. INTRODUCTION

The power of the wind, though potentially destructive, has been harnessed by man for centuries to do useful work. His first use of wind was probably in sailing ships and it was not until much later that windmills were first utilized to pump water, grind grain, etc. The windmill was used for centuries as an important source of power until the development of power systems utilizing low cost fossil fuels. Interest was renewed in windmill systems in the early part of this century as a candidate for furnishing power to remote areas.

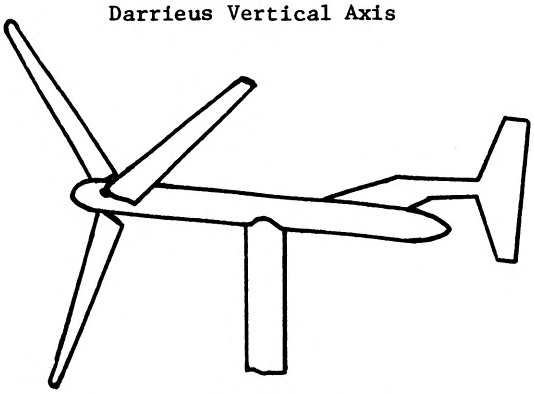
Atmospheric winds are an attractive energy source because they are virtually pollution free and constantly replenished by solar heating. However, operational and economic factors tend to hinder immediate utilization of this energy source on a scale that is significant in comparision to our current conventional sources of energy. Amoung these are the fact that wind velocity can fluctuate widely in magnitude and direction and the energy absorbing capability is low (about 59% of the energy available in a moving airstream can be absorbed for power production). Thus, windmills are hampered by a relatively large size in comparison to power output, problems with structural integrity under high wind conditions, and a fluctuating level of power production. Technologies developed in recent years are being applied to these problems so that wind power can be harnessed as a viable and economic source of energy for mankind.

Although the production of large-scale power (10^3 kw) from the atmospheric winds requires relatively large sized windmill systems, the production of power in the range from 1 to 10 kw presents much less of a problem with respect to system size. Many types of wind power systems have been developed in recent years as contenders for low power level generators. Two of these types are shown in Figure 1 as the vertical-axis wind power generator developed at the Canadian

National Aeronautical Establishment[1] from an invention in 1927 by Darrieus, and a rather standard propeller system that has evolved over the years. As an example of size and power output, it will be possible to generate about 1 kw of power with a 15-ft. diameter rotor operating in a wind of 15 mph.



Darrieus Vertical Axis



Conventional Propeller

Figure 1. Basic Wind Power Rotor Systems

It is the purpose of the recently initiated study here at the University of Missouri-Rolla to develop a prototype wind power generator for use by small farms, rural and isolated homes. It is anticipated that the small wind power generator may supply power as base electrical power (including energy storage), supplemental power, or in other forms (e.g., water pumping, nitrogen or hydrogen manufacture, and direct mechanical drive). The study will seek to produce a system(s) of high efficiency, low construction cost, and minimum maintenance requirement.

2. EXPERIMENTAL PROGRAM

Any attempt to design an economic windmill system must incorporate many important factors. These factors include a high aerodynamic blade efficiency, a high velocity ratio (rotor rotational tip speed/wind speed), and a simple and inexpensive design. Before describing the experimental program it is important to look at the energy available in the wind, and to determine what fraction of this energy can be extracted.

2.1 POWER AVAILABLE IN THE WIND

The power in the wind stream, P_s, of cross sectional area, A, is given by the equation

$$P_s = 1/2\ \rho A V^3$$

where

ρ = air density

A = cross sectional area

V = wind speed

However, even the ideal or optimum windmill cannot extract all of this power. It has been shown by Glauert[2] that the maximum power that can be extracted from a wind stream, P_m, is 59.3% of the power available in thet stream. The power coefficient for the windmill, C_p, is defined as the rotor (actual) power output divided by the power available in the wind stream, P_s, and is given by the equation

$$C_p = \frac{\text{Power Output}}{1/2\ \rho A V^3}$$

The value of C_p for modern windmills approaches 0.42, a value which is about 70% of the power that can be ideally extracted from the wind.

It is apparent that for a given windmill blade design the amount of power that can be generated depends principally on the wind speed, V, and the area swept by the blades, A. Since the power increases with the wind speed cubed, there is considerably more power available in high winds than in low winds. For example, there is four times the power available in a 16 mph wind than in a 10 mph wind. In addition, an increase in blade diameter of 40% would double the power available for a given wind speed.

2.2 TEST TOWER

A 40-ft. tall self supporting tower (see Figure 2) is now being erected at a test site on campus to provide the facility for continuous testing of the full size prototype wind power generators. The tower, a one-man fire watch tower acquired from the Clark National Forest, is rectangular in cross section with four legs, 11 ft. on a side at the base and 3-ft. on a side at the top. This basic test tower will be a permanent installation and will allow for long time testing of the various wind generator blade designs. Initial design work has been completed on the basic power system and windmill shaft to be designated as the standard test bed.

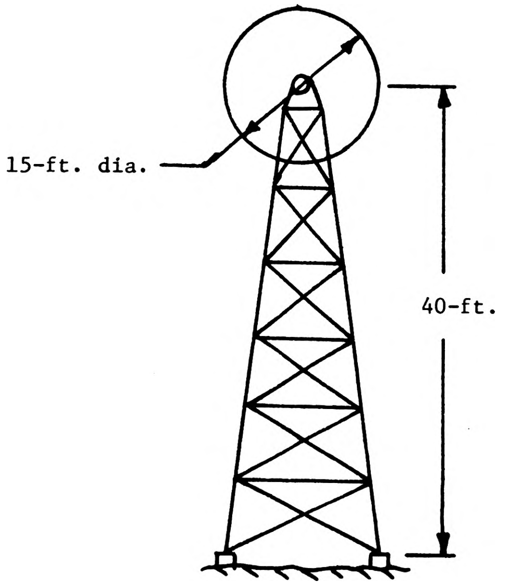


Figure 2. Tower Arrangement

2.3 BLADE DESIGNS

The basic blade designs to be tested are illustrated in Figure 1. The rigid-blade conventional propeller and the vertical-axis Darrieus designs will be tested in both a two-bladed and three-bladed configuration. Preliminary wind tunnel tests[3,4] on models of these designs suggest the need for prototype testing of the two-bladed and three-bladed designs to best satisfy the test objective of developing a system of high efficiency, low construction cost, and minimum maintenance requirement. It is anticipated that blade construction will follow two methods: (1) fiberglass skin bonded to a paper honeycomb core assembled on an aluminum tubular shaft[5], and (2) wood ribs assembled on an aluminum shaft, with urethane foam filling rasped to shape after pouring, then covered with a fiberglass skin[6].

The conventional propeller with three-blades may be necessary (as compared with the two-bladed type) to prevent excessive vibrations when a shift of wind direction requires a rotation of the propeller system to alter its facing direction on the tower. This will be a particularly important consideration for the proposed tests since it is planned to use a vertical tail vane in some cases to keep the propeller axis in line with the wind.

The blade airfoil section to be chosen must produce a high lift to drag ratio, L/D, in order to produce a high output torque and low blade drag. The new general aviation series airfoil sections generate high L/D at high lift coefficients. The first generation airfoil of this family, the GA(W)-1, will be used for the conventional propeller blade section.

Figure 3 is included to show the comparative performance of various blade systems. Note that the maximum or ideal power that can be extracted (C_p of 0.593) is only approached when the tip speed of a windmill exceeds about 4 times the wind speed; that is, when the tip speed ratio exceeds about 4.

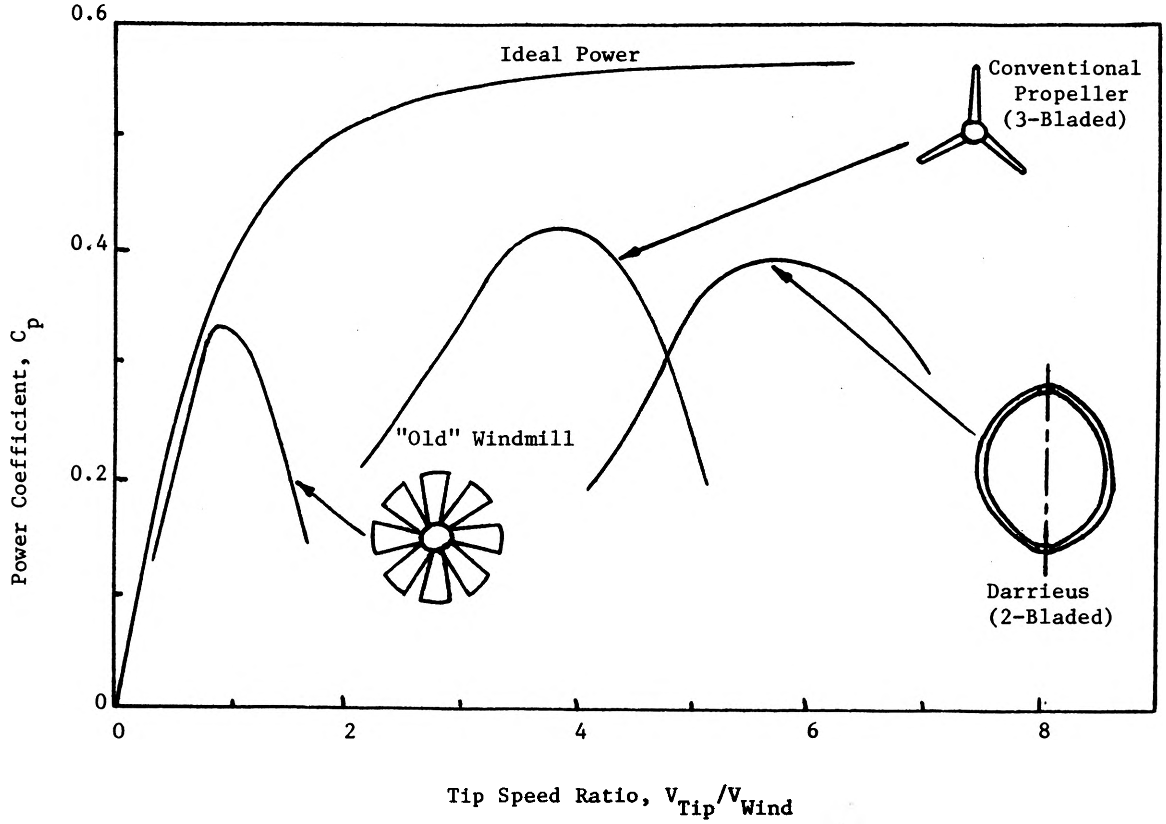


Figure 3. Blade System Performance Comparison

2.4 WIND DATA

In small size applications of wind energy the general rule is that the tower site is determined by the geographical location of the user and is not selected because it is a particularly windy place. Thus, siting is a matter of determining whether or not there is sufficient wind at a given place to economically justify installation of the wind power generator. Although the acquisition of wind characteristics for a one-year period is desirable for proper design and/or selection of a wind generating unit, it may be possible to acquire the needed wind data in a much shorter time utilizing a technique suggested by Thomas[7]. This method requires a few months measurement of average wind speed and very little data analysis. By either method the data available on an hourly basis is compiled to yield a wind frequency curve giving the number of hours for which the wind lies within a given speed interval. From this the available energy for a year for each speed interval per unit area is obtained for the site. Wind speed and direction data is currently being gathered at the site to accomplish this task.

2.5 POWER TRAIN

Energy input from the wind into wind energy conversion systems is a variable one resulting in variable speed of the prime mover unless rotative speed is regulated by a change in (for example) angle of attack of the propeller blades. Such mechanical systems designed to convert to constant rotative speed require dissipative conversion mechanisms resulting in reduced efficiency. Furthermore, since the wind power available varies as the cube of the wind speed, it would be more cost effective to allow the prime mover to rotate at varying speeds and extract a larger percentage of that available power. Not only is energy extraction improved but a simpler design of the mechanical elements is realized.

The basic factors to be considered when examining the electrical technology associated with converting wind energy to electrical energy are: (1) type of output (D.C., variable or constant frequency A.C.), (2) propeller system rotative speed (constant or variable), (3) utilization of the electrical energy output (battery storage, other storage forms, interconnection with an A.C. grid).

The utilization of the electrical energy output for interconnection with an A.C. grid requires a close examination of existing generator systems, especially if it is desired to obtain constant frequency output for a variable speed shaft. Such systems fall into two broad categories: (1) differential methods (mechanical techniques to get constant speed and then employ synchronous generators, or electrical techniques to get constant frequency), (2) non-differential methods (static frequency changes, i.e., AC-DC-AC, or rotary devices).

The proposed series of tests will begin by utilizing a D.C. generator of approximately 1 kw output. This simple system will allow for the needed time early in the test program to get the system operating. Once the system is operating effectively prototype testing will begin utilizing existing generator systems described above.

3. SUMMARY

The purpose of the recently initiated study at the University of Missouri-Rolla is to develop a prototype wind power generator for use by small farms, rural and isolated homes in the state of Missouri. The emphasis will be on optimizing the blade number and configuration to obtain maximum power output for a given wind speed range while maintaining simplicity in design and construction technique for low initial and maintenance cost. These objectives will be realized through: (1) the establishment of a standard method for the continuous testing of full size prototype wind power generators on top of a 40-ft. tall self-supporting tower located at a test site on campus, (2) the performance of long term tests on blade systems developed through wind tunnel tests, (3) establishing a set of design criteria for blade system selection based on site location, wind conditions (average and peak speeds, wind direction, duration, etc.), (4) the development of a prototype "portable" wind power generator for demonstration at selected sites throughout the State.

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