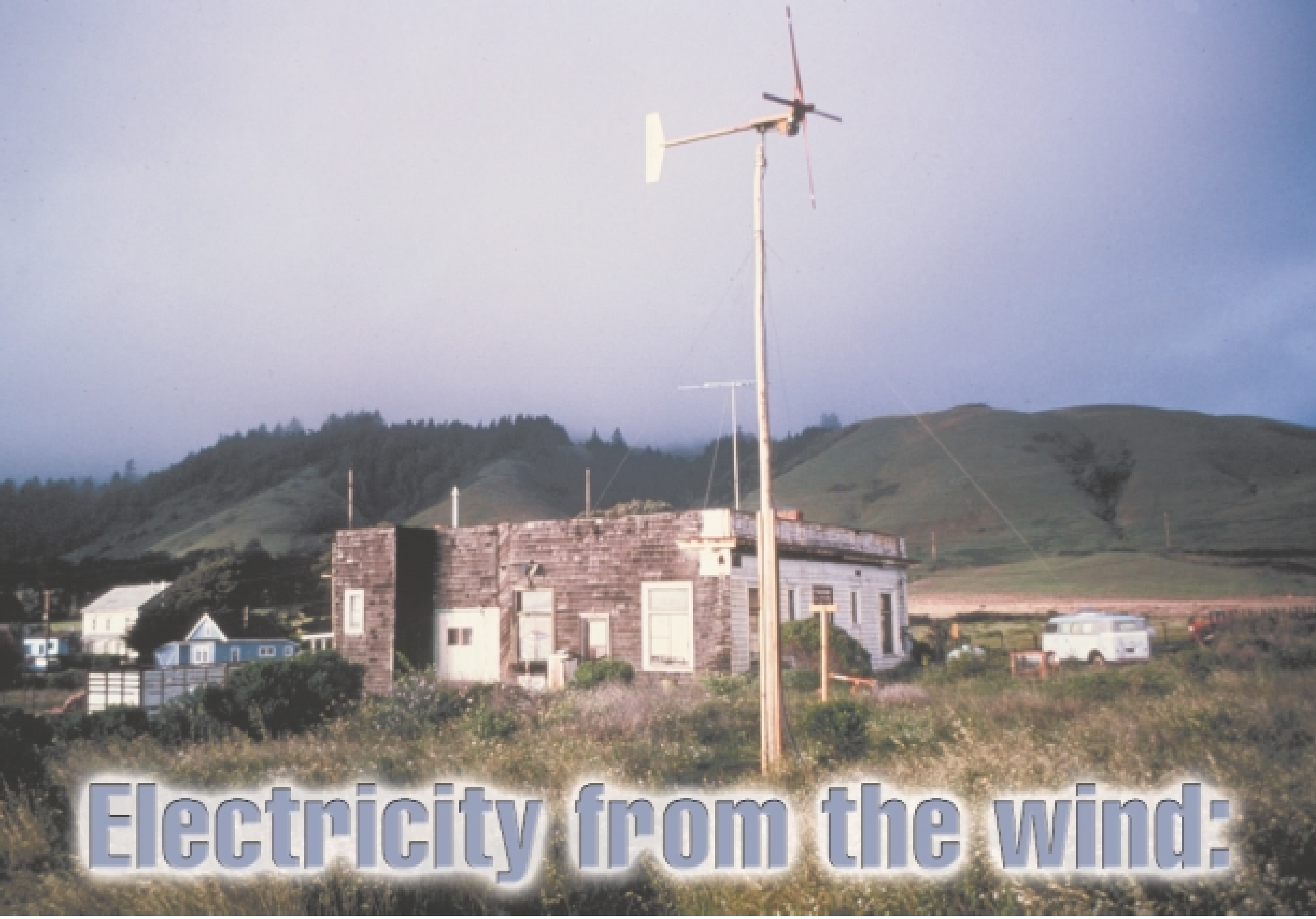

Electricity from the wind:

Assessing wind energy potential

By Michael Hackleman

Is there wind where you live? The wind's energy can spin a generator to make electricity or drive a shaft to pump water. The questions are: Is there enough wind energy available? What's involved in setting up the system? How big a windplant do you need? How tall a tower will it need?

My first foray into using independent energy sources began in 1972 and focused on wind. In the intervening years, I've evaluated the wind energy potential of hundreds of sites. In any field of work there are tricks to the trade that come with time and experience. In this article I will try to distill my experiences down into tricks anyone can use to assess the viability of adding wind energy to one's own personal energy equation.

Understand the wind

Tapping the energy in wind is a hit-and-miss proposition without first understanding the nature of wind. Windplant installers or owners will make critical errors in selection, siting, and use without this knowledge.

Wind is born from the unequal heating of the earth's surface and oceans by solar energy. Wind is, simply enough, a moving mass of air. What air lacks in density it more than makes up for in speed. Put a windturbine in its flow and the wind will spin it. In effect, the wind machine is "gathering" some of the wind's energy. It must not take it all. Observations and calculations predict that only 60% of the wind's energy can be extracted without adversely affecting performance. So, enough energy must be left in the wind to allow it to move on.

To the casual observer, there may seem to be little pattern to the wind. However, in years of data measurement and recording at airports and climatological stations, distinct patterns have emerged in both wind direction and velocities. Annual, monthly, and even weekly patterns exist.

Figure 1.

One of the most interesting patterns shows that in most areas the windiest months are in the midst of winter and the calmest months are in summer. This one feature makes wind energy practical even for an independent system designed around solar energy. A windplant produces the bulk of its power in those months when the solar influx is minimum, or weakest. Indeed, wind and solar energy complement each other nicely in a year's time.

Another pattern that emerges indicates that there are two distinct types of wind. The first type is called "prevaling winds," since they blow most of the time and "prevail" over the second type, referred to as "energy winds." Energy winds often piggyback the prevaling winds. In an average week, we will get five days of prevaling winds (rarely exceeding 10 mph) and one day of energy winds.

To the novice it might seem that the windplant should be designed to extract power from low windspeeds because they occur more often. Alas, this is not entirely true. It is a fact that energy winds, though they may blow only 15% of the time, contain 75% of the energy that can be extracted in a week's time.

Visit your climatological station

It is the long-term data gathered on wind speeds that first revealed the patterns in wind. This data was originally gathered at airports. The general need for monitoring and recording weather data led to the creation of climatological stations throughout the USA and other areas of the world. Wind data has been gathered at many of these sites for 50 to 75 years.

There are two factors related to wind measurement: wind speed and wind direction. Hourly measurements of each are the norm. This data is condensed into a useful form in the wind rosetta. The wind rosetta is a graphic display that averages the recorded wind speeds and plots them about a 360 degree circle divided into 16 equidistant quadrants. At a glance, the rosetta gives you a good idea of the strength, duration, and direction of wind. The one I obtained in 1977 for my land in the Sierras included the average values for rosettas dating back almost 50 years. Along with a compass, the rosetta is indispensable when looking for potential tower sites.

Rosettas and accompanying data tables are available to the general public, at little or no charge, from the state government. These may even be available at a nearby climatological station but it's unlikely. Many data-logging sites are now automated and unstaffed. You'll want a current rosetta, and ones for a number of years back (to see the variances) and an averaged rosetta for as long a period as possible. If unavailable, get the data tables, and do a little study. In any case, locate and visit the site of the climatological station in your area.

In his workshops, Mick Sagrillo, founder of *Lake Michigan Wind and Sun*, shows station sites that have been neglected or poorly sited. What do you look for? How high is the wind speed and direction indicator? Have trees grown up or buildings been added in the area that will interfere with readings in one or more directions? If the current rossetta shows an overall drop in average wind speeds, particularly in some directions, it may be explained by these influences. By whatever means, assure yourself that the data you gather is untarnished.

Of course, the rosetta's information reveals wind patterns in the general area, not on your land. At best, a certain amount of extrapolation will be necessary. Worse, it won't tell you enough. At very worst, there may not even be a station close by, either. This is okay.

Successful wind sites have been found without the use of rosettas. Onsite observations or those of local landowners are equally valuable. If you want your own onsite data, you can rent, lease, or purchase wind monitoring equipment. Install it at a likely site for a few winter months or longer. This can be a bit pricey, but so is the investment in a windplant and tower.

If you can't afford monitoring equipment, purchase a handheld wind-measuring device and log the wind potential onsite. Humans are actually fairly good as instruments. Log your readings on a calendar, noting the wind speed, direction, and duration (hours) of wind.

Wind speeds at ground level will read lower than wind speeds recorded at 20, 40, 60, and 80 feet above the same point at the same moment. Even a flat, smooth field will slow and tumble the wind. A formula exists to help predict wind speeds at heights above ground level, converting your ground-based readings into real information to assist in good decision-making.

Figure 2.

Dissect the wind equation

How much energy we get from the wind is related to the size of the machine, its efficiency, the wind's speed, and the air's density. The precise way these factors work together to produce real power is expressed (in a ready-to-use format) in the following adjusted formula.

$$P = .0015AV^3$$

where
P = power in watts
.0015 = (air density)x(50% windmachine efficiency)/2
A = Area swept by turbine in square feet
V= Velocity of the wind in mp

Some folks like to crunch numbers with formulas, but I'm not one of them. Still, anyone who wants to use wind energy will find some useful information here. For example, what minimal change in any one factor will result in the greatest increase in the value of power? Windplant area or wind speed velocity?

The answer is implied in the formula. Note that any increase in the value of A (turbine area) will produce an increase in P (power) in direct proportion. However, a change in V (windspeed) will result in an increase in P (power) equal to the cube of that value of windspeed. Velocity cubed (V^3) means that we multiply V times V times V.

Understand the cube law

The influence of windspeed in the wind power equation is quite remarkable: whatever power is available at any given windspeed, at twice that windspeed there is eight times (8X) the power available. This effect is called the cube law.

You can prove this to yourself by running two examples through the formula. Since V is the only thing that changes, may I suggest a shortcut. Let's pick a value, V, for the initial windspeed. Cube it, and the result is V^3. Now, let's double this windspeed, which can be represented by 2V. Cube it, and the result is $(2)^3(V)^3$, or $8V^3$. The difference in power between the initial value V^3 and the second value $8V^3$ is the factor eight (8). So, double the windspeed, and there's eight times the power available.

No wonder a 100 mph wind is so destructive. It has eight times the power of a 50 mph wind. Or 1,000 times the power of a 10-mph wind.

Incidentally, what's the average annual windspeed (AAW) for your area? Climatological stations compute AAW by adding together the values of their hourly readings (including zeros) and dividing this sum by the number of readings taken. What value of AAW do we want? For years, the wind energy industry has advocated a minimum of an AAW of 8 mph for a successful wind energy system. This recognizes that to achieve an average AAW of 8 mph over a period of one year means that you'd have to have higher-than-8 mph windspeeds of significant value and duration to balance out all those zeros (dead calms).

Still unresolved, however, is the actual amount of energy yield from the wind in a year. Or, better yet, during the windiest months. If climatological stations averaged only the cubes of those hourly windspeeds, we'd have solid info on the power we could harvest from the wind in a given month, season, or year.

Examine windplant ratings

There are a number of established methods for extracting some of the wind's energy and putting it to good use. Windmachine, aeroturbine, windplant, and airscrew are all terms used to describe the machinery that will convert energy from the wind into mechanical motion. While these terms are used by the layperson somewhat interchangeably, they are intended to be descriptive of function. For example, wind-electric units, aero-electric units, and windplants produce electricity. Water-pumpers are used to pump water. Windmills are designed to power mills for grinding grain.

There are two classes of aeroturbine: horizontal and vertical. The terms are used to describe the axis about which the windmachine itself rotates. There are at least five types of horizontal-axis windplants and three types of the vertical-axis windplants. Of these designs, only two of the horizontal-axis types have proven commercially viable. One is the multiblade, curved impeller machine used for water-pumping (**Fig. 2**). It is designed to work at very low windspeeds and rpm. The second type of successful windplant is the propeller type used for generating electricity (**Fig. 1**). It uses between two and six airfoil-shaped blades, is highly efficient, and works in higher windspeeds and at higher rpm. The remainder of this article will focus on the propeller-type windplant.

Note: It has been said of my first two books on wind power that, while written for the do-it-yourselfer, they actually discourage someone from building their own windmachine. That's the nature of reality. There are many subtleties to building a windplant and good machines are no accident. If you insist on homebrewing a windmachine, prepare to do some major homework. Read everything you can on the types of windplant that match your application, get plans if possible, and don't downplay any shortcomings. Homebrew windplants are experimental in every sense of the word, and they are likely to involve a number of test-tune cycles. Allow for outright failure. It is a big mistake to expect reliable power production from a homebrew windplant.

All aeroturbines, irrespective of size or type, have lower and upper limits (usually expressed as particular windspeeds). Below the lower limit, called cut-in, the aeroturbine is stationary or moving too slow to be effective. Don't expect power below a windspeed of 10 mph. At the upper limit, usually refferred to as the "rated" or "maximum" windspeed, the machine is developing its designed power level. Above that limit, depending on the governor type, the wind plant will decrease in output or maintain the rated power.

The cube law describes the power curve in wind. Suppose that a specific windplant produces 100 watts at 15 mph. Using the cube law, at 30 mph this aeroturbine could generate 800 watts. In a 45 mph wind, the cube law says the windplant could generate 2,700 watts. Note that the increase in power between 15 and 30 mph (700 watts) is small compared with the increase in power between 30 and 45 mph (1,900 watts).

Windplants have both a power rating and windspeed rating. The power rating is the maximum power the windplant can safely produce and is expressed as a specific wattage, i.e., 700 watts or 1500 watts, for the system voltage, i.e., 12V or 24V. The windings and brushes of the generator and/or the control system may be adversely affected by the extra current if the rating is exceeded. The windspeed rating of a windplant is defined as that windspeed at which the windplant produces its rated power. It may also reflect the highest rpm the windplant can safely experience. Whatever type of governing system is used, it should not permit either an increase in windplant rpm or generated wattage with further increases in windspeed.

There are no standards for windplant ratings in the wind industry today. At the least, this makes it difficult to compare windplants from different manufacturers, or ones of different ratings from any one manufacturer. At worst, the consumer must validate manufacturer claims and interpret ratings. Does the specified power rating represent continuous or peak power? At what windspeed does the windplant begin to produce power? How much power will the windplant produce at any given windspeed?

Unfortunately, the specification sheets for most windplants do not give these figures. More often, these figures must be extrapolated from a tiny graph that plots windspeed vs wattage via a curved line. If you want to know if a particular windplant is going to work for your situation or wish to simply compare various brands, you must involve yourself in a bit of calculation for each one. Here, your knowledge of the cube law will help you make informed choices.

Figure 3.

If (H/H_0) is	For a H_0 of 6 ft. H is (in feet)	5th Root of H/H_0=Z is
2	12	1.15
3	18	1.20
4	24	1.32
5	30	1.38
6	36	1.43
7	42	1.48
8	48	1.52
9	54	1.55
10	60	1.59
11	66	1.62
12	72	1.65
13	78	1.67
14	84	1.70
15	90	1.72

An important question is: how much power at what windspeed? Many windplants currently manufactured are rated to deliver full power at 25 mph, or higher windspeeds. This rating is useful only for those areas of the world experiencing AAWs (average annual windspeeds) of 12-14 mph. A windplant that develops its full (rated) power at 18 mph would be a much more suitable machine for 90% of the U.S.

Don't shrug off the 7-mph difference between 18 mph and 25 mph. If one windplant is rated to deliver 2,000 watts at 25 mph, how much power will it produce at 18 mph? Using the cube law, my answer comes to 746 watts on the nose. This means that a second windplant rated to deliver 750 watts at 18 mph will equal the output of the 2,000-watt machine in 18 mph winds. Given the difference of cost and weight between the two machines, it is possible to achieve a higher overall cost/benefit ratio with a small windplant on a tall, lightweight tower than a big machine on a short, heavy tower.

A good way to check various brands or models of windplants is to talk to dealers and customers. A dealer who services the equipment he or she sells is likely to be candid about brands that work well and ones that are troublesome. Customers are another source of information. Find articles written by these people on their systems. You may also be able to communicate with them directly. Be thoughtful. Compensate them for their time and include a SASE (self-addressed, stamped envelope) with any queries.

Evaluate tower height

System inefficiencies can be compensated for somewhat by increasing the amount of power available from the windplant in any given wind. Manufacturers will tell you to increase the rating of the windplant, thus effectively increasing rotor diameter and harvesting a bigger chunk of the wind's energy. However, the best way to get more power is to increase the windspeed to the windplant by placing the windmachine higher off the ground by using a taller tower.

There are three primary reasons to put a windplant on a tower. One, to clear trees, houses, and other obstacles that will slow the wind down. Two, to position the windplant in a smooth flow of wind. The presence of uneven terrain and obstructions both slow and turbulates the wind, robbing a windplant of power. And, three, to expose the windplant to higher windspeeds.

As the cube law dictates, if we want to make leaping increases in power output of a windplant for small increases in any ONE factor, let it be windspeed. Earlier, you learned that there is an eightfold increase in power output by going from, say, 10 mph windspeed to 20 mph. It shouldn't be difficult to see that if we increase the windspeed by 2 or 3 miles per hour, say to 13 mph, we will have **doubled** the power that's available at 10 mph. In this situation, the swept area of the aeroturbine or its efficiency would have to be doubled to achieve the same effect as a (calculated) 2.6 mph increase in windspeed.

A formula exists to help estimate the windspeed (V) at various distances (H) above even terrain from a reading taken at 6 feet above ground (H_0) for any windspeed (V_0) up to 35 mph. It is expressed as: $V = V_0 (H/H_0)^{1/5}$

I found this unwieldy, since it requires that I find the fifth root of the ratio H/H_0, something a simple calculator wouldn't help me do. For this reason, I've built up a table that reduces the math to a single factor (z) for tower heights up to 96 feet (**Fig. 3**). The new formula is:

$$V = z (V_0)$$

where:
V=Velocity in miles per hour
z=the 5th root of H/H_0 (the third column in Figure 3)
V_0=Velocity of wind at height H_0

Let's work an example. Let's say you measure 8 mph of windspeed (V_0) with a windspeed indicator held the required 6 feet above the ground. Using the table, for a 24-foot tower, find z (1.32) and multiply by 8 mph. This yields 10.56 mph. Similar math yields 11.4 mph for a 36-foot tower, 12.2 mph for a 48-foot tower, 12.7 mph for a 60-foot tower, 13.2 mph for a 72-foot tower, 13.6 mph for an 84-foot tower, and 13.9 mph for a 96-foot tower. These figures indicate that whatever power the windplant might produce on a 36-foot tower would be almost doubled if it were situated on a 96-foot tower at the same spot. Even if you plug in different windspeeds, the formula holds the same proportions. Therefore, independent of the windplant rating or the actual windspeed, you get double the power on a 96-foot tower as you do on a 36-foot tower. Compare the cost of an additional 60 feet of tower and rigging with the cost of a windplant of twice the power rating. Let's hear it for the cube law.

All of this helps explain why it is so important to distribute the investment you make in a wind-energy system between the windplant and the tower.

A large windplant requires a strong tower to support its weight. A small windplant may use a correspondingly lighter tower. It's true that free-standing towers must be strong enough to withstand the side-loading effect of high windspeeds. However, guyed towers are able to transfer side-loading to the guy wires themselves, minimizing the structural requirements for the tower to primarily compressive ones (windplant weight). Translated, this means that a tall, lightweight, guyed tower topped with a small windplant may give you more "bang for your buck" than a big windplant on a heavy tower that your budget must curb in overall height.

Match windplant to system

Can your system's batteries absorb a big windfall of energy? Some attention should be given to matching the windplant's output to the system to which it is connected.

Where wind is the primary or singular energy source in a system, the battery capacity should be large enough to absorb the power generated from energy winds. These winds are both infrequent and irregular, meaning the system's batteries may be quite depleted before they are refilled. In this case, extra care must be afforded the battery pack to protect it from cold when its state-of-charge (SoC) is low.

A different strategy is required when wind is a supplemental energy source, say, to PV (photovoltaic) and/or small-scale hydroelectric energy, or where a standby generator exists to replenish the battery pack as needed. In these scenarios, a small windplant positioned to generate energy from intermediate winds makes more sense than a large windplant that takes big energy from big wind. This is because the system itself is not able to absorb the huge inrush of power. Its batteries are never that depleted.

This is not to say that there is no place for a big windplant in a system. If load diversion is effectively utilized, large amounts of generated electricity can be diverted to direct use in space heating or water heating applications. This procedure might relieve other energy sources, like wood or propane, in performing these same functions. This strategy works best wherever there is a lot of strong wind and a lack of viable alternatives for generating electricity other than from wind.

We'd all like as much power as possible from any energy source we tap. One of the most expensive components in a system based on wind-generated electricity is the windplant itself. As this article illustrates, bigger is not necessarily better, nor will it necessarily result in greater overall power production. Don't let the tower be an afterthought. Strive for a balance in windplant size, tower height, and energy storage considerations. I hope that I've given you some ideas on ways to achieve the best cost/benefit ratio possible.

(Drawings and slides for this article were taken, in part, from Wind and Windspinners, The Homebuilt Wind Generated Electricity Handbook, and At Home with Alternative Energy, all by Michael Hackleman. For a current publications list, send an SASE to him at P.O. Box 327, Willits, CA 95490. E-mail: mhackleman@saber.net.)Δ