Electric Power from the Wind

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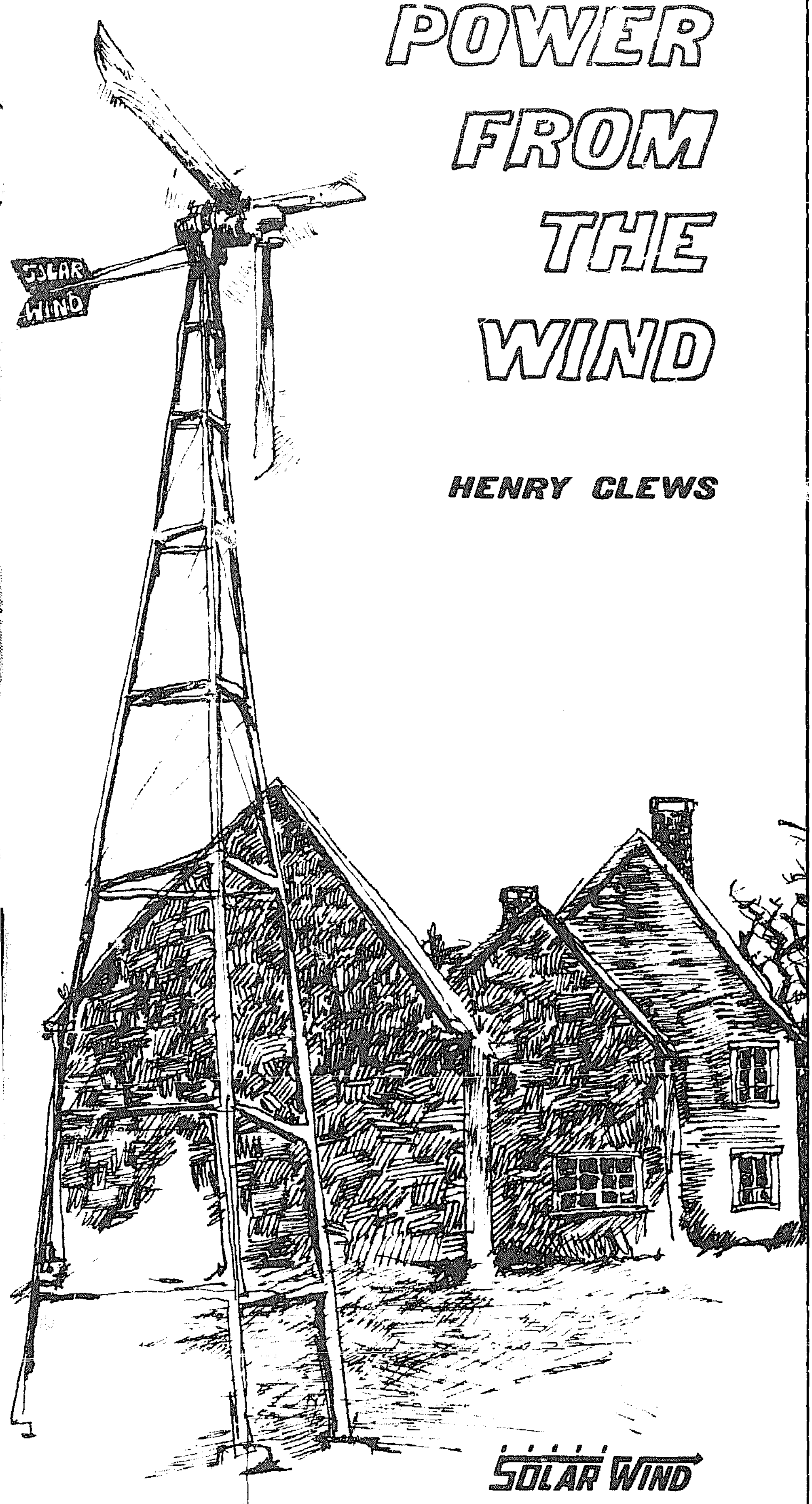

HENRY CLEWS

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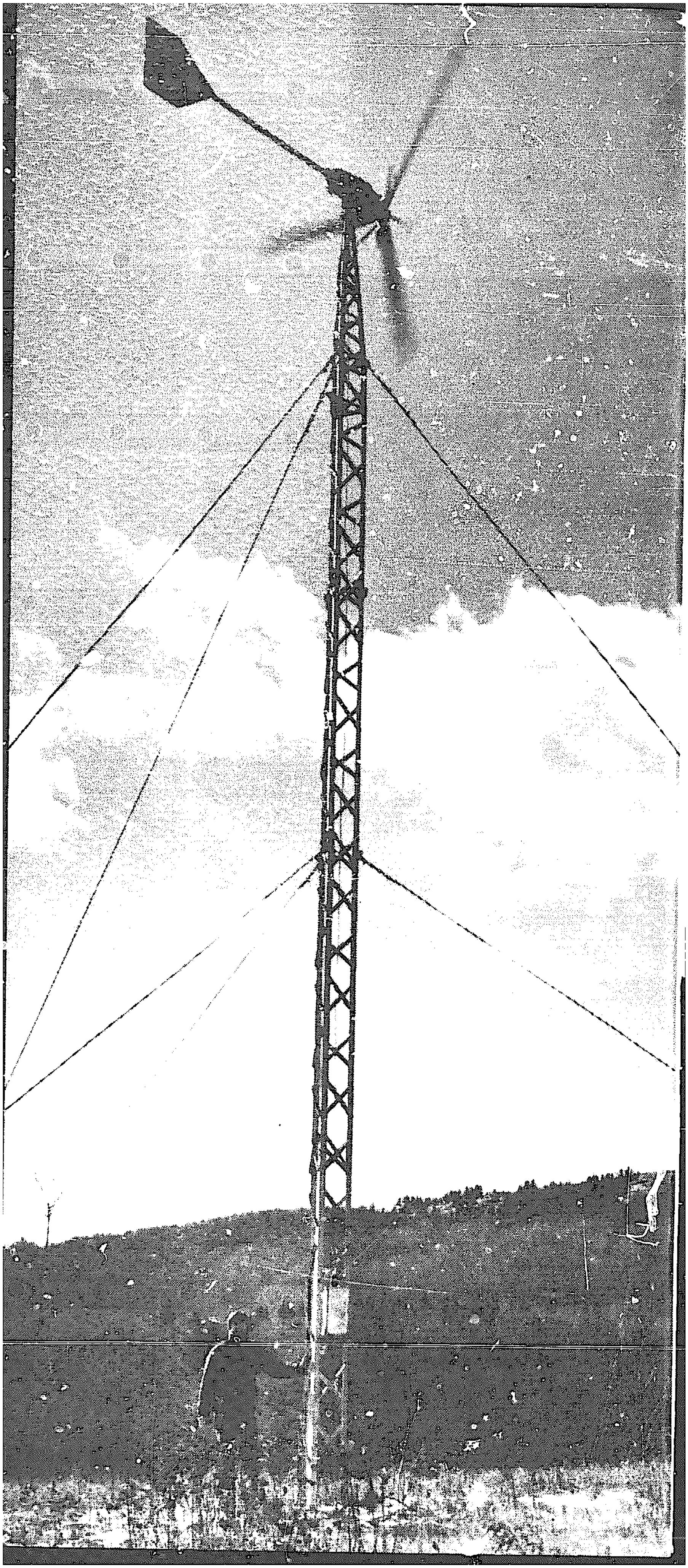

ELECTRIC POWER FROM THE WIND

A practical guide to wind-generated power systems for individual applications.

by Henry Clews

Revised, Expanded, and Updated, Fall 1974

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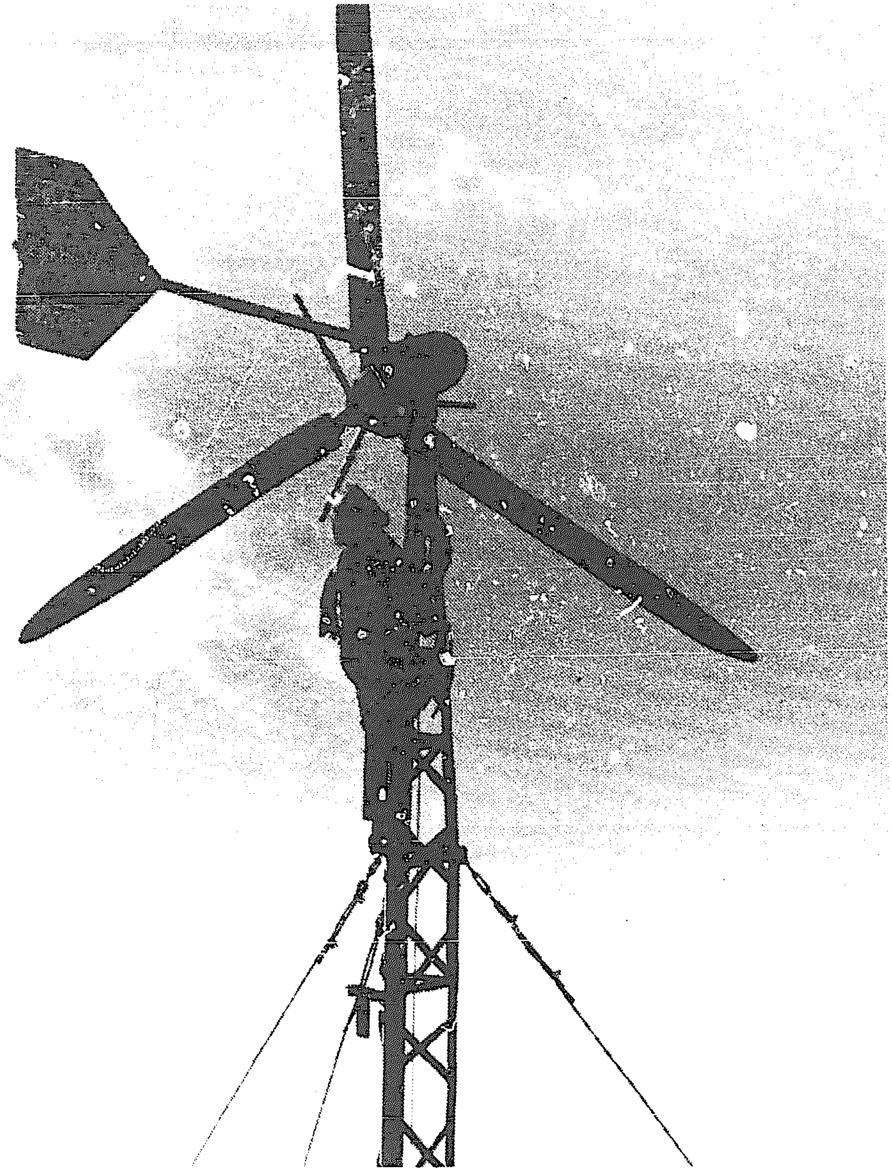


Preface to the Revised Edition

Two years have passed since I first wrote this booklet on wind power. Back then, we had just finished setting up the first large Australian wind-driven generator ever to be installed in this country to power our homestead in Maine. Even then, and that was well before the "energy crisis", there was considerable interest in our wind-powered electrical system. We responded to that interest by forming the Solar Wind Company to import and sell the Australian windplants and other related equipment; and we published this little booklet to try to answer the many questions on wind power which suddenly began coming our way.

This revised version of the booklet contains all the material of the original with minor corrections and revisions plus several new chapters, beginning with **Update 1974**, and covering the time period from spring 1973 to fall 1974. I have also expanded and brought up to date the listings of equipment manufacturers and other sources and references which appear at the back of, as well as throughout, the booklet.

ELECTRIC POWER FROM THE WIND

Revised and updated, Fall 1974

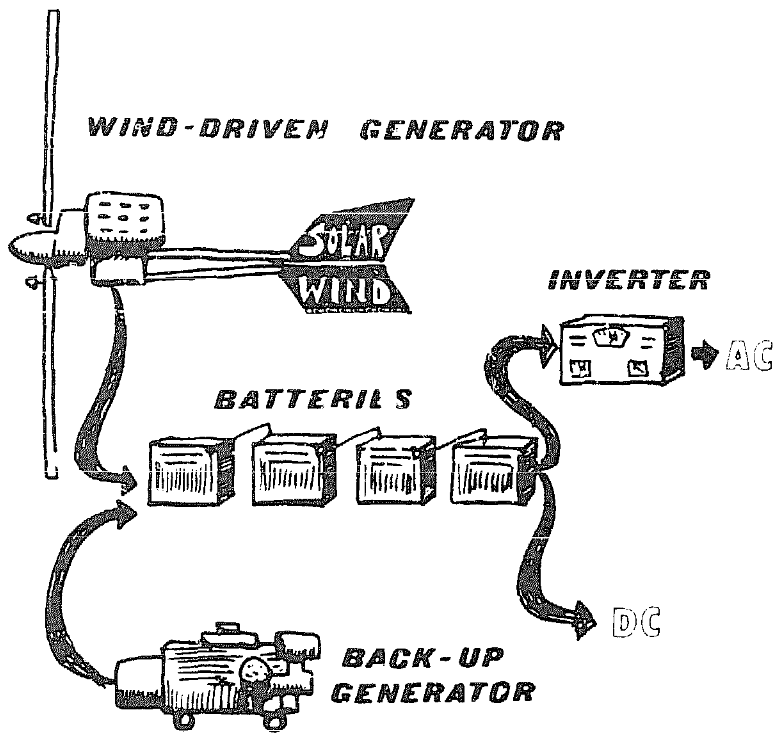
Thirty or forty years ago, wind-generated power played an active part in the electrification of many rural homesteads all across the country. Then the government pushed through the Rural Electrification program and within a few years banished these fledgling attempts at electrical self-sufficiency. The Power Company could provide more power at a lower cost by burning coal in huge plants and distributing the power on a network of wires to individual users. It was a case of mass production outstripping the individual manufacturer.

But there was one important difference. The Power Company was consuming an irreplaceable natural resource to produce its power. Coal represents millions of years of condensed energy taken from the sun and stored by prehistoric life on earth. Sure, it is cheaper to use this condensed high energy fuel than it is to use other lower energy sources. Cheaper in the short run, perhaps. But do we have the right to steal this limited resource from past and future generations, and to use up in a couple of hundred years what it took millions of years to produce? And to pollute our air and water in the process? And to rape our earth by strip mining? We at Solar Wind cannot accept this as a rational approach to power generation. And perhaps others are beginning to share our doubts, for suddenly there seems to be a tremendous interest in "new" sources of energy. Let's use the sun, the wind, the rain, the tides, the natural heat of the earth — but let's not use anything up!

By giving us "cheap" power, the Power Companies have taught us to be greedy consumers of power indeed. The United States at present consumes almost as much energy as all the other nations of the world combined, and about five times the per capita world average. We give little thought to the increased power consumption of modern conveniences. A frostless refrigerator, for example, uses almost twice the power of a conventional model. Electric heat consumes more than twice the energy that would be required if the same fuel were used directly as heat in the house. Most houses and buildings today are built completely without regard for natural sources of heat and light and cooling, as it is considered "cheaper" to let electricity perform these functions instead of nature.

If we are to successfully return to the use of "natural sources" we must begin by completely reassessing our present use of power. We must resist such Power Company propaganda as, "If it has a plug, she'll give you a hug!" Because, it turns out that when you use only natural, replaceable, low energy power sources such as wind, you just don't get huge amounts of "cheap" power. Instead you get moderate amounts of free, non-polluting, environmentally safe power from an independent source which only costs whatever you are willing to put into the apparatus for harnessing it. The choice is up to you.

So much for the sermon. Now for a detailed account of the workings of a modern wind powered generating system. Primarily, I will describe the operation of present day, production equipment which is available right now ready-built and fully assembled. But for the many people who are interested in systems they might build at home on a limited budget, I have included a good deal of general information which, I hope, will prove of value.



A complete self-sufficient home wind generating system consists of three or four parts: (1) the wind-driven **power plant** itself, (2) a **storage system** (usually a bank of batteries) to store the power for windless periods, (3) **conversion devices** to convert the generated or stored power to usable forms (usually from DC to 115 volts AC or standard "house current"), and (4) an optional **back-up system** such as a gasoline or methane generator for times when the stored power is not sufficient to last through a long calm spell.

The Wind Driven Power Plant

Virtually all electricity is produced by rotating electric generators which produce electricity by rotating magnets in front of each other. The Power Company uses huge generators turned by steam turbines, (or in the rare case of hydroelectric power, by water turbines). The steam to turn the turbines is produced by boiling water over a coal fire. New atomic energy plants function in the same way except that the heat to produce the steam comes from radioactive fission instead of coal. In an automobile, the generator is turned through a V-belt by the gasoline engine. Similarly, in a small portable power plant, the generator is turned by a gasoline, diesel, or LP gas engine. Thus all forms of useable electricity come from some type of a rotating generator which is driven by an external power source. The wind generator is no exception. A wind-driven generator consists of a rotating generator turned by a propeller which in turn is pushed around by the force of the wind upon it. The propeller can be thought of as a wind engine using wind as its only fuel.

Now, the amount of electricity that can be generated by a wind generator is dependent on four things: the amount of wind blowing on it, the diameter of the propeller, the size of the generator, and the efficiency of the whole system. Here are some specific examples to show you how this works. First consider an 8-foot diameter propeller with well-designed blades having an aerodynamic efficiency of 70% connected to a generator (also with an efficiency of 70%) capable of delivering 1000 watts. In a 5 mph breeze you might get 10 watts of power from it; at 10 mph about 75 watts; at 15 mph, 250 watts; and at 20 mph about 600 watts. As you can see, the more wind the more power. But it is not a simple relationship. In theory, the power available from the wind is proportional to the **cube of the wind speed**. In other words, if you double the wind speed you will get eight times as much power. The actual power output of a real windplant will, however, fall a bit short of the theory because of the inefficiencies of the system.

Now let's consider a propeller with a 16-foot diameter and with efficiencies similar to the 8-footer considered above. At 5 mph we might get 40 watts output; at 10 mph, 300 watts; at 15 mph, 1000 watts; and at 20 mph, 2400 watts (if the generator were capable of delivering this much power). As you can see the power output of the 16-foot diameter windmill is about four times that of the 8-foot diameter windmill. This shows that the power is proportional to the **square of the diameter**, or that doubling the size of the propeller will increase the output by a factor of four. And there you have the two basic relationships which are fundamental in the design of any wind-driven power plant. A careful study of Table No. 1 will further serve to illustrate these relationships.

Propeller Diameter in feet	Wind Velocity in mph					
	5	10	15	20	25	30
2	.6	5	16	37	72	125
4	2	19	62	150	290	500
6	5	42	140	335	650	1100
8	9	75	250	590	1150	2000
10	14	115	390	930	1800	3100
12	21	165	560	1350	2600	4500
14	28	225	770	1800	3550	6100
16	37	300	1000	2400	4650	8000
18	47	375	1270	3000	5900	10000
20	58	465	1570	3700	7250	12500
22	70	560	1900	4500	8800	15000
24	84	670	2250	5350	10500	18000
26	98	785	2650	6300	12000	21000
28	115	910	3075	7300	14000	24500
30	130	1040	3500	8350	16000	28000
32	150	1190	4000	9500	18500	32000
TABLE 1	**Wind-Driven Generator Output in Watts** 70% aerodynamic efficiency, 70% transmission & generator efficiency					

But what about efficiency and generator size? The efficiency (defined as the ratio of the power you **actually** get to the theoretical maximum power you **could** get at a certain wind speed) depends largely on what type of propeller you use. All modern electric wind-driven generating plants use two or three long, slender, aerodynamically shaped blades resembling an aircraft propeller. These propellers, with a typical efficiency of about 70%, operate at a high **tip speed ratio** which is the ratio of propeller tip speed to wind velocity. The Australian windplant propeller, for example, runs at a tip speed ratio of about 5, while for some of the Swiss Elektro units this ratio runs as high as 8. This compares to ratios of 1 to 3 for the slower running multi-blade American water-pumping windmill. But while the latter type is less efficient they do have a much higher starting torque and their steadier speed at low wind velocities makes them more suited for pumping applications.

Ideally, the propeller of a wind machine used for generating electricity should have a cross-section resembling that of an aircraft wing, with a thick rounded leading edge tapering down to a sharp trailing edge. It should be noted, however, that the most efficient airfoils for aircraft propellers, helicopter blades, or fan blades (all designed to **move** air) are not the most efficient airfoils for windmills (which are intended to be **moved by** air). An old airplane propeller, in other words, has neither the proper contour nor angle of attack to satisfactorily extract energy from the wind. If you have the ability and time, and wish to construct a propeller of your own, you will find several good designs to copy in the United Nations publication listed as Reference 3 in the back of this booklet. Also see Vol. 14 of A.S.E. magazine, Reference 8.

The Generator

The generator itself forms the vital link between wind power and electrical power. Unfortunately, most generators which would seem to be suitable suffer from the requirement that they need to be driven at high speeds; they are built to be driven by gasoline engines at speeds from 1800 rpm to 5000 rpm. But windmill speed, especially in the larger sizes, seldom exceeds 300 rpm. This means that one must either find special low speed generators (which are expensive and cumbersome) or resort to some method of stepping up the speed of the generator using belts, sprockets, or gears. The large commercially available units generally make a compromise here. They use a relatively low speed generator (1000 rpm) and they gear the generator to the propeller through a small transmission at about a 5 to 1 step-up ratio.

The next question is, how to decide what size generator to use with what size propeller. Well, here again some compromises are in order. First, you must decide what windspeed will be required for your generator to put out its full electrical output. If you want full output at low wind speeds you will need a large propeller, whereas if you are satisfied with full output only at high wind velocities, a smaller propeller will suffice.

In general light winds are more common than strong winds. Statistical studies of wind data show that each month there is a well-defined group of wind velocities which predominate. These are called the **prevalent** winds. There is also a well-defined group which contains the bulk of the energy each month called, appropriately enough, **energy winds**. The first group, consisting of 5 to 15 mph winds, blows 5 out of 7 days on the average, while the energy winds of 10 to 25 mph blow only 2 out of 7 days. It might seem, at first glance that you should design for maximum output at, say, 15 mph to take advantage of all those prevalent winds, but this would require a very large propeller for the power produced, and all the power from winds higher than 15 mph would be thrown away. As an example, consider a 2000 watt generator which is to yield its full output at 15 mph. From Table 1 we can deduce (assuming a 70% efficient system) that to get 2000 watts at 15 mph we will need something over a 22 foot diameter propeller. Now this will be large and expensive to build, and difficult to control in high winds. Besides, look at all that power you are throwing away at higher wind speeds. If you really are going to build a 22 foot diameter rotor, then you might as well install a bigger generator on it and get some of that power at higher wind speeds, right?

Well, in practice this is what is done. Most working wind generators are designed to put out full power in wind speeds of about 25 mph, and in so doing they do sacrifice some performance at low wind speeds. Usually they deliver almost no output at wind speeds below 6 or 8 mph, but this is really not a serious drawback because there is so little energy available from these light winds anyway.

Now you can begin to understand just what is meant by a "2000 watt" wind generator. As you can see it is hard to compare the rated output of a wind generator to that of a conventional generating plant with the same rating. In the case of the wind generator, the power rating merely tells you what the **maximum output** of the generator will be at a certain wind speed — and you must know what this wind speed is if you want to calculate how much power you will actually get from a certain windplant under varying wind conditions.

What Size System?

This brings us to the final problem in choosing a suitable wind electric system for your homestead. The question is, how much total electric energy will a certain size system produce over a period of time in your particular location? This is the main concern of anyone attempting to determine the feasibility of a wind generator in their area — and it is also the most difficult question to answer. Suppose you have sat down and, with the help of the tables in the back of this booklet, you have figured out that, to run everything you want to run in your new wind-powered homestead, you will need 200 kilowatt-hours of electricity per month. If all your power is to come from the wind, you will need a system that will provide at least this much per month and a little more besides to allow for the slight inefficiency of the storage batteries.

Well, to actually figure out precisely how much a certain system will deliver in a given location, you must know not only the complete output characteristics of your wind generator at different wind speeds, but also you must have complete windspeed data for the proposed installation site. And by complete, I mean enough data to plot a continuous graph of the wind speed for a year or two. Such a graph would allow you to compute the *total* energy available from the wind in your particular location. Roughly, the power available would correspond to the area under the curve, but even this is not mathematically correct because of the cubic dependency of power on wind speed. To do it right, would require some pretty sophisticated statistical analysis which we will certainly not venture into here — and actually it all becomes pretty academic since few people have good enough wind data for their location, anyway. But, if you **do** want to know more about this, References 1 and 2 at the back of this booklet will be of some help.

Now, lest you begin to despair, let me give you some idea of how to procede in the absence of all the facts. This might be considered "fudging it", but unless you're planning a very expensive commercial installation, it will certainly get you into the right ball park. First, find out what the **average** yearly winds are in your location. The Weather Bureau records wind speeds hourly at several hundred stations across the country, and if you write them (see Source 7) you can get this information including average wind speeds for each month and year at a station near you. Use this as a start, but don't consider it definitive. Winds at your actual site may vary considerably from those at the local weather station, so you will probably want to carry out some tests of your own, especially if you are in a doubtful area, i.e. official average winds much under 10 mph.

Later we will discuss measuring wind speed and selecting the best site in more detail, but for now let's assume you have satisfied yourself that the average winds at your location are, say, 12 mph. Well, we have prepared a handy-dandy little table based on our limited experience in this field, which will hopefully give you some idea of what you can expect from different size windplants at various average wind speeds. As you will appreciate, many factors enter into this and we have had to make several assumptions. First, these figures are based on typical present production wind generator designs with tip speed ratios on the order of 5 and efficiencies of about 70%. It is also assumed that there is negligible output below wind speeds of 7 mph and that maximum output is reached at 25 mph. This table represents a composite of actual measurements, plus some figures put out by several wind generator manufacturers plus a fair amount of interpolation.

As I said, this table should only be considered as a rough estimate of what you can expect from wind generated power in different wind areas. Many manufactureres of wind generators refuse to commit themselves to anything as specific as the figures listed in this table because they claim that conditions vary so much, what with the effect of turbulence, temperature, etc., that they would only be sticking their necks out to make any specific predictions of long term energy output. Nevertheless, I feel that this is the one basic statistic that everybody wants to know when he considers installing a wind electric system and so have included this table for your use.

Nominal Output Rating of Generator in Watts	Average Monthly Wind Speed in mph					
	6	8	10	12	14	16
50	1.5	3	5	7	9	10
100	3	5	8	11	13	15
250	6	12	18	24	29	32
500	12	24	35	46	55	62
1000	22	45	65	86	104	120
2000	40	80	120	160	200	235
4000	75	150	230	310	390	460
6000	115	230	350	470	590	710
8000	150	300	450	600	750	900
10,000	185	370	550	730	910	1090
12,000	215	430	650	870	1090	1310
TABLE 2	AVERAGE MONTHLY OUTPUT IN KILOWATT-HOURS					

Now we may proceed to use the table to solve the original problem which was, how large a system will you need to get that 200 kW-hrs per month in an area with a 12 mph average wind speed? Checking Table 2 under the 12 mph column we find that a 2000 watt system would produce only 160 kW-hrs while a 4000 watt generator would produce 310 kW-hrs. Interpolating between these two values we can estimate that a 3000 watt unit might produce 230 kW-hrs per month which is just about right allowing for the inefficiencies of batteries, inverters, etc. Of course, when it comes around to buying or building such a system you may be forced by financial considerations, or by what is actually available, to install a larger or smaller system, but at least you'll have some idea what you can expect from it when it's all done.

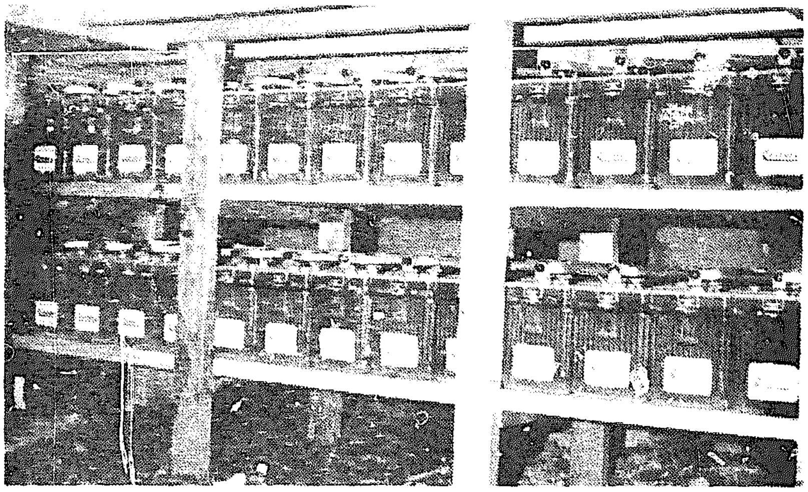
Perhaps, as we were talking about maximum outputs at 25 mph and such, you were wondering what happens at higher wind speeds. Well, all modern production windplants are designed to function completely automatically in winds up to at least 80 mph or even higher, so rest assured that there is no such thing as a site with **too much** wind. In order to survive all kinds of winds, wind generators employ some method of holding down their speed in heavy winds. The most common method of spilling excess wind, whenever the power from the wind exceeds the power rating of the generator, is a system of weights mounted on the propeller which act centrifugally to change the pitch of the blades, thus reducing the wind force on the propeller. This system, which amounts to a built-in governor, holds the propeller at a constant speed and prevents overspeeding when there is little or no load on the generator — which happens whenever the batteries are fully charged and no power is needed. This is one area where the modern windplant has come a long way in solving a problem that plagued the windchargers of forty years ago. Burned out bulbs and even burned out generators were not uncommon with the old units as the windplant raced out of control in heavy winds.

But even with the modern version, the manufacturers generally recommend that if wind speeds greater than 80 mph are anticipated, as in a hurricane, the propeller should be manually stopped and/or rotated sideways to the wind. Most models have a brake control located at the bottom of the tower for this purpose. Such "furling" of the wind generator during a storm greatly reduces the strain of high wind loads on the propeller and on the entire tower structure. The Swiss Elektro unit can be purchased with an automatic furling control which allows for unattended operation in winds up to 120 mph.

The Storage System

Power **storage** is certainly the key to any successful wind powered electrical system. About the only thing you can say for certain about the wind is that it is always changing; and really, the only reason wind power isn't used more widely is because of its unsteady nature — sometimes it's there and sometimes it isn't. Well, the obvious solution to this problem is to get your power while you can and put it away for when you need it. In theory, at least, there are many ways of doing this. And right now plenty of people are working hard on the problems of energy storage, because they know that this is the key to efficient use of many forms of natural energy which persist in coming in intermittent doses. One of the most promising types of storage for wind generated electricity, I feel, is conversion of electrical power to hydrogen and oxygen gases by electrolysis of water. These gases may then be stored in tanks and later used to produce power either by direct combustion, or in a fuel cell to produce electricity.

But right now, if we are to proceed to construct an operating wind power system from reliable existing components, we must content ourselves with the good old lead-acid battery. This type of battery has been around for a long time and we know a lot about its behavior. We can predict just how it will act under various conditions and how long it will last. And as of now, it still represents the cheapest practical method of electrical energy storage available for the individual user of wind power.



The storage batteries used in wind systems are similar to ordinary automobile batteries, but they have thicker lead plates and are specifically designed for repeated cycling over a period of many years. This means they can go from a fully charged to a fully discharged state over and over again without damage. The ability to withstand over 1000 complete cycles is typical of this type of battery. Often they come with built-in "Pilot Ball" charge indicators which tell you at a glance the state of charge of the batteries. Batteries specially made for this purpose are known as "stationary" or "house lighting" storage batteries and are available in sizes from 10 amp-hours to 8000 amp-hours. The smaller sizes (up to 150 amp-hrs) usually come as three-cell six-volt batteries, while the large ones come as single-cell two-volt batteries. It takes sixty 2-volt cells connected in series to produce 120 volts. The number of cells determine the voltage, but the amount of power storage capacity is determined by the size of the batteries and the number of plates in each cell.

The battery set used in each home power installation must be carefully chosen to meet the needs of the individual situation. A typical modern wind power installation will employ battery storage capacity sufficient to meet normal electrical needs for a period of at least three days without wind, and often sufficient capacity is provided for as many as seven windless days. Here is a case where you must balance the initial investment of the batteries against the continued smaller expense of fuel for the back-up system.

If you opt for only two days of storage you will probably find yourself starting up the gas generator three or four times a month to pull you through the flat spots. But if you can store a week's worth of power, you might not need that back-up system at all.

Power Conversion Devices

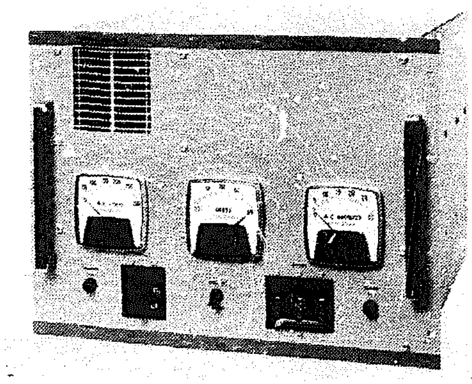
And now we get to the technical part. To begin with, there are two basic types of electric generators: the **alternator** which generates alternating current (AC) and the brush type **generator** which generates direct current (DC). All power companies in the U.S. use alternators which generate 60 cycle per second alternating current. This means that the electricity pulses back and forth, changing its direction of travel in the wire 120 times each second. Since this is the standard power available, all electrical appliances and devices are made to operate on this type of steadily pulsating electricity. So if we are to have a practical power source for everyday household use, we must somehow supply this type of alternating current, and at the standard voltage which is about 115 volts.

Now this poses a definite problem for a wind generating system because 60 cycle alternating current is produced only by an alternator turning at a constant speed, usually 60 revolutions per second. But since the wind never blows at a constant speed, you cannot get a constant number of revolutions per second from a wind-driven alternator. Instead, you get an rpm which varies with the wind speed. (The main reason power companies provide us with AC is for **their** convenience: AC can be transmitted along power lines more easily.)

One solution to this problem is to go ahead and use an alternator to generate the power (because it is more efficient and lasts longer than a generator) but don't worry about the uneven rpm. Pass this AC through rectifier diodes and convert it to a steady DC current which can then be sent directly to the batteries for storage. Now, to get that steady 60-cycle AC we've been working up to, you can use another alternator run by a DC electric motor which can run off all that nice DC current you just stored in your batteries. This DC will not fluctuate and so your alternator will turn at a constant rpm! Such a device is called a "motor-generator" or a "rotary inverter" and it produces electricity which is indistinguishable from the Power Company variety. The reason I mention this is that there are other ways of converting DC to AC but often these produce a "square wave" instead of a sine wave, which is what the Power Company makes. You need the sine wave for static-free stereos and distortion-free television sets. In other words, many electronic devices are sensitive about the shape of the wave.

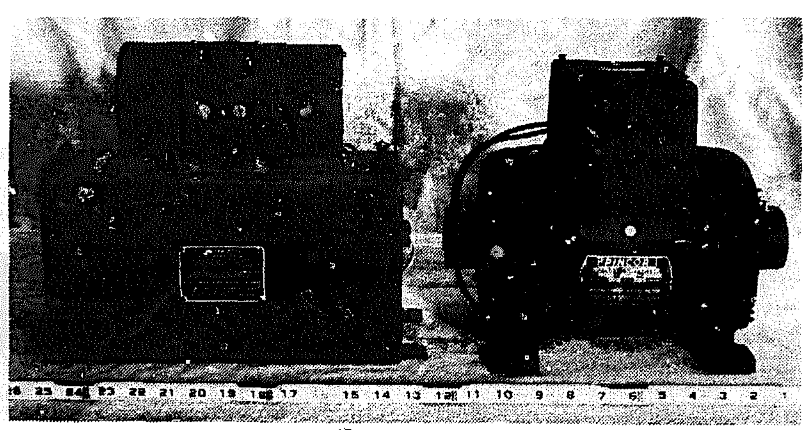
A "wave" is produced when you make a graph of the voltage on one axis and time on the other axis. It shows you graphically how the voltage (or current) is fluctuating with passing time. A graph of DC current would be just a straight line. (I told you this was going to be the technical part!)

The mechanical rotary inverter is only one way of converting DC to AC. Although it does a good job, it is not very efficient—on the order of 60%. There are now available many types of electronic, solid state inverters, which perform the same function as the rotary inverter, but more efficiently — about 80% is typical for these units. They contain no moving parts at all and many of them produce an approximation of a sine wave which is good enough for all practical purposes. The only problem is that they still tend to be more expensive than the old-fashioned rotary inverters which are available as army-navy surplus items.



A modern electronic DC to AC inverter

One final remark about power conversion. As it turns out, if you have chosen a convenient voltage for your whole system (such as 12 or 115 volts), you can use much of your power directly from the windmill and batteries as DC, and not put all your power through an inverter. Since the inverter uses some power just to run it, you want to use it as little as possible and save that power. Light bulbs, all devices with simple heating elements, hand power tools and other appliances with universal AC-DC motors, will work very nicely right off your DC with no conversion as long as the voltage is right. (This is one important reason for choosing a 115 volt system.) Now you can save your inverter for the record player, electric typewriter, radio, or television. This is what we do.



Government surplus rotary inverters. Left, 60 watt; right, 300-watt.

Our Original Wind Electric System

Speaking of what we do . . . We presently have in operation at our homestead in North Orland, Maine, a complete wind electric system which provides **all** of our power for lights, power tools, appliances, and water pump. The original windplant, installed in the summer of 1972, is a 2000 watt, 115 volt, Dunlite "brushless windplant" mounted atop a 40-foot steel tower out behind our house. These components, as well as the 130 amp-hr houselighting batteries which provide our storage for windless periods, are all standard production items which we purchased and imported from Quirk's in Australia. (Later we found out that Quirk's is merely a sales representative for the Dunlite company who is the actual manufacturer of the equipment, and so we began to deal directly with them.)

Our Dunlite windplant consists of a large 115 volt, three-phase AC, low speed alternator which is attached through a gearbox to a propeller hub which holds three long slender aerodynamically shaped propeller blades. The diameter of the propeller is 12 feet. The whole unit, generator, gearbox, and propeller is mounted on a free-swivelling platform onto which a tail has been attached to keep the propeller blades facing into the wind. Also contained in the swivelling base are three silver-coated slipring commutators which conduct the electricity from the generator above, down to the fixed tower top below.

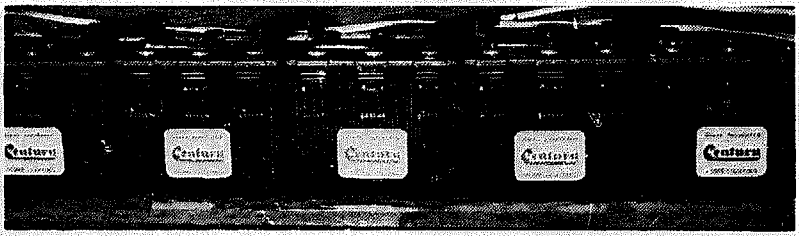
The Dunlite company manufacturers windplants in several different models. The one we chose is their largest size and is one of two alternator models offered. The prime advantage of an alternator is that it has no brushes to wear out and need replacement. The **only** maintenance required on these units is an oil change of the gearbox oil (one quart) once every five years. Dunlite claims that several of these windplants have been in continuous operation for over 30 years without need of service. It is hard to imagine any engine driven generating plant giving such service. In fact most common models require a complete overhaul over 1000 hours of use — which figures out to only 42 days of continuous use! This is something to consider when comparing costs of wind electric systems to conventional systems — not to mention the costs of fuel for the engine driven rig.

Our windplant begins to turn in about 5 mph winds and actually starts charging the batteries in 9 mph winds. Outputs at various wind speeds, from our measurements, are: 10 mph, 60 watts; 15 mph, 600 watts, 20 mph, 1200 watts; and 25 mph, 2000 watts or the full rated output of the generator. This data shows close agreement with the theoretical output of a 12-foot diameter wind generator with 70% efficiency (see Table 1). At full output the propeller is turning at only 150 rpm while the generator which is geared to it at a 5 to 1 ratio, turns at 750 rpm — or about the idling speed of an automobile engine. The slow speed of the Dunlite generator is responsible for its long life. For the propeller the slow speed is not only desirable, but necessary. It is desirable because the efficiency actually decreases when tip speeds begin to exceed 100 mph, and it is necessary because large, and potentially destructive, centrifugal loads can build up in a large propeller at high speeds. The huge 175 foot diameter wind generator on Granpa's Knob in Vermont (pictured below) developed its full power at a propeller speed of only 28 rpm!

For more information on this gargantuan wind machine, see Ref. No. 1 at the back of this booklet.

Now you begin to see the importance of the batteries. The more, and the larger the batteries, the bigger the tank and the better you can maintain continuous power through periods of fluctuating winds.

Our battery set consists of nineteen, 6-volt, plastic-encased, lead-acid storage batteries. Connected in series, these batteries have an output of 115 volts and a capacity of 130 amp-hrs. This means (roughly) that you can draw 1 amp for 130 hours, or 10 amps for 13 hours, or anything in between. In practice this seems to give us about four days of storage without wind. These batteries were manufactured by Century Storage Battery Company in Australia, and they have built-in "gravity ball" indicators which tell you at a glance their state of charge. In our house, they are mounted in a long row under a bench which can be folded up to inspect them; the addition of water is required about once a year. A lifetime of more than 10 years is claimed by the manufacturer for these batteries in this type of service.



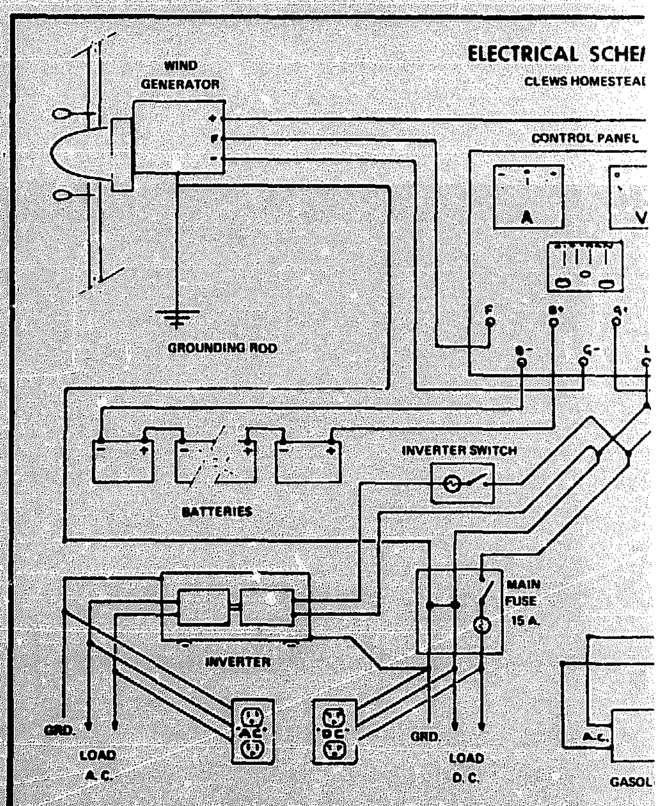
In the first six months that the wind electric system was in operation, we ran our auxiliary gasoline generator a total of 20 hours to maintain continuous power. This consumed 5½ gallons of gas at a total cost of $1.75. If you are really dependent on power, for instance running a refrigerator or freezer, a back-up power source is definitely recommended — unless you are willing to buy enough batteries to store a week's worth of power. Our back-up generator, purchased from Sears, is a 1600 watt model that cost about $200. More permanent models operating on LP gas or diesel fuel are also available and will outlast the small portable models. In any case, a standard 115 volt AC generator can be used to charge 115 volt batteries simply by passing the current through a full-wave rectifier assembly (available from Solar Wind).

Our Power Conversion Devices

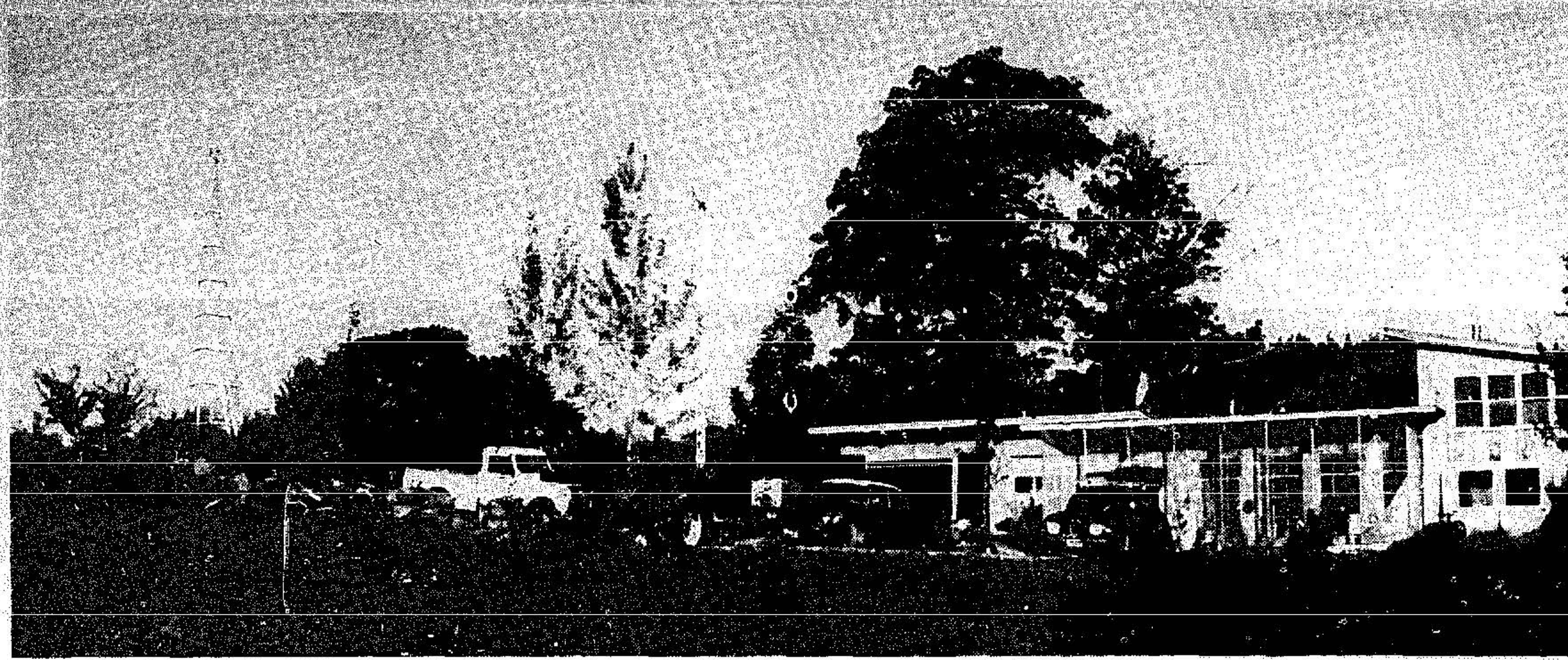
In order to convert our 115 volt DC power to AC we initially installed a 250 watt navy surplus rotary inverter. This was a motor-generator type unit like the one described earlier and it has built-in controls which maintain the voltage and 60-cycle frequency constantly no matter what load is being drawn. This inverter gave us perfect TV, radio, and stereo operation, and it provided a good source of steady 115-volt AC "house current" for all small appliances which use 250 watts (2.2 amps) or less.

What we have done is to run two sets of wire ouse
and in most places put two outlets side by sid abeled
"AC" the other "DC." The DC outlets are alwa out the
AC outlets come to life only when the inverter on —
which is now done by flipping a switch near the ol panel.
Many modern inverters come equipped with itomatic
load-sensing switch which will start up the unit never an
AC appliance is turned on, but of course this cc dditional
money. As it is now, since the inverter draws current
just to run it, it is switched on only when nee But even
doing this, we found that it was quite wastef use our
original 250 watt inverter for such items as electric
typewriter and solid-state stereo. These draw than 50
watts apiece but were often on for long periods e. When
run through the inverter, these appliances drawing
about 150 watts DC or about three times the mal AC
consumption. The reason for this is that
inverters are very inefficient at small loads.
when there is no AC load on the inverter, it draw
DC power from the batteries just to run itself —
"no load" power consumption.

To solve this problem, and to make the syster
as possible, we purchased another smaller 75
inverter which only draws 15 watts at no loa
inverter, the hi-fi and typewriter only use 50
power. So you can see that by matching the
inverter to the load, you can drastically cut dow
using the relatively inefficient, but cheap, rot



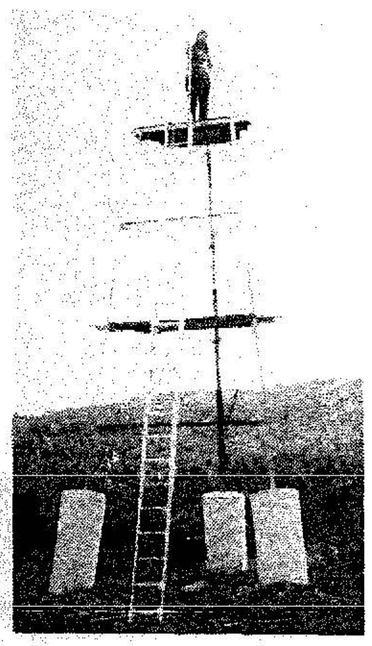
Schematic showing how our wind electric system was or using one rotary inverter to provide AC.



Our wind-powered homestead, summer 1974. Dunlite 2000-watt left, Elektro 6000-watt center.

Of course, the best answer to the problem of DC to AC conversion is an electronic, solid-state inverter. These units are about 80% efficient and have low no-load power drain (or no drain at all in the case of the load-demand starting type). Also, these units can be purchased in sizes large enough to provide AC power for an entire household, making dual AC and DC wiring unnecessary. The biggest drawback to these large units is their expense; a 3000 watt electronic, sine-wave inverter with automatic load-demand start presently sells for over $4000!

Installation



Although we purchased all the components as factory-built items, we installed them ourselves without outside help. As a base for the tower, we used cardboard "Sonotube" forms and filled them with concrete to form 3 eight-foot pylons buried three feet in the ground. There is one cubic yard of concrete in each pylon. The tower comes in all these little pieces and must be bolted together — the biggest Erector Set you ever saw! We chose to set the base first and build the tower up from the ground, which is not too hard if you're not scared of heights. The top is as high as a four story building. (Wife adds here that the scary part was for the helpers on the ground who were constantly dodging falling tools!)

The only problem with building it from the ground up, as we discovered to our chagrin, is the setting of the windplant — a mere 400 pounds — on top of the completed 48 foot tower. Of course you could hire a crane, but that's no fun. What we did was much more interesting. After several false starts, again involving falling objects and bad tempers, we got a wooden tripod on top of the tower, with a pulley under the tripod's peak. We passed a stout rope through the pulley and attached one end to the 400 pound windplant and the other end to a 4000 pound Land Rover. Retta, my wife, drove the Land Rover slowly away from the tower while the kids sat under a nearby tractor for protection and shouted directions. Up went the windplant — oh yes, with a guy wire attached to a brother-in-law — and I, waiting at the top to receive it, wasted no time in bolting it quickly in place. Mostly it worked out OK and it proved that the whole installation can be done without expensive equipment or hired professional help.

In the second installation of an identical unit, some 35 miles south of here, they did it differently. There, they assembled the entire tower lying down. The complete windplant was attached, and even wired, and then the whole rig was pulled up into position by a small crane hired for the job. Although this cost a little more than our method, the entire job was completed, and the windplant was put into operation, within 10 days after the equipment was unloaded from the freighter in Boston!

This installation, in Lincolnville, Maine, was the second Dunlite system to be put into operation in the United States. It was installed to replace a 5000 watt LP gas generating plant which previously supplied power at a cost over $50.00 per month (plus many headaches with service and maintenance problems). A wind electric system may have trouble competing financially with Power Company power, but it really comes into its own when compared with any other type of independent power plant. In his new installation in Lincolnville, the owner figures that, compared to his gas generator, the wind generator installation will have completely paid for itself in 3 to 4 years time. From then on the power is FREE!

Pros and Cons

But there are always skeptics. We have received many letters saying, "Sounds neat, but how does it work out in practice?", or, "If it is such a great idea, why aren't other people doing it?" Well, the fact is that quite a few other people are putting wind power to practical use. In the mountains of Switzerland there are several hotels and restaurants with modern electrical equipment which rely completely on the wind for their electrical power. And near Albuquerque, New Mexico, Robert Reines lives in a house which is completely powered by the wind — and heated by the sun! (See photo below). And there are many others. We have received many letters describing wind electric systems either planned, or already in operation, all through the U.S. and Canada.

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never an
dditional
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n, there's us. We are a family of four living quite ly in the wilds of Maine with only the power we get gle Dunlite windplant. How does it work out in Well, so far it's done all we've asked it to do. That power enough for six or eight 75-watt light bulbs ning, radio, TV, stereo, electric typewriter, aster, vacuum cleaner, skill saw, electric drill, as a ⅓ hp deep-well water pump. Compared to life had power at all, it's heaven. An old hand pump romantic, but it ain't!

nain fuse box we have 15-amp fuses, so I guess if o compare our wind electric system to the Power service, you could say we have a 15 amp service. the tools are used during the day and the lights at ve had no problem with overloads as yet. We hat with our system, which has been in operation ıst 15, 1972, we are getting about 110 kilowatt-hours al energy per month. This is on the order of one amount of power that the average American nsumes from the Power Company. If you check nd 4 in the back of this booklet you can get a better nat 110 kW-hrs of power really means in terms of ıome appliances. A refrigerator, for example, requires about 95 kW-hrs per month, and as you can ystem could not supply this much more in addition esent load. So, even if we had an inverter large handle a refrigerator, right now we do not have the wer to run one. At present we use an LP gas tor which works very well, but we are already to add additional wind powered generating ıt to provide for an electric refrigerator and freezer. ıeral we are well pleased by our present system and to be amazed at its day in day out trouble-free through rain, sleet, snow. Even ice storms and to 60 mph have had no adverse affect on our wind

A wind electric system does have some limitations — that is, unless you are willing to go all out for a really large system. Most systems do not provide 230 volts for large appliances such as electric ranges, clothes dryers, air conditioners, baseboard heat, etc. It is possible to obtain 230 volt wind generators on special order, but generally the items which require this voltage also use large amounts of power and require a large expensive system. One approach to this problem is to use **two** large 115 volt wind plants to provide both 115 volt and 230 volt power using a dual set of batteries as well. A complete system of this type using dual 6000 watt generators, 500 amp-hr batteries, a 3000 watt dual voltage inverter, etc., might cost about $18000. and would provide up to 1000 kW-hrs of power per month in a good wind area. Now something like this **would** provide enough power for an electric range, electric hot water heater, electric dryer, and even some electric heat. And just think, it's all free after the initial installation!

But our present system isn't quite so elaborate, and for the time being anyway, we are content to use wood for heat and cooking in the winter and bottled gas in the summer. And for a clothes dryer we use a special "solar-wind" model, which you too can set up in your own back yard for less than one dollar! (Think about it.)

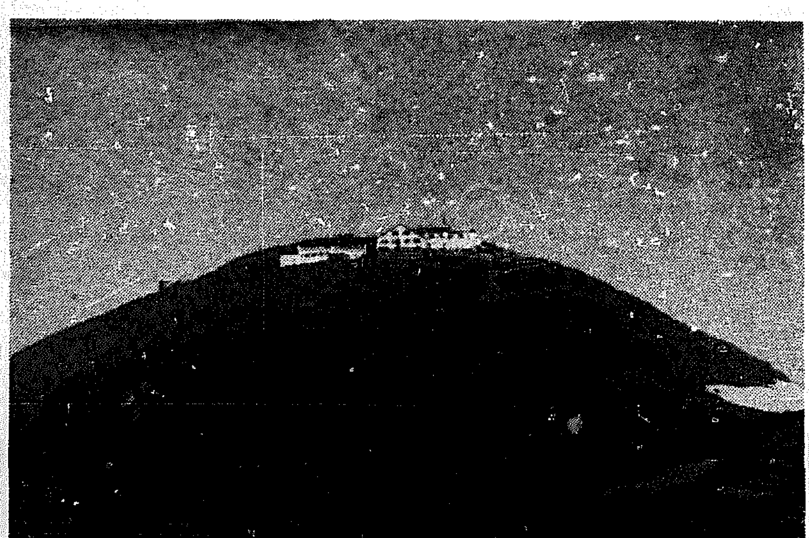
Wind Speeds and Site Selection

Our location is about 15 miles inland from the Atlantic coast roughly on a line between Southwest Harbor and Bangor, Maine. Our elevation here is 500 feet above sea level but we are not located on the highest ground around by any means. There is a 950 foot mountain a half mile to the southwest and an 850 foot hill a quarter mile to the northeast. But inspite of these wind blocks we still get winds which seem to average 9 mph which is exactly the published average wind speed at our nearest weather station, the Bangor International Airport. Of course, it's not the average winds that give you power, but the 15 to 20 mph breezes that really count. I would guess that we get 2 to 3 of these per week for a period of at least 6 hours. There is no doubt that the immediate topography has a very important effect on the winds. You should not rely too heavily on statistics for nearby areas, but instead carry out some tests of your own. And in actually selecting the exact site for the windplant you might want to make some careful studies of wind behavior in your particular area. For example, we have found that while maximum height is generally desirable, locations even fairly high up on the side of a hill (especially the east side) may not be as good as a location much lower but farther away from the hill. Usually if you cannot get right on top of a hill, it is better to stay away from it altogether.

If you want to find out more about the winds in your location, you might try the following. Get yourself a wind guage, (a hand-held model, the Dwyer Wind Meter, can be purchased from Solar Wind for $7.50 postpaid), and go out and take a reading every day at the same time, preferably in the afternoon, in the location, or locations, that you consider best for your windplant. Of course this may mean climbing a fifty-foot tree every afternoon at 3 P.M. but the exercise will do you good! If getting up into the air is a problem, try to find a location nearby that will allow you to get up into clear air. I would think that if the results of your tests show that there is over a 10 mph wind an average of 2 to 3 days per week you have an adequate site for wind power.

You might also wish to compare your own local readings with those of your closest weather station. If, after you have faithfully recorded wind speeds every day for a month, you go visit your local weather station, you can compare your figures to theirs taken at the same times. In this way you should be able to form a direct correlation between your figures and theirs and thus establish a relationship that will allow you to apply the long-term wind data collected by the Weather Bureau over many years to your particular location. (This statistical weather data is available from Source No. 7).

Remember that even in an open field with no trees around, the wind speed at 30 feet above the ground is always 20% to 50% stronger than at the surface. I think that any successful large wind generator should be mounted at least 30 feet above the ground and additionally about 10 feet above any surrounding objects, trees, buildings, etc., within a 500 foot radius. Distances up to 1000 feet away from your house are acceptable but the closer the better and the cheaper the lead-in wire will be.



An ideal site for a wind-driven generator! [Switzerland]

Update 1974

Since the original version of this booklet was written in early 1972, we have made some of those changes anticipated back then. In the summer of 1972, we erected a second wind driven generator, a 6000 watt, 115 volt Swiss Elektro windplant with a 16½ foot diameter propeller. This unit was placed atop a 50-foot guyed tower and connected to a second, and larger, set of houselighting storage batteries. Again, we did the installation ourselves, proving that it can be done without any expensive equipment.

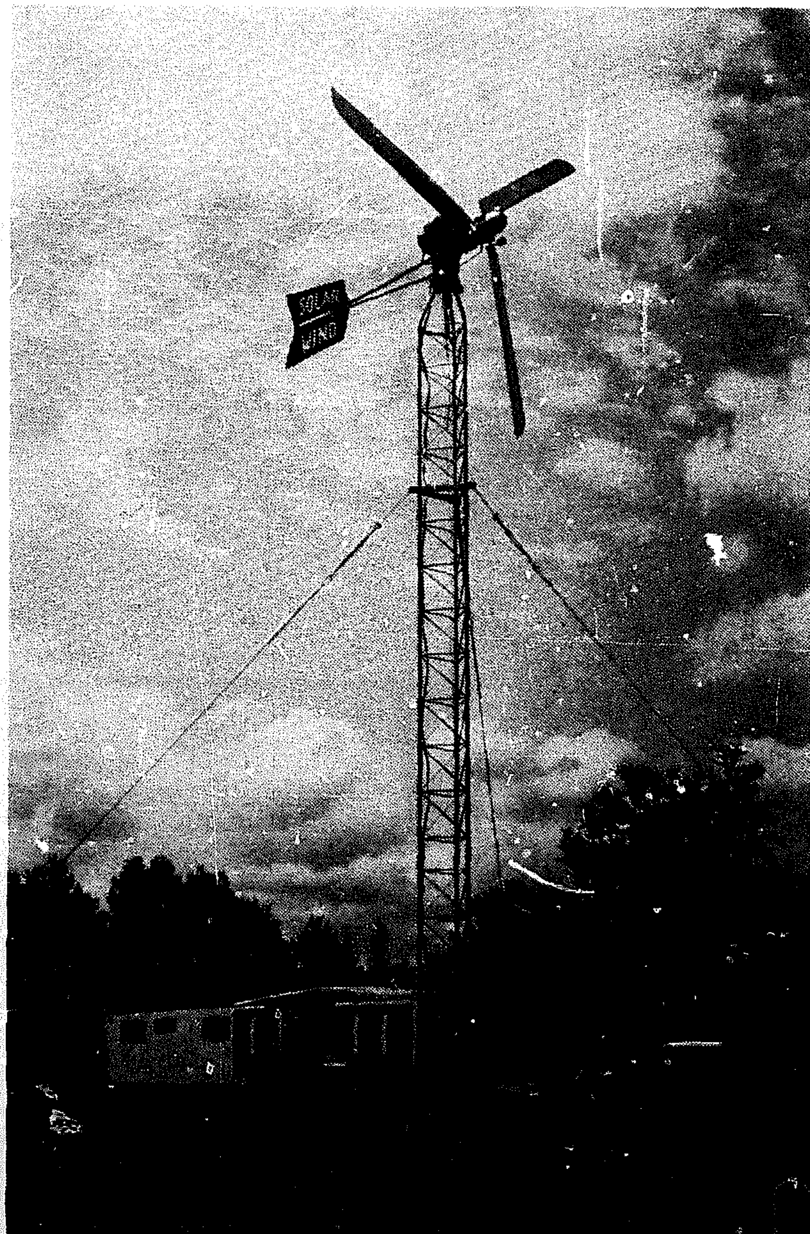
The installation of the second windplant along with the addition of a new 3000 watt electronic inverter, more than doubled the capacity of our wind electric system. We now have 60 amp fuses in the main DC fuse box and 30 amps on the AC side.

The two battery sets are connected together in parallel so that power from either wind generator can flow into either set. Even though neither the windplants nor the battery sets are equal in size, this arrangement seems to work out very well as there is always a tendency for the charge in the batteries to equalize.

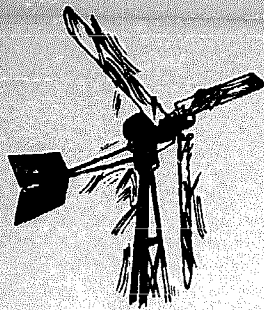
The large inverter gives us an efficient and abundant source of standard 115 volt, 60 cycle AC current for large shop tools and appliances. (Previously we were limited to about 300 watts of AC power which we used for TV, stereo, etc., but we had to convert all larger appliances, such as the water pump and table saw, to operate directly on DC power.) Now we can run any standard 115-volt AC appliance including those with up to a 1 hp motor.

Our present set-up, then, includes two wind-driven generators, two battery sets, a large inverter, and a small back-up generator with rectifier diodes for charging the batteries during prolonged calm spells. We use our wind generated electricity to power our house and shop, as well as a nearby guest house which houses our resident electrical engineer. So we are powering two houses, which includes some ten 75 watt lights, ten small flourescent lights in the workshop, a ½ hp. deep-well water pump, a small refrigerator, radio, stereo, TV (color, no less), miscellaneous appliances such as a blender, toaster, waffle iron, vacuum cleaner, sewing machine, etc., and a variety of shop tools including a drill press, band saw, grinder, sander, skill saw, table saw, etc. We also now have an electric hot water heater which is hooked up to operate in conjunction with our gas unit. An automatic relay switch allows the heater to come on only when there is excess power available from the wind generators, but it cannot draw power from the batteries. This allows us to use power which is normally wasted and at the same time cuts down considerably on our gas bill. A similar relay switch unit can be used to operate a space heater to supplement home heating during prolonged windy spells when the batteries can no longer accept further charge.

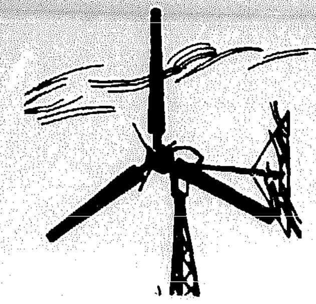
In all, our present system works well. I think you could say that we are proving that wind power is a viable source of power for a rural homestead given the proper circumstances. Our average wind of only 8.6 mph is now providing power for seven people living in two houses with more than a minimum of modern conveniences. We are still totally delighted with our windpower system and can find no fault with it whatsoever besides the high initial cost of the equipment. We are still hoping to get to work on developing cheaper models that we can manufacture in this country, but so far we've received so much interest in the "furrin" units, that we just haven't had the time to get to that new design!



A 2000-watt Dunlite windplant mounted atop a 30-foot Rohn guyed tower powers the new Solar Wind office trailer located on the Bar Harbor Road in East Holden, Maine.



Dunlite vs. Elektro



When people see the two different windplants operating at our house, they invariably ask, "which one do you like better?" Well, I don't have a quick answer to that question, perhaps because each machine has its own personality and I like them both.

The original Dunlite windplant continues to function flawlessly after two and a half years. We did change the oil in the gearbox last year when we found out that a thinner oil (SAE 90) is recommended in our colder climate. But other than this, the unit has required no attention whatever.

The 2000-watt Dunlite windplant has a 12-foot diameter propeller with metal blades, while the 6000-watt Elektro unit has a 16½ foot diameter propeller with wooden blades. Both machines have gear-driven generators which turn about five times faster than the propellers. Both units also have automatically feathering propeller blades which change pitch at a certain RPM to limit overspeeding in high winds.

The feathering propeller acts as a governor to limit propeller and generator speed, but it does not regulate the output voltage. This function is performed by a separate voltage regulator system which differs between the two machines. The Dunlite comes with a "Diotran" voltage regulator as standard equipment. This regulator acts in just the same way as the voltage regulator in a modern automobile. When the voltage rises above a certain level (which can be adjusted by a knob on the control panel) corresponding to fully charged batteries, the Dunlite regulator automatically reduces the voltage going to the generator field windings and thus reduces the generator output — no matter how fast the propeller is spinning. Thus when the batteries are fully charged (and no power is being used), the wind generator continues to rotate but does not generate any electricity — it is merely "freewheeling." In this unloaded condition, the wind generator relies heavily on the propeller feathering system to keep from overspeeding. And this is why the manufacturer recommends that the unit be shut down (by manually pulling a brake lever at the tower base) if winds in excess of 75 mph are expected.

The tail on the Dunlite unit is fixed, so that the unit always faces into the wind — whether running or braked. The Swiss Elektro wind generator, on the other hand, works on a somewhat different principle which the designer, Mr. Schaufelberger, claims is superior for severe climates (such as the Swiss Alps) where wind speeds can reach 120 mph. In the Elektro windplants, there is no way to regulate field voltage. (In fact most of the units don't have a field to regulate; they use permanent magnet rotors.) Instead, the output of the generator is tied directly to the propeller speed and the output is reduced by reducing the wind pressure on the propeller. This is accomplished by turning the tail fin gradually to the side and thus rotating the whole propeller out of the wind. To stop the Elektro units, the tail is pulled completely parallel to the blades. This causes the unit to orient itself sideways to the wind which causes the propellers to stop turning. In this position, the unit can withstand 120 mph winds without damage.

When the "automatic control" is ordered with the Elektro wind generators, this shutting-down function is performed automatically by a servo-motor assembly mounted at the base of the tower. The automatic control serves as both a safety-device (shutting the wind generator down in high winds) and as the voltage regulator for these units. The automatic control senses battery voltage and when this reaches a certain level corresponding to fully charged batteries, it activates the control and shuts down the unit. The unit then remains shut down until it is either restarted manually (by pushing the "start" button on the control panel) or by the time clock which is built into the "auto-reset" models. The time clock triggers the restarting mechanism once every twelve hours.

In actual practice, this systems works out OK but it has some limitations. It is possible, especially when the batteries are nearly fully charged, for the system to shut down during a strong gust, and then remain shut down for as much as twelve hours, thus missing a good deal of potential generating time. For this reason, I personally prefer the voltage regulating system used in the Dunlite wind generators. It is more flexible with respect to varying wind conditions and power loadings. It also allows power to flow directly past the batteries and into the load when the batteries are fully charged. The Elektro system cannot provide for this possibility as effectively.

We have improved the automatic control on our Elektro windplant by replacing the 12-hour timer with a one-hour timer, thus the unit now attempts to re-start every hour, rather than waiting twelve hours after each shut down. If the conditions still exist which caused the unit to shut down in the first place, this overrides the re-start signal and the unit remains stopped.

So, each unit has its points. The Dunlite is simpler and requires less maintenance, but is limited to 2000 watts output and it must be manually shut down in very high winds. The large Elektro, on the other hand, offers more power (roughly 2½ times as many kW-hrs per month as the Dunlite) at less than twice the cost and so appears to be the better choice where a large amount of power is required or where unattended operation in high winds is an important consideration.

Other Wind Generator Manufacturers

A three-month search for all the manufacturers of wind driven generators throughout the world in the spring of 1973 (including a 3-week trip to Europe) produced the following surprising results: in the entire world right now there are only **five** companies manufacturing wind driven generators, and only one of these is in the United States.

(1) Dyna Technology of Sioux City, Iowa continues to manufacture a single model **Wincharger** which is of a proven design, but basically unchanged in the last 20 years. The **Wincharger** is a small, 200 watt, 12-volt unit and is limited to small power applications.

(2) The Davey-Dunlite Company of Adelaide, South Australia, (a subsidiary of PYE Industries Sales Pty. Ltd. of Melbourne) manufactures several larger and more modern wind generators. (These units are also sold by Quirk's of Sydney, a sales representative for the manufacturer, thus the Quirk's name on some Australian equipment.) The Australian **Dunlite** wind generator is a simple and relatively modern machine. The "brushless windplants" were designed about 10 years ago and feature all-metal, full feathering blades, a very large, underrated, 2000-watt, three-phase alternator and a simple, but effective, transistorized control system. Under conditions which are not too severe, this unit will endure for over 20 years with minimum maintenance. Unfortunately, their largest unit is a 2000-watt model and the price is such that multiple installations become very expensive compared to other larger units which are available.

(3) Elektro G.m.b.H. of Winterthur, Switzerland has been in the wind generator business for some 30 years now and they produce a wide variety of wind driven generators to meet the electrical needs of remote areas. As many of their sales have been to mountain hotels and restaurants, with relatively large electrical requirements, they have developed larger units to meet this demand. Their model WVG 50 G, 6000-watt wind generator is the largest unit currently in production in the world and appears to be the best unit available at the price. Unfortunately, this is a very small company and they have not been able to deal effectively with the sudden world-wide demand for their product; long delivery delays and some erosion of quality have been the result.

(4) Aerowatt of Paris, France builds very fine wind generators designed for commercial and marine applications but the price for their equipment is very high. Their 4 kW unit lists for well over $10,000 without controls or accessories, but it has the advantage of being able to produce its full 4 kW output in very low 15 kt. winds.

(5) Finally, there is Lubing Maschinenfabrik of Barnstorf (near Bremen), West Germany. They build

modern variable pitch, high speed wind machines, but primarily directed at water pumping operations. They make a single model electric generator which is rated at 400 watts, 24 volts. One interesting feature of the Lubing wind generators is that they operate downwind with no tail vane.

And that's it! There are several other companies, individuals, and institutions which have designed, and even built, wind powered generators, but none of these presently have any hardware to sell on a production basis.

But They Are Expensive!

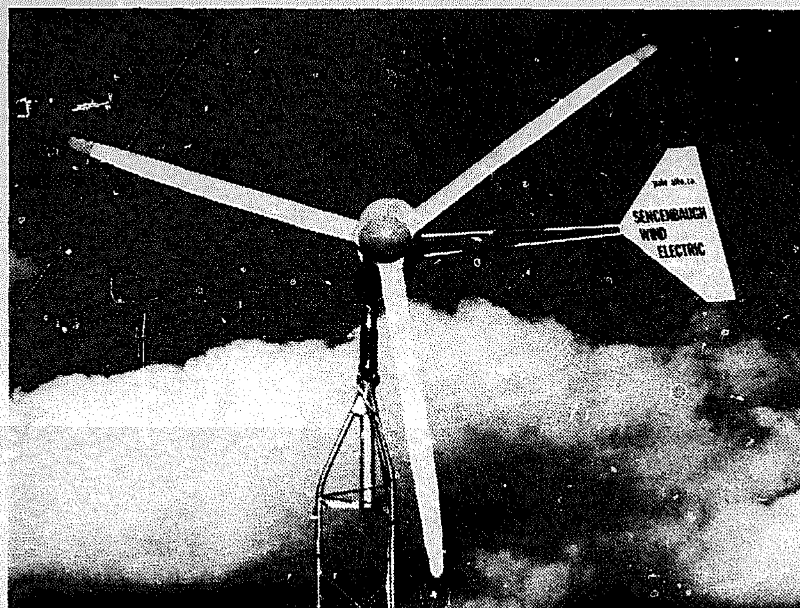
So far we have discussed wind generators mainly in terms of those which are commercially available. And if what you want is a complete, reliable installation which will produce relatively large amounts of power for many years to come without problems, you should probably consider one of these production units. There are wind generators currently in production in various parts of the world ranging in output from 50 watts to 6 kW (6000 watts). Solar Wind, as well as several other companies in the U.S., have franchises with these manufacturers and can offer a variety of production wind powered generating equipment ranging from an individual windplant for less than $500 to a large complete wind electric system for well over $10,000. But for many people interested in wind generated power, the price of the commercially available equipment is simply prohibitively high.

One alternative to the purchase of a new windplant is to find a used one and recondition it. A small number of the old American wind driven generators still exist hidden away in barns and garages or even mounted aloft on the original tower. If you can locate one of these, and have the time and ability to restore it to operating condition, the chances are you will end up with a better unit than you can build yourself.

The two most common American windplants were the Wincharger and the Jacobs — respectively, the Chevrolet and Cadillac of homestead wind electric plants. The Jacobs is becoming hard to find nowadays, but it is a real find if you can locate one in reasonably good condition. Both units are likely to be found in 32-volt models which is a distinct drawback, but a 32-volt DC to 115-volt AC inverter can be purchased which largely overcomes this problem. Also many marine electric systems still operate today on this voltage, so 32-volt equipment is available.

The next alternative to buying a used windplant is to build a new one from a kit. Unfortunately, there are few kits available and some of the cheaper kits I've seen on the market recently offer little more than recycled or junkyard equipment at inflated prices. It's not easy to design and build a good wind driven generator, so beware of bargain basement designs; you may be wasting your money!

One kit which looks very promising is the unit being developed by Sencenbaugh Wind Electric of Palo Alto, California. Although rated at only 750 watts, this windplant promises to deliver close to 100 kW-hrs of power per month in a 10 mph average wind area due to its relatively large (12-foot diameter) propeller and low rated windspeed. This unit will produce 12-volt DC power from a modified automotive type alternator to be supplied with the kit.



The Sencenbaugh kit uses a fixed-pitch propeller with an automatically folding tail to shut it down in high winds.

Building Your Own Wind Generator

Many people will find even the price of a kit well above their budget, I'm sure, in which case the remaining alternative is to build a unit from scratch — or from plans. Both Windworks of Mukwonago, Wisconsin and Sencenbaugh offer a set of plans for small home-built windplants. An early version of the Windworks design was described in the November 1972 issue of Popular Science. Plans for their latest model, "The Twelve-Footer" can be ordered directly from Windworks for about $15.

Both the Windworks and Sencenbaugh plans call for a fair amount of knowledge and ability on the part of the builder as well as access to good shop facilities. These designs represent a good starting point for the homebuilder, but should be thought of more as experimental designs rather than fully-perfected wind machines.

In addition to the two mentioned above, there are several other sources of information on home-built wind generators. These include the VITA and Brace publications (see Sources in Appendix for full listings) as well as the many articles which have appeared in the Mother Earth News magazine and their recent book, **Handbook of Homemade Power.**

Just about all of these home-built designs, it seems, rely on the common automobile alternator for power generation. This is because they are both the cheapest generators available considering their output, and they are also readily available, new or used. But there are two basic problems which must be overcome with the automobile alternator. First, it is designed to deliver its power at the relatively high speed of 2000 to 5000 rpm. So it must be geared to the propeller by belts, gears, or chains and sprockets. Gear ratios of at least 5 to 1 and as high as 10 to 1 are used in most successful designs. The second problem is that, in order for the automobile alternator to start charging, the field must be energized; (in your car this happens as soon as you turn on the key). But in a wind generator this means that someone has to be around to turn it on when the wind is blowing, and off when it is not, or it will quietly sit there and drain your batteries during calm spells. One way to overcome this problem is to incorporate a small wind-sensitive switch in your unit — just a microswitch with a little wind-paddle attached to it, that automatically turns it on at wind speeds over 7 mph, or at whatever speed your windplant begins charging.

Most of the home-built designs using car alternators also use auto voltage regulators as well and operate as 12-volt systems with 12-volt batteries. This is actually quite practical as there are many devices available which are built to operate on 12 volts DC including light bulbs, radio and stereo equipment, water pumps, and even inverters that will step the voltage up to 115 volts AC. Electronic inverters of this type are mass produced (for campers, etc) and are available for under $100. But something many people are not aware of is that the common auto alternator will also produce 115 volts. All you have to do is throw away the regulator, and disconnect one output terminal from the battery (but leave the field wire connected to a 12 volt source). Now if you spin the alternator up to 4000 rpm you can get 115 volts and a vastly increased power output. Of course the alternator diodes may burn out on you, but they can be replaced with larger ones quite inexpensively.

Many people are presently working on their own designs and some of them are coming up with some very ingenious solutions to the problems of a practical and cheap wind generator. Perhaps you can make a contribution to this field. But, before you begin, arm yourself with as much knowledge as you possibly can about this complicated subject. And remember that your completed design must be capable of withstanding the strongest winds you will ever get in your area. Don't be one of the people who writes us that they had a windmill that worked "beautifully" for a few days only to be demolished by the first strong winds that came along. Apparently, this is not an uncommon experience. The references, sources, and tables at the back of this booklet should help you get started. Good luck!

Calculating Your Power Needs

Here is some information to help you figure out how much power you will really need in your wind powered homestead. First, a basic electrical formula that will help you juggle watts, volts and amps around.

Watts = Amps x Volts

From which follows: **Amps = Watts / Volts**

And: **Volts = Watts / Amps**

Watts are a measure of power. A 75-watt bulb requires 75 watts of power to run it. If it is a standard 115 volt bulb, then it will draw 75/115 or .65 amps of current. If it is a 12-volt, 75-watt bulb, however, it will draw 75/12 or 6.25 amps. This illustrates that more current is needed to get the same power at a lower voltage. This is important to keep in mind because the size wire required in a given application is determined solely by the **current** which will be flowing through it and not the power. So, if you're running a wire which will power four 75-watt bulbs, for example, at 115 volts this would only represent 2.6 amps, whereas at 12 volts it would be 25 amps and might require special heavy duty wiring. This is also something you'll want to consider when choosing a voltage for your system.

Another relationship you will want to understand is the connection between kilowatt-hours and amp-hours and how this measure of total energy consumed relates to the volts, amps, and watts of a specific appliance in your house. Batteries are usually rated in amp-hour capacity. This tells you how many amps they will deliver for how long. A 100 amp-hour battery will deliver 1 amp for 100 hours, or 10 amps for 10 hours, etc. An amp-hour is just what it sounds like: amps times hours. But as we have seen, the current in amps that a certain item draws depends on the voltage it is operating at. So an amp-hour rating in itself doesn't tell you very much about how much **power** you can store in the batteries. In order to determine this, you must also specify a voltage — such as 100 amp-hours **at 115 volts**. Now, since we know that amps times volts equals watts, we can infer that amp-hours times volts equals **watt-hours** which in fact it does! And 1000 watt-hours equals one kilowatt-hour, and this is what the Electric Company bills you for every month. A kilowatt-hour is nothing more than 1000 watts of power used for a period of one hour (or 500 watts for 2 hours, etc.). Now if this isn't all crystal clear, a careful study of the following tables should help.

APPLIANCES	Power in Watts	Current Req'd in Amps at 12V	Current Req'd in Amps at 115V	Time used per mo. in hrs.	Total KW-hrs. per mo
Air Conditioner (window)	1,566	130.	13.7	74	116.
Blanket, electric	177	14.5	1.5	73	13.
Blender	350	29.2	3.0	1.5	0.5
Broiler	1,436	120.	12.5	6	8.5
Clothes Dryer (electric)	4,856	—	42.0	18	86.
Clothes Dryer (gas)	325	27.	2.8	18	6.0
Coffee Pot	894	75.	7.8	10	9.
Dishwasher	1,200	100.	10.4	25	30.
Drill - ¼ in.	250	20.8	2.2	2	.5
Fan (attic)	370	30.8	3.2	65	24.
Freezer (15 cu. ft.)	340	28.4	3.0	290	100.
Freezer (15 cu. ft.) frostless	440	36.6	3.8	330	145.
Frying Pan	1,196	99.6	10.4	12	15.
Garbage Disposal	445	36.	3.9	6	3.
Heat, electric baseboard, ave. size home	10,000	—	87.	160	1600.
Iron	1,088	90.5	9.5	11	12.
Light Bulb, 75-Watt	75	6.25	.65	120	9.
Light Bulb, 40-Watt	40	3.3	.35	120	4.8
Light Bulb, 25-Watt	25	2.1	.22	120	3.
Oil Burner, 1/8 HP	250	20.8	2.2	64	16.
Range	12,200	—	106.0	8	98.
Record Player (tube)	150	12.5	1.3	50	7.5
Record Player (solid st.)	60	5.0	.52	50	3.
Refrigerator - Freezer (14 cu. ft.)	326	27.2	2.8	290	95.
Refrigerator-Freezer (14 cu. ft.) frostless	615	51.3	5.35	250	152.
Skill Saw	1,000	83.5	8.7	6	6.
Sun Lamp	279	23.2	2.4	5.4	1.5
Television (B&W)	237	19.8	2.1	110	25.
Television (color)	332	27.6	2.9	125	42.
Toaster	1,146	95.5	10.0	2.6	3.
Typewriter	30	2.5	.26	15	.45
Vacuum Cleaner	630	52.5	5.5	6.4	4.
Washing Machine (auto)	512	42.5	4.5	17.6	9.
Washing Machine (ringer)	275	23.	2.4	15	4.
Water Heater	4,474	—	39.	89	400.
Water Pump	460	38.3	4.0	44.	20.

TABLE 3 POWER, CURRENT, & MONTHLY KW-HR CONSUMPTION OF VARIOUS APPLIANCES
[These are average, not exact, values]

Here is how you can use this table to figure out what size system you'll need. First, prepare yourself a similar table listing only those items you will use in your wind powered home. The table will be most accurate if you substitute actual figures for the average values listed in the table. For example, if you can read directly off the label on your toaster that it draws 1000 watts instead of the 1146 listed in the table, then use this figure in your table. To find the current for your toaster at 115 volts use the formula, A=W/V to get 1000/115 or 8.7 amps. You may also wish to revise the average times that the appliance will be used each month according to your own use patterns. The values listed in the table are statistical averages for a family of four living with unlimited power from the Power Company.

Now, to find the actual kilowatt-hours per month, multiply watts times hours used per month (this gives you watt-hours per month) and then divide by 1000, by moving the decimal point three places to the left, to get kilowatt-hours per month.

APPLIANCE	Power in Watts	Amps @ 115 V.	Time used per mo. in hrs.	Total KW-hrs. per mo.
Blender	350	3.0	0.5	0.2
Drill (¼ in elec.)	250	2.2	0.5	0.1
Lights - eight 75-Watt bulbs	600	5.2	120.0	72.0
Sabre Saw	325	2.8	0.5	0.1
Stereo	50	0.4	50.0	2.5
Skill Saw	1000	8.7	6.0	6.0
Typewriter	40	0.35	15.0	0.6
Vacuum Cleaner	630	5.5	1.2	0.8
Water Pump ⅓ hp Jet Pump	420	3.6	30.0	12.5
TABLE 4	Total Circled Amps	12.3	Total KW-hrs.	94.8

SAMPLE POWER CONSUMPTION TABLE FOR CLEWS HOMESTEAD WITH ORIGINAL WIND-ELECTRIC SYSTEM.

From this table we can tell several things. First, we can see that to supply all our electrical requirements we will need about 95 kW-hrs of electrical energy per month. Going back to Table No. 2 we find that a 2000-watt system operating in an area with 10 mph average winds will produce about 120 kW-hrs per month, so we're OK (which we know anyway because we've been doing it for six months) but this shows that our current usage is fairly near the natural limits of our system in this particular area.

Secondly, from Table 4 we can also figure out what size batteries we will need. There are two things which determine what size batteries are needed in a given application. These are (1) total energy storage required, and (2) maximum current to be drawn at any one time. The first condition is usually the more important. In our case (see Table 4) our total monthly consumption is 95 kW-hr per month. Dividing this by 30, we can find that the average daily consumption is about 3.2 kW-hr which is the same as 3200 watt-hrs per day.

(One kilowatt equals 1000 watts.) Now to convert this to amp-hours, we use the formula A = W/V, or Amp-hr = 3200 watt-hrs / 115 volts or 28 amp-hrs. This means that our daily consumption is equivalent to 28 amp-hrs at 115 volts, and if we want to provide storage enough for at least 4 days, we need 4 times 28, or at least 100 amp-hrs worth of batteries. In our case we actually have batteries rated at 130 amp-hrs, so again we're OK.

The second consideration in choosing a battery set is the maximum current that will be drawn. House lighting storage batteries are designed to give relatively low currents for long periods. Our 130 amp-hr set, for example is rated at 15 amps maximum discharge rate. (Automobile batteries often deliver over 100 amps during starting). This low current rating is part of the reason that house lighting batteries have such a long life. But this means that during periods with no wind, you must limit yourself to the current rating of your batteries — in our case 15 amps. This is why we have 15-amp fuses in our main fuse box. In Table 4 we have circled the items which might be operating simultaneously to produce the maximum load, and as you can see this adds up to 12.3 amps, which again is OK.

Finally, here is a table (Table 5) which lists the average power requirements for various size electric motors. DC motors are available in all sizes and voltages (see Sources 4 and 5) and represent the most efficient means of obtaining power from a wind electric system. Many common appliances can be converted to DC simply by replacing the AC motor with a DC motor which matches the voltage of your installation. In this case you need only concern yourself with the "running" loads as the batteries are easily capable of absorbing the transient starting loads. If, however you are considering running AC equipment through an inverter, and this may be the only practical way to run certain items such as modern refrigerators, etc., then you must consider the starting loads as well, because most inverters are not capable of handling even temporary overloads.

Electric Motor Size	RUNNING	STARTING		
		Induction	Capacitor	Split Phase
1/6 hp	275	600	850	2050
1/4 hp	400	850	1050	2400
1/3 hp	450	975	1350	2700
1/2 hp	600	1300	1800	3600
3/4 hp	850	1900	2600	-
1 hp	1100	2500	3300	-

TABLE 5 POWER REQUIREMENTS OF MOTORS IN WATTS

So there you have it. As you can begin to appreciate the business of designing a good wind electric system is no simple matter; but I think you will find it to be a richly rewarding endeavor. We have found that a modern, well designed, wind generating system can truly be a source of constant delight.

References

1) **Power from the Wind** by Palmer C. Putnam, Van Nostrand Co., New York, 1948, 224 pages. (Recently reprinted, and available through: Science News, Rm. 1740, 11 West 42nd st., New York, NY 100036, at $9.95 ea.)

The complete story of the largest wind-driven generator ever built — the 1500 kW windplant erected on Grandpa's Knob in Vermont. Includes sections on wind data analysis, theory of wind power, site selection and a good, but dated, bibliography.

2) **The Generation of Electricity by Wind Power**, by E. W. Golding, Philosophical Library, New York, 1956, 318 pages (out of print).

Although dated, this remains the best textbook available on the subject. Technical, but readable.

3) **Proceedings of the United Nations Conference on New Sources of Energy, Rome, 1961, Volume 7, Windpower.** United Nations Publications, Room LX-2300, New York, NY 10017, 408 pages, now in print again at $16 ea.

Includes the texts of some 40 articles on wind power, wind behavior, site selection, home-built designs, and recent developments.

4) **Mark's Standard Handbook for Mechanical Engineers,** Theodore Baumeister, editor. Many prints since 1916, now in its Seventh Edition. McGraw-Hill, NY, 1967.

Contains a six-page article by E. N. Fales on windmills with many formulas and tables. Check at your library for this reference work.

5) **Proceedings of the Wind Energy Conversion Systems Workshop, December 1973,** edited by Joseph Savino. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio, $15.50 ea.

Proceedings of a workshop conducted by NASA to assess the future of windpower in the U.S. A good summary of the most recent developments in windpower technology.

6) **Handbook of Homemade Power,** by the staff of the Mother Earth News, Bantam Books, NY, 1974, paperback, 374 pages.

A collection of articles, most of which originally appeared in the Mother Earth News magazine on wind, solar, water, methane, and wood energy and technology.

7) **Wind Energy Bibliography,** edited by Ben Wolff. Published by Windworks, Box 329, Route 3, Mukwonago, Wisconsin, 53149, 70 pages. (Available from Solar Wind at $3.25 ea. postpaid).

An extensive listing of sources and references under the headings wind, windmills, aerodynamics, electrical, towers, storage conversion, etc. Over 500 listings.

8) **Alternate Sources of Energy,** Route 2, Box 90A Milaca, Mn. 56353 ($5 for 4 quarterly issues).

A magazine with good windpower articles almost every issue. Especially recommended: Vol. 8, Jan. 1973 and Vol. 14, May 1974.

9) **The Mother Earth News,** P.O. Box 70, Hendersonville, North Carolina, 28739, ($10 for 1-year subscription).

A bi-monthly magazine with many up-to-date articles on the practical aspects of setting up a self-sufficient homestead. Volumes 5,6,17,18,20,26, and 27 contain articles on windpower.

10) **Popular Science,** November 1972 issue contains several articles on windpower including plans for a home-built design, page 103. Also see July 1974 issue for newer developments.

11) **Wind and Windspinners,** by Michael A. Hackleman Published by Earthmind, 4844 Hirsch Rd., Mariposa, Ca. 95338, 1974, 115 pages, $7.50 ea.

Subtitled "A Nuts and Bolts Approach to Wind-Electric Systems," this rather lengthy but down-to-earth treatise deals mainly with the Savonius vertical-axis rotor, but also contains solid material on generators, batteries, controls, etc., valuable to the homebuilder.

Sources

1) **Sencenbaugh Wind Electric**, P.O. Box 11174, Palo Alto, CA 94306.

2) **Windworks**, Box 329, Route 3, Mukwonago, WI 53149.

Plans for home-built windplants, paper honeycomb blocks for windmill blades, Wind Energy Bibliography.

3) **Dyna Technology**, P.O. Box 3263, Sioux City, Iowa 51102.

Manufacturer of the 200 watt, 12 volt "Wincharger", the only complete windplant manufactured in the U.S. at present.

4) **Automatic Power Division**, Pennwalt Corporation, P.O. Box 18738, Houston, TX 77023.

U.S. Distributors of the French Aerowatt wind-driven generators.

5) **Real Gas and Electric Co.**, P.O. Box F., Santa Rosa, Ca. 95402.

West Coast agent for Dunlite and Elektro windplants as well as other alternative energy equipment.

6) **National Weather Records Center**, National Climatic Center, Federal Building, Asheville, NC 28801.

The major source of weather and wind data for many U.S. locations for the past 50 years.

7) **Electro Sales Company, Inc.**, 100 Fellsway West, Somerville, Mass. 02145.

Surplus rotary inverters, motors, and controls.

8) **Nova Manufacturing Co.**, 263 Hillside Ave., Nutley, NJ 07110.

Large selection of electronic DC-to-AC inverters.

9) **Brace Research Institute**, MacDonald College, McGill University, Ste. Anne de Bellevue 800, Quebec, Canada.

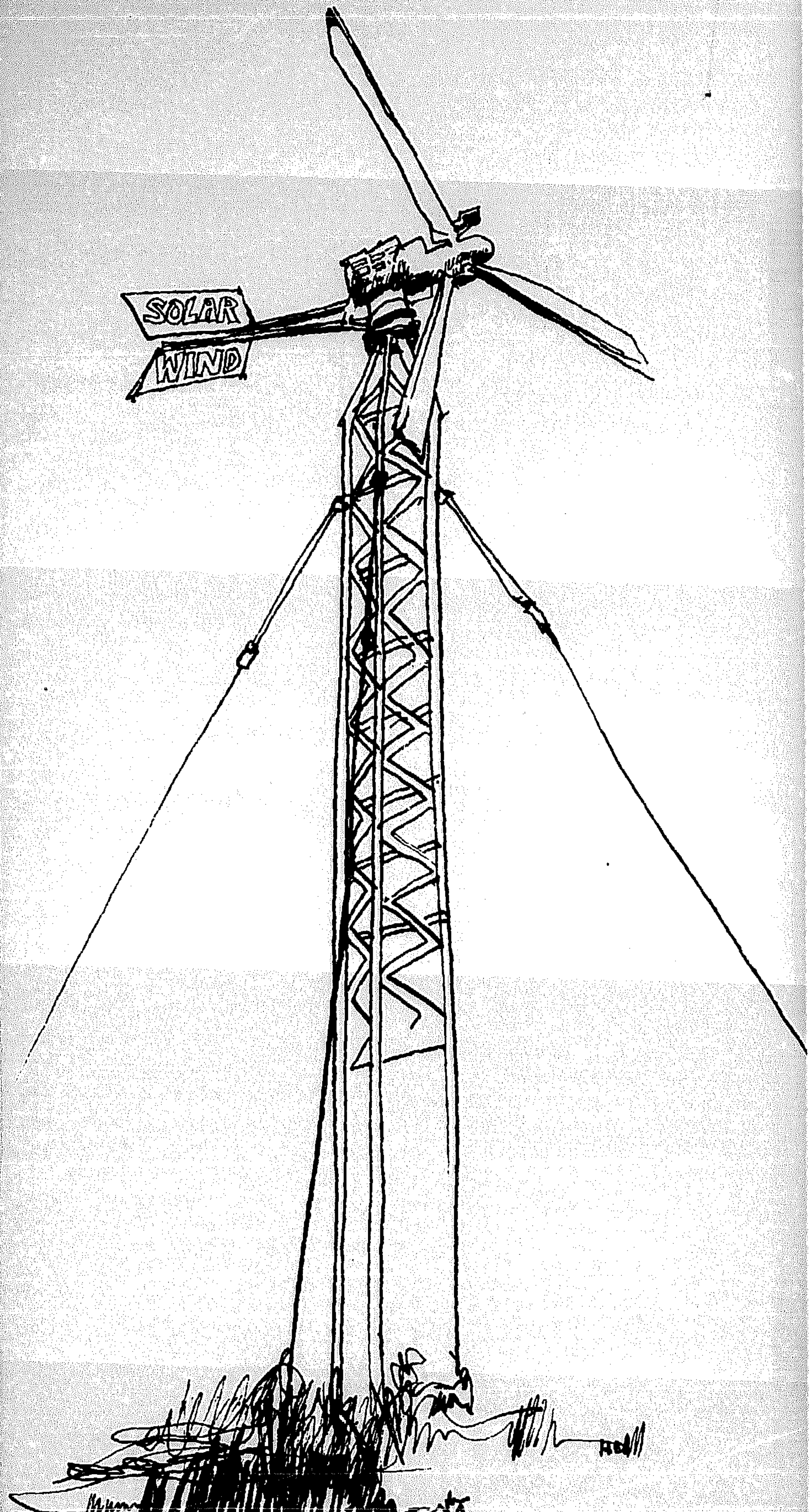
Many publications relating to simple and direct applications of wind and solar energy including a 32-foot windmill design.

10) **Volunteers in Technical Assistance (VITA)**, 3706 Rhode Island Ave., Mount Rainier, MD 20822.

Several designs for low cost windmills intended for use by developing countries.

11) **Enertech**, P.O. Box 420, Norwich, Vermont 05055.

New England agent for Dunlite, Wincharger and Sencenbaugh as well as other manufacturers of alternative energy equipment. Manufacturer of the Enertech 1800.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