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NF96-304 An Introduction to Wind Power for Nebraskans

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An Introduction to Wind Power for Nebraskans

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Windmills are a common sight in Nebraska. The historian Walter Prescott Webb argued that the windmill, barbed wire and the six-shooter made homesteading on the Great Plains possible.

Windmills ensured early homesteaders had a constant supply of water, and early in this century, they were used to produce electricity for homesteads. Many Nebraskans remember the 32-volt Wincharger. With the coming of inexpensive public power to rural Nebraska, most small electric windmills were abandoned.

During the 1970s, the sudden increase in energy costs coupled with spot shortages of oil caused a renewed interest in wind energy. Federal tax breaks encouraged the development of utility-scale windmills. However, these early developments were plagued with technological and economic problems. With the end of tax breaks in 1985, wind farm development came to a virtual halt. Many thought the wind energy industry was dead.

However, in the last few years, several technological advances have made wind power economically competitive with more traditional energy forms such as coal and oil. Nebraska has many promising locations for large utility-scale wind farm development. However, before wind farm development can take place, an assessment of the wind power potential must be made. Identifying the most promising sites will take several years. Thus major wind farm development in Nebraska will not occur until after the turn of the century.

Wind Energy Fundamentals

In this section we will show that **wind power depends on the wind speed raised to the third power (wind speed cubed)**. This means that an increase in wind speed from 13 mph (5.8 m/s) to 15 mph (6.7 m/s) will increase wind power production by 54 percent. The cubic relationship between wind power and wind speed makes it important that the true wind speed at a location be known before developing a wind farm.

In general, most people overestimate the wind speed at a location. Therefore, a multiyear monitoring program is the only reliable method to determine the true wind speed at a location. The mathematical form of the wind power-wind speed relationship is

Equation 1

$$\text{Power} = k \times (\text{wind speed}) \times (\text{wind speed}) \times (\text{wind speed})$$

or

Equation 2

$$\text{Power} = k \times (\text{wind speed})^3$$

where k is a constant of proportionality.

In physics, energy is defined as the ability to do work. While this definition is technically correct, it is not very meaningful in this form. We can ask, how much *energy* is required to lift a bucket of water from the bottom of a well? But we can also ask, how much *work* is required to lift a bucket of water from the bottom of a well? These are really the same question.

It is useful to differentiate between kinetic energy and potential energy. Kinetic energy is the energy associated with motion. All moving objects have kinetic energy. A windmill transfers kinetic energy from the wind to an electrical generator (the wind makes the windmill blades turn on a shaft that connects to the generator). The turning generator creates a field that forces electrons to move through the power line. Moving electrons form an electric current. Thus, a windmill transforms the kinetic energy of air into electric current. Potential energy is stored energy. Batteries, food, and water behind a dam are examples of potential energy.

How much power is produced by a windmill? To answer this question, we must first calculate kinetic energy of the wind. Kinetic energy has the mathematical form

Equation 3

$$KE = 1/2 \times (\text{mass of the object}) \times (\text{speed of object}) \times (\text{speed of the object})$$

The kinetic energy equation is usually written

Equation 4

$$KE = 1/2mv^2$$

where m is the mass of the object (mass of air in this case) and v is the speed of the object (the wind speed in this case).

In order to calculate the kinetic energy of the air moving a windmill blade, we first must calculate the mass of the air. It is easier to calculate mass per unit of time (mass/time) of air instead of the mass of air. The mass/time of air depends on the air density, the area swept by the windmill blades, and the speed of the wind. This brings us to the following equation

Equation 5

$$\text{mass/time} = (\text{air density}) \times (\text{area}) \times (\text{wind speed})$$

where area is the area swept by the wind mill blades.

We can now calculate the kinetic energy (KE). However, our mass term (*Equation 5*) is mass per time. This is not the problem that it appears. If we divide the kinetic energy by time (KE/time), we have the definition of power. Thus it will be easier to calculate power than to calculate kinetic energy. Since calculating the power is our ultimate goal, we will calculate power instead of KE.

Equation 6

$$\text{Power} = \text{KE/time} = 1/2 \times (\text{mass/time}) \times (\text{wind speed}) \times (\text{wind speed})$$

Now substitute [(air density) × (area) × (wind speed)] for mass/time, we get

Equation 7

$$\text{Power} = 1/2 \times [(\text{air density}) \times (\text{area}) \times (\text{wind speed})] \times (\text{wind speed}) \times (\text{wind speed})$$

This can be simplified to

Equation 8

$$\text{Power} = 1/2 \times (\text{air density}) \times (\text{area}) \times (\text{wind speed})^3$$

In wind energy, it is common to use Power per area swept by the windmill blade (Power/area). Power/area is called Power Density. Power density allows us to compare windmills of different sizes.

Equation 9

$$\text{Power Density} = \text{Power/area} = 1/2 \times (\text{air density}) \times (\text{wind speed})^3$$

If we use the MKS (meter, kilogram, second) units system, the Power/area equation will give us our answer in watts/m2. The average density of air is almost 1 kg/m^3. This allows us to simplify the power density equation to

Equation 10

$$\text{Power Density} = 1/2\ \text{kg/m}^3 \times (\text{wind speed})^3$$

Equation 10 requires that the wind speed be expressed in m/s, not mph. From equation 10, we see that the power density is a function of the wind speed raised to the third power (or wind speed cubed). As a specific example, increasing the wind from 13 mph (5.8 m/s) to 15 mph (6.7 m/s) will increase the wind power by 54 percent.

Wind Farm Siting

As shown in the Wind Energy Fundamental section above, it is imperative to know what the actual wind speed is at a site before developing a wind farm. Three years of wind data are usually considered the minimum data requirement. In addition to wind speed there are economic and environmental considerations in choosing a wind farm site.

A major economic concern for utilities is the distance from the proposed wind farm to existing high-voltage power lines. Construction of high-voltage lines is very expensive. As a general rule, wind farm sites cannot be more than 10 miles from an existing high-voltage power line.

Another economic concern is the cost of constructing a wind farm. Is the site already accessible by road or will a road need to be built? What is the slope of the site. Steep sites will require extra construction expense.

Other economic concerns include: What are the property taxes? How long will it take for the wind farm to make a profit?

The environmental impact of a wind farm is also a concern. Some people are concerned because of the large land area required by wind farms. Large wind farms may require hundreds of acres. However, only five percent (5 percent) of the land on a wind farm is needed for towers, roads, and support structures. The remaining 95 percent of the land may be used for other purposes such as row crops or ranching.

Another environmental concern is the "avian problem." In California, birds of prey (raptors) were killed by windmills. Current research indicates that this may be a local problem and seems to be associated with fog. A third environmental concern is noise from windmills. Early generation windmills were very noisy. The new windmills are much quieter; at a distance of 100 yards, they are barely audible. A final environmental concern is aesthetics — the looks of windmills. Some people consider them a blight on the landscape. Others find their turning in the wind graceful.

Current Developments in Nebraska

As of 1996, there are several wind energy monitoring sites in Nebraska. Most of the sites are being monitored by public power. A few sites are being monitored by private individuals or companies. The most promising sites for wind energy development are in the western quarter of the state and along the South Dakota border. The Sand Hills also have some promising sites. As shown above, it will be necessary to monitor these sites for several years in order to obtain the necessary data. It will be several years before we see large utility-scale wind farms being developed in Nebraska.

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