ALASKAN WIND ENERGY HANDBOOK

by

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PREFACE

The winds of Alaska are a renewable resource that may one day displace substantial amounts of electrical energy presently being generated by the burning of fossil fuels. The interest of the DOTPF in the potential of wind power in Alaska has been to give it due consideration as an alternative to conventional energy sources when constructing public facilities in various locations in the State. The depth of this consideration has been limited however, since the information concerning the wind resources of the State and the technology to harness them has not been generally available.

The Research Section of the DOTPF has attempted to alleviate this problem by providing two publications of which this is the second. The first, "Alaska Wind Power User's Manual," which was released in August 1980 was prepared under contract by Dr. Tunis Wentink of the Geophysical Institute, University of Alaska. This manual provided the basics of wind power use in Alaska and provided valuable reference material concerning the wind regimes of many locations in the State which Dr. Wentink has developed after many years of wind energy research.

In this, our second publication, we have attempted to expand on the various subjects covered in the first. Prepared by Matt Reckard, a DOTPF engineer with previous wind energy research experience at Brookhaven National Laboratory, and Mark Newell, an Anchorage based private consulting engineer specializing in wind energy systems, this handbook focuses more closely on the mechanical aspects of wind energy systems, installation, required maintenance, economics, and existing Alaskan wind power installations. Each publication is complete in and unto itself and neither should be considered a supplement to the other as they have been prepared independently. The critical reader may find small inconsistencies between the two, but this is to be expected since independent experts often disagree on details. We have not attempted to resolve these questions, recognizing that such differences may reflect legitimate points of view on a complex subject.

We believe that in combination the two volumes represent a distillation of the best wind energy expertise in the State of Alaska. We hope that these two publications, either together or independently, can contribute to the further development of wind energy use in Alaska.

Lee Leonard
Chief of Energy and
Building Research

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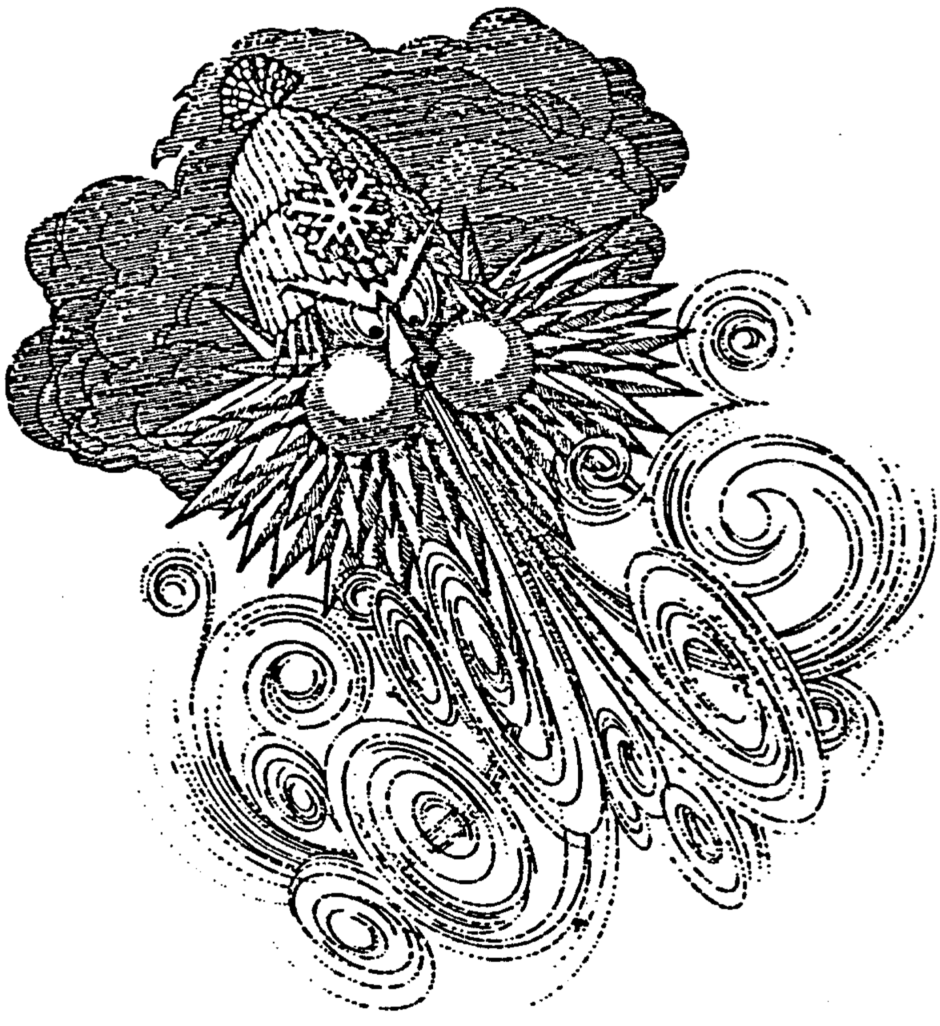


THE WIND AND IT'S USES

1:A Historical Background

1:A:1 SAILING VESSELS

After human and animal power, the wind was probably the first source of mechanical power harnessed by man. The first use of the wind was for transportation - the sailing vessel - and this use predates recorded history in many cultures. In the Mediterranean area, the sailing ship brought dominance in trade and, to a large extent, military power to a succession of civilizations: the Egyptians, the Cretans, the Phoenicians, the Greeks, and finally the Romans. More than a thousand years ago, long ocean voyages in sailing vessels were being made by Norsemen, by Chinese, and by Polynesians.

The use of wind powered vessels peaked during the "great age of sail", the first half of the 19th century. With the development of steam-powered ships, sailing vessels began to be abandoned, and use of them was in decline during the last third of the century. The large cargo carriers of the 19th century were the largest wind machines ever built, reportedly developing up to 4 MW (4000 kilowatts) of power.

There is little commercial use of sailing vessels remaining today. Some commercial fishing boats, including a few in this country, are still wind powered. Some freight transport is still performed by sailboats too (on a small scale), notably in Egypt (on the Nile) and in the Arabian Sea. Recently the Japanese have introduced a modern wind powered ocean vessel with a computer controlled sail assist.

1:A:2 WINDMILLS FOR MECHANICAL POWER

The date of the first use of wind machines to generate shaft power is unknown, but was almost certainly long after the first use of sailing vessels. Wind machines of all kinds have commonly been known as "**windmills**" for a long time; this is really only an accurate term if the output is used for milling purposes (e.g., sawmill, gristmill). *This handbook will refer to wind turbines which turn a mill as "**windmills**", wind turbines which pump water as "**windpumpers**" and wind turbines which generate electricity as "**windgenerators**".*

<u>Carousel Windmills</u>. There is some evidence that **windmills** may have been used in China and Japan as early as 2000 B.C. Hammurabi, king of Babylon (1798 - 1750 B.C.) is reported to have mentioned the use of **windmills** in plans for an irrigations system. The earliest **windmills** about which very much is known, however, date from 10th century A.D. Persia, and were used both for grinding grain and for pumping water. These machines were built, like a **"carousel"**, around a central, **vertical axis**, with "sails" mounted around the perimeter. A drawing of one of these mills is shown in Fig. 1-1. A wall or other structure shielded one side of the **"carousel"** from the wind and helped funnel the wind onto the sails on the other side. This turned the wheel, providing power for pumping or milling.

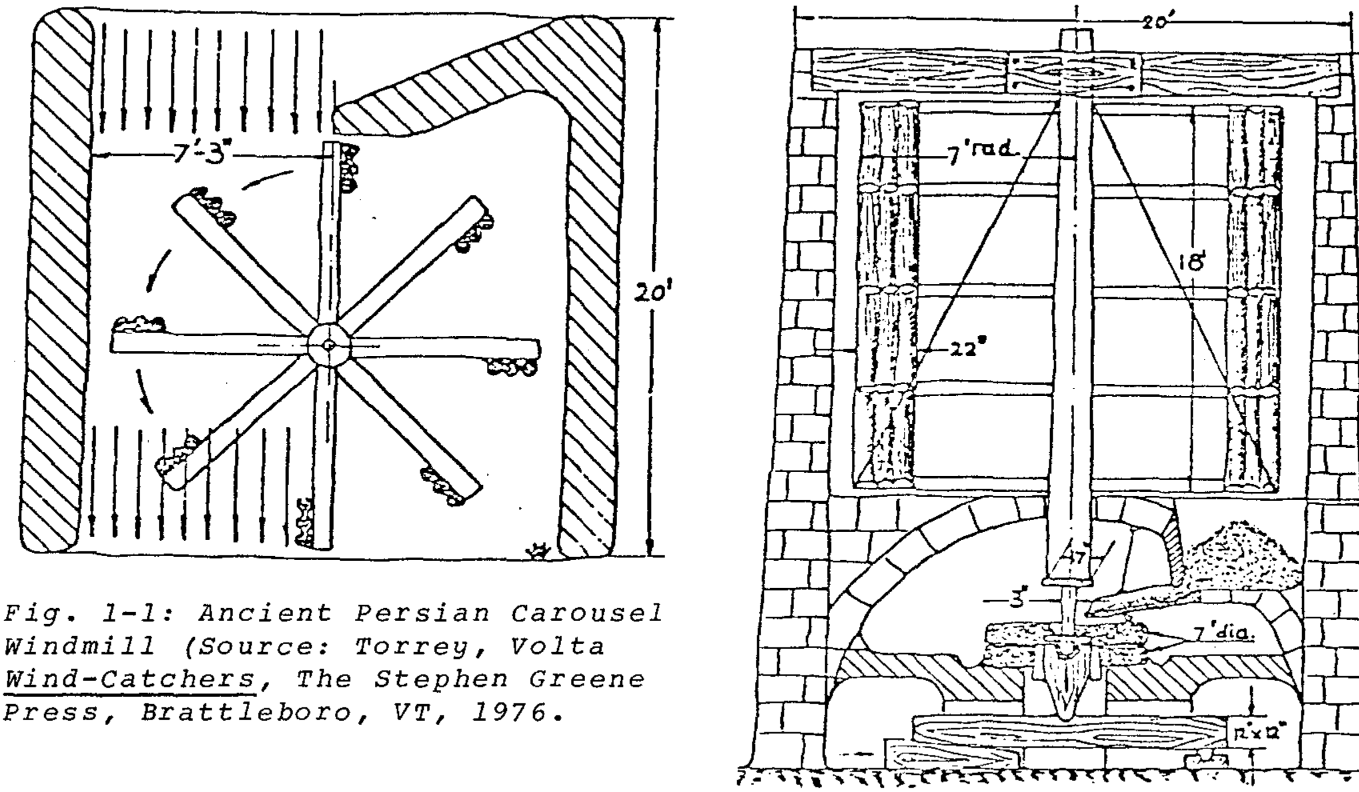


Fig. 1-1: Ancient Persian Carousel Windmill (Source: Torrey, Volta <u>Wind-Catchers</u>, The Stephen Greene Press, Brattleboro, VT, 1976.

The stationary shields of these mills meant that they could not follow shifting wind directions; they were built to face the prevailing winds and would only operate when they were blowing. Other **"carousel" windmills** have been used in many parts of the world (from the American midwest to China) since the 10th century. In some, the wind shield was mounted with a tail vane so that it could swivel; in this way, winds from all directions could be used. In others, the "sails" were designed to put up less resistance to the wind in one direction than the other. In this case the shield was unnecessary, and these mills, too, would operate with winds from any direction. The modern cup anemometer is one such design. The **Savonius** rotor, developed in Finland in the 1920's, is basically an advanced type of **"carousel" windmill** design.

European Windmills. The horizontal axis **"European" windmills** began to appear in Europe during the 12th and 13th centuries. These **windmills** had large towers, housing milling machinery, storage areas, and often living quarters for the miller and his family. With numerous variations, this type of **windmill** has seen continual use to the present day (one type is the well known **"Dutch" windmill**). At the time that they appeared (the era of the Crusades) there was a great deal of exchange of artistic, philosophical and technological ideas between the Middle East and Europe and within Europe itself. It has been suggested, because of this, that these **windmills** originated in the Middle East and the ideas were brought back to Europe by returning Crusaders. There is apparently no concrete evidence of this, however; the technology could have spread, at this time, from an origin anywhere in Europe as easily as from one in the Middle East.

The **European windmills** usually had four large "sails", although some had up to twice this number. In the Mediterranean region, these sails were usually made of cloth, roughly triangular in shape, which were attached to a wooden spar at the leading edge and were held by rope at the trailing edge. Windmills of this type are still fairly numerous in this region; Crete is particularly famous for them (See Figure 1-2). In northern Europe the "sails" were of sturdier construction; a wooden framework supported the cloth sails which were stretched across them.

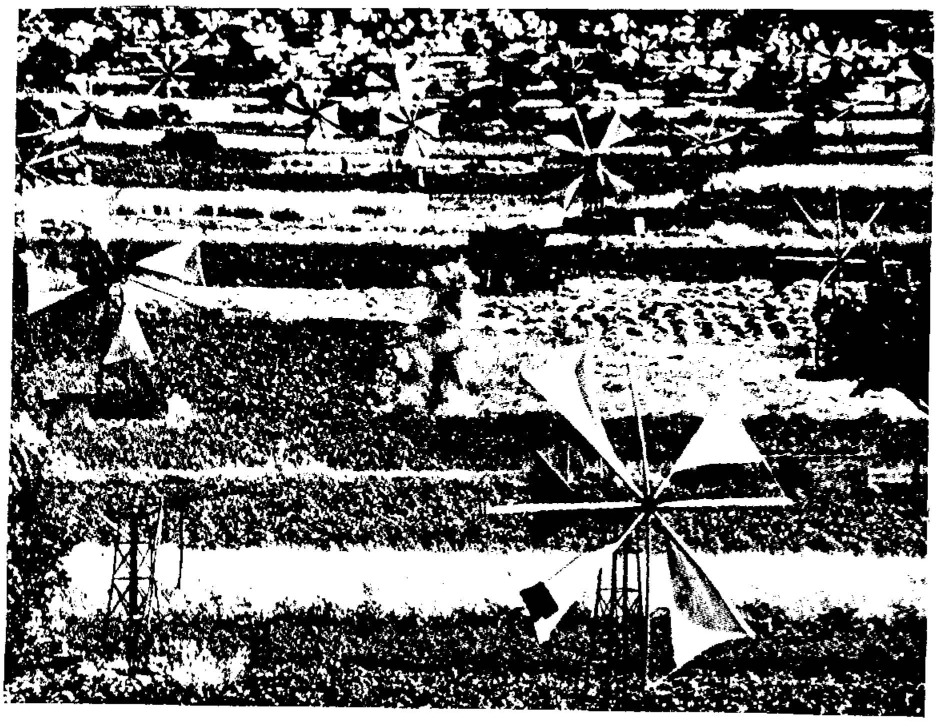
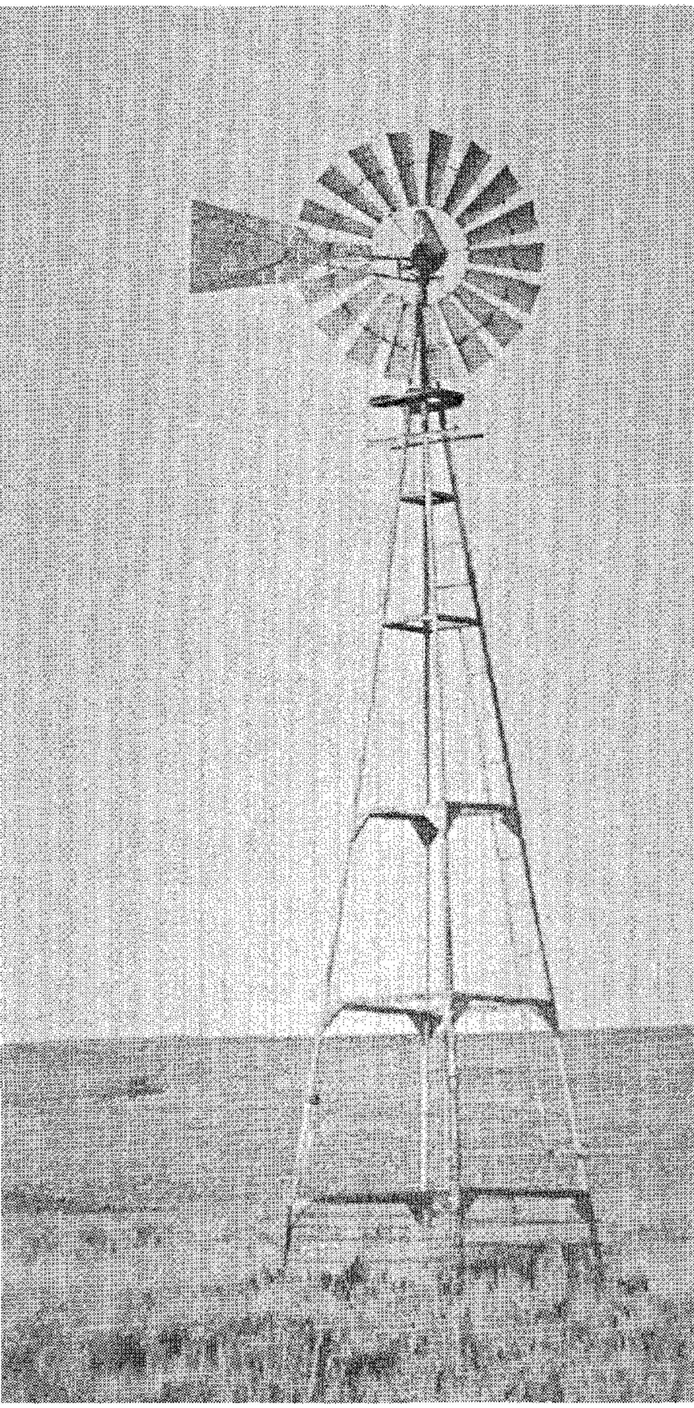


Fig.1-2: Some of the more than 10,000 sail windmills in Crete (Source: Inglis)

The earliest **European windmills**, like the earliest carousel types, could not be swiveled to face the wind; they were built to face the prevailing winds. Later mills were built so that the entire tower and sail assembly could be swiveled around on a supporting post; these were known as "post mills". In others, the bottom part of the tower was stationary, but the top of the tower, along with the sails, could be turned, these were known as "tower" or "smock" mills.

Numerous technical improvements were made on the design and operating features of the **European type windmill.** The "fantail", for example, automated the procedure of turning the mill into the wind; this was one of the first uses of a mechanical feedback device. Other devices were invented which automatically furled the sails. These improvements eliminated much of the time consuming and laborious operating procedures required of the mill operator. A complete description of these devices, and of the numerous **windmill** variations found throughout Europe and the New World, is beyond the scope of this report; a more comprehensive treatment of the subject can be found in **Reynolds.** (See the Bibliography for reference).

American Fanwheel. Shortly before the American Civil War, small horizontal axis, multibladed **windpumpers** began to appear in this country. The multiple blades of these **windpumpers** (some large ones had more than 100 blades) provided a high torque and a low operating speed. The use of these spread quickly, and at one time there were about six million of these operating in the U.S. Although use of these **windpumpers** declined after the 1930's it is estimated that there are still about 200,000 in operation.



These **windpumpers** were used most often for pumping water on farms and ranches, although they were also used to provide water for railroad steam engines and residential uses. They were generally much more modest in scale than the **European windpumpers**; pumping water for a single homestead was typical, whereas the **European windpumpers** might serve several thousand people. For pumping purposes, there was no need for a massive tower housing mechanical equipment, storerooms, etc. The towers were thus made of light framework of wood or metal; this as well as their smaller scale made them less striking in appearance than the **European windpumpers**.

Fig.1-3: Farm windpumper used on a cattle ranch (photo: Newell)

The **American fanwheel** was more automatic in operation and required less maintenance than earlier European type **windpumpers.** This was a necessary component of their widespread use; a farmer could not be expected to spend as much time adjusting and maintaining a **windmill** as a miller could. A complete discussion of the **windpumper** and the related control equipment requires much more attention than can be given the subject here. The variety found in these **windpumpers** is not unexpected in an industry which, in 1889, supported 77 different manufacturers. Only three manufacturers of these **windpumpers** remain in the U.S. today.

1:A:3 ELECTRICITY PRODUCING WINDGENERATORS

Battery Chargers. It was not long after the use of electric lights and radios became widespread before people began trying to supply power to them with **windgenerators.** They soon found that the speed required for electricity generation was much greater than that normally provided by the **multibladed fanwheels** designed for pumping. The first successful electric **windgenerators** were built by mating rewound automobile generators with airplane propellers or hand carved copies of them. By the end of the 1920's, commercial systems began to appear.

These early systems were small in scale, as were the electrical demands they supplied. Two, three or four bladed turbines, six feet or so in diameter, supplied power to a DC generator, which could charge a battery with enough power to run a radio and a few lights. Voltage regulators provided protection from overcharging of the battery, and simple mechanical devices, activated by the action of the wind, protected the turbine from overspeeding. In many rural parts of the country, these **windgenerators** were the first and, for years, the only source of electricity for household use.

During the peak sales period of the 1930's, there were over 300 manufacturers of **windgenerators** worldwide; one of these, the Wincharger Co. of Sioux City, Iowa, is reported to have built up to 1,000 units per day.

The widespread electrification of rural areas by the Rural Electrification Administration however, began to make larger (and cheaper) amounts of power available to rural residents. By 1960 only one U.S. manufacturer of **windgenerators** remained.

Large Electric Windgenerators. The heyday of the small **windgenerators** - the period between the World Wars - also saw the first proposals for, and prototypes of, large wind generating systems. A 100 kw machine was installed near Balaclava, Crimea (USSR) in 1931. In 1942, a 200 kw machine was built in Gedser, Denmark. These machines, however, were pale in comparison to the 1,250 kw machine erected on Grandpa's Knob, Vermont, in 1941. This machine, the largest ever built until it was finally surpassed in 1978, operated for 3.5 years before throwing one of its two blades, (the failure was attributed to a known flaw in the casting,which because of wartime shortages was not recast) "Power From the Wind", written by **P.C. Putnam,** one of the designers of the Grandpa's Knob **windgenerator,** contains an interesting historical account of the project, as well as a great deal of information of the technical design and performance of this **windgenerator,** much of which is applicable to wind systems in general.

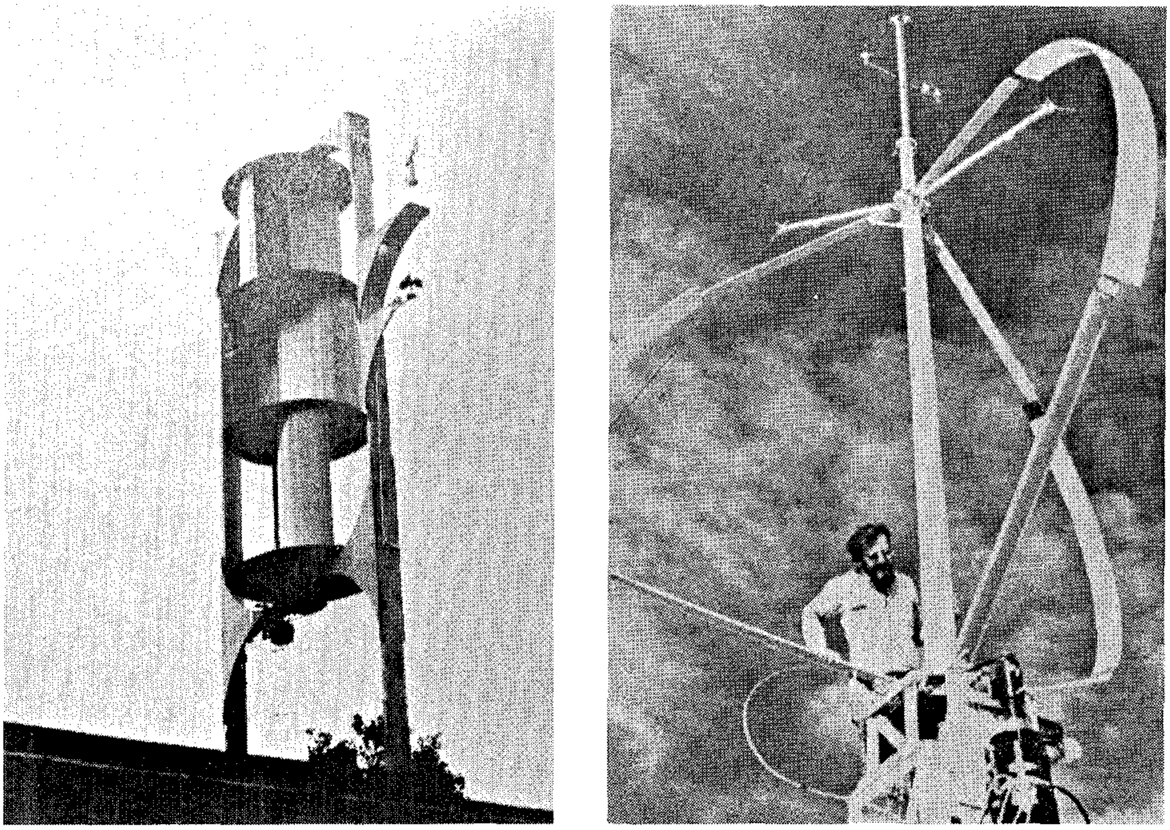


Fig. 1-4: Savonius rotor (on left) and Darrieus rotor (on right) vertical axis (Source: Hackleman)

Darrieus and Savonius Rotors. The above machines were all horizontal axis, but during the 1920's and 1930's there was developmental work being done, not only on large wind machines, but also on entirely new **wind plant** designs. Two of these designs, which have gained renewed interest in recent years, are **vertical axis** machines, the **Darrieus** rotor and the **Savonius** rotor. The former type, invented in 1926 by **G.J.M. Darrieus** in France, consists of two or more long, thin airfoils like those used for helicopter rotors, bent in a bowed shape, and attached at each end to a vertical axle. The resulting machine looks something like an **eggbeater**, and this has become a nickname for the design. The **Savonius** rotor, named after **S.J. Savonius** of Finland, is a modified form of the **"carousel" windmill.** It consists of two half-cylinders mounted in a staggered fashion around a central **vertical axis.** With this configuration, some of the wind hitting one half-cylinder spills into the other, yielding more power output than would otherwise be produced.

After WWII, both research and commercial use of **wind power** declined. Oil and gas were plentiful, and most interest in new forms of power generation was centered on nuclear systems. It was not until the early 1970's, when the first signs of the approaching "energy crisis" appeared, that interest in **wind power** was revived.

1:A:4 WIND POWER IN ALASKA

The first use of wind energy in Alaska is attributable to the Alaskan natives with limited accounts of sailing vessels. The early explorers and the Russian fur traders came in large sailed ships, as did the pioneers, and seekers of fortunes during the gold rush. No accounts of **windmills**, or **wind pumpers** has been found by the authors in Alaska's history. The first **windgenerators** were brought to Alaska during gold rush days and placed on miner's cabins for lights. Evidence of these early **windchargers** can be seen today, their stub towers now being used for radio or TV antennas. Outside of the remote cabins the first electricity in the coastal villages was produced by **windgenerators** at the BIA schools. But soon the diesel generator could be heard throughout the village as the white man's ways were brought to the Alaskan natives.

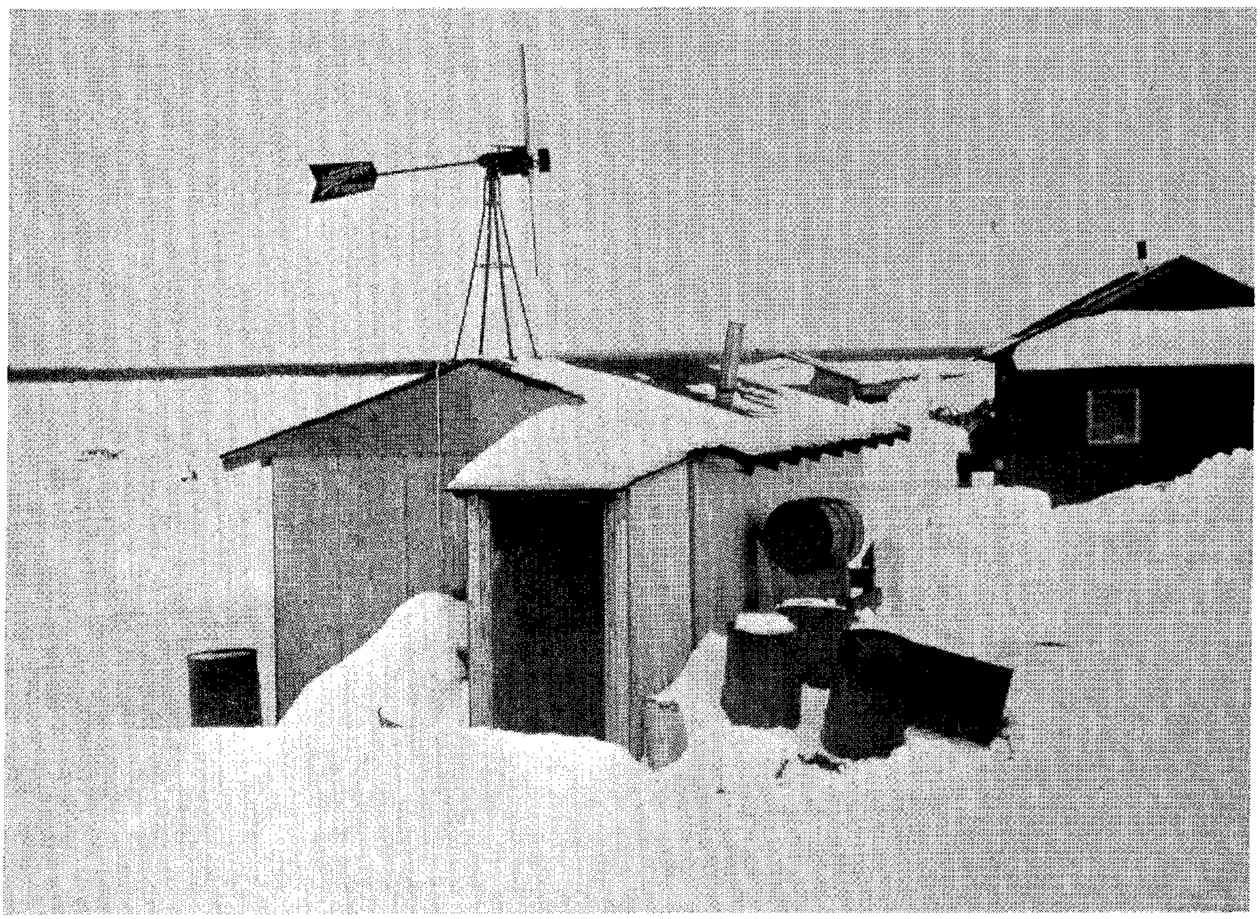


Fig.1-5: Windgenerator on PHS pumphouse in Bethel area,circa 1960 (Photo: WSE file)

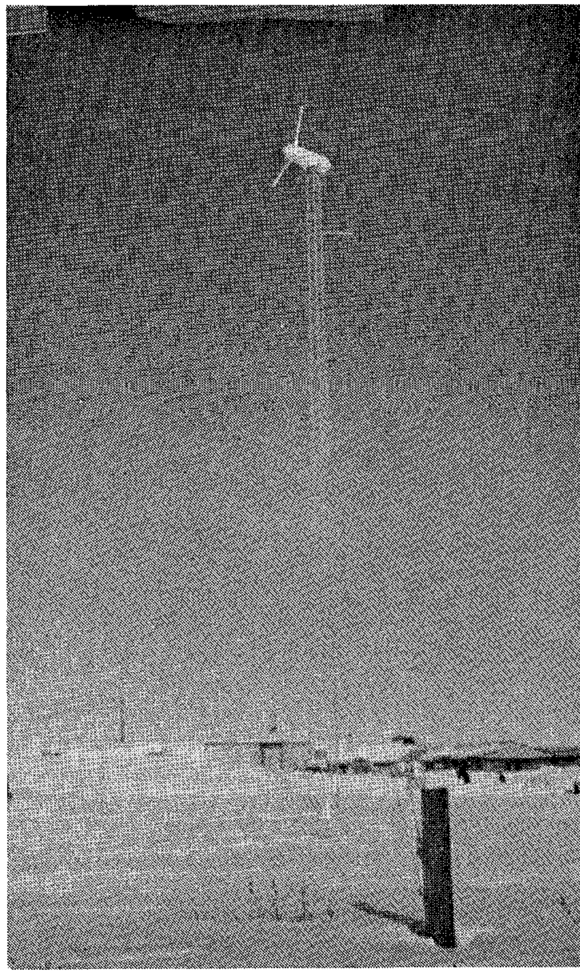


Fig.1-6: (above) One of the remote systems in the Lake Illiamna area (Source: 4 Winds of Alaska)
Fig.1-7: (right) Utility intertie unit in Kotzebue (Source: Newell)

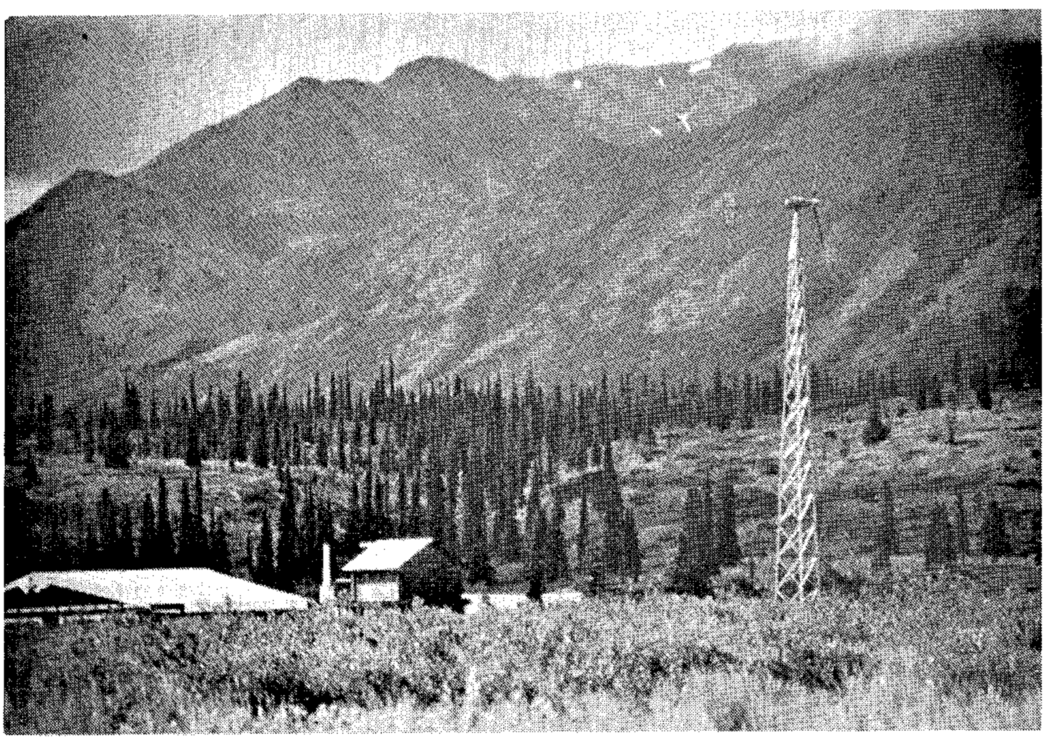


Fig.1-8: Battery charger in Cantwell (Source: Newell)

The cost of running a diesel, both in fuel cost and maintenance, has gotten higher by the year. In places where fuel must be flown in, like in some remote hunting lodges, **wind generators** with battery banks have been used competively for years with diesel generators as back-ups. Many remote telecommunication devices use **wind generators** to provide for the relay stations.

The communication network used to support the construction of the Alaska pipeline was powered by rebuilt **Jacobs** battery charging **windgenerators** scattered on mountain tops across the State.

Today there are roughly 100 wind generators in the State with the sales volume increasing weekly. A partial list of **generators** by region is given in Appendix A. Most of the systems are remote from the utility power lines using battery storage systems. These applications typically have low power requirements (less than 1,000 watts) and use a 12 volt system, taking advantage of the 12VDC accessories available for recreation vehicles. Although these small remote systems make up a majority of the **windgenerators** in the State, there are about a dozen battery systems which are larger than 3kw (3,000 watts) and there are several proposed installations presently in the design and construction phase which exceed 10kw (10,000 watts).

Because of high utility rates, tax advantages, (see Economics Section) and a desire by Alaskans to be as independant as possible, about a dozen **generators** which tie into the utility power lines have been installed in this State. These units do not require batteries and act to save the owner money by generating electricity when the wind is blowing. When the wind power is not enough to meet all the owner's needs the utility grid is used. If the **windgenerator** is providing more power than the owner needs the excess power will be fed back into the utility grid thus reversing the meter (this topic is discussed more thoroughly in the **Design Section**).

In general the small (under 3 kilowatts) ***windgenerators*** *in Alaska have been very successful. The failures that have occurred can all be traced to one cause:* ***poor planning.***

Whether the failure was due to poor siting, bad selection of hardware or lack of proper maintenance, if an experienced, reliable, professional in the wind energy business had been consulted at the onset most of the failures could have been avoided.

The wind industry itself has come a long way in the past few years, as have Alaskan wind systems. It is important for a potential user to get as much information on what is available and what is working in this State as possible. As of this writing Alaska hosts two distributors, over ten **windgenerator** dealers, a full time installation crew, and an engineering firm dedicated to wind systems. The State government has been very active in commercialization and experimentation with **windgenerators** and boasts a loan program surpassed by no other State.

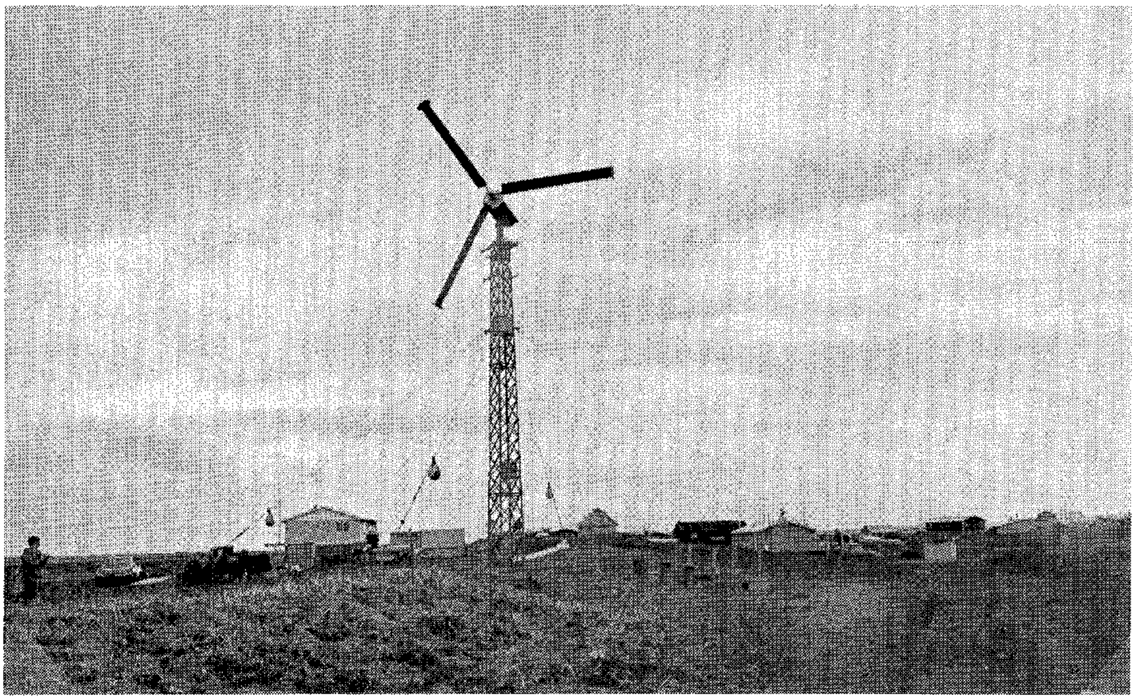


Fig.1-9: Nelson Lagoon's new utility intertie 20 KW machine (Source: Newell)

1:B The Wind Resource

1:B:1 WIND: ITS SOURCE AND MAGNITUDE

Solar energy unevenly heats the atmosphere of the earth, and the convection currents that result from this are what we know as the winds. Some of these winds ('prevailing winds') are global in nature and more or less permanent; examples of these are the 'trade winds' and the high elevation 'jet streams'. Others are more local and temporary in nature, such as the daily cycle of onshore/offshore breezes along the coasts.

The total energy contained in the winds is tremendous - a little less than 2% of solar input or 26 x 10^{15} kwh per year (twenty-six quadrillion kilowatt hours). Nearly all of this wind energy is useless, however, because it is so high above the earth's surface. Even the amount of energy within 1000 feet of the earth - and thus at least potentially useful - is staggering; an estimated 65 x 10^{12} kwh per year (equal to about 30 times current U.S. electrical consumption). Yet even this figure is nearly meaningless, since it is clearly impossible to harness it all (much less at 100% efficiency).

The winds of concern to people interested in wind energy production, then, are only those in areas where relatively high speed winds are consistently found near ground level. Moreover, as will be seen in this handbook, the areas of interest must be ones where other, more conventional means of power generation are expensive and/or unreliable. Interest in wind power has grown largely because the latter areas have made up an increasingly large part of the world in recent years.

1:B:2 POWER IN THE WIND

The following section is included for those with an interest in physics; a complete understanding of the equations is _not_ necessary.

The most important fact about the power in the wind is that it is proportional to the **_cube of wind speed_**. The other two determining factors of wind power are the vertical area (perpendicular to the wind) swept by the **windgenerators** blades, and the density of the air. The power (that is to say the rate at which energy is delivered) is expressed mathematically as

$$P = 1/2 \beta A V^3 \qquad \textbf{Equation (1)}$$

where P = power, β = air density, A = area swept by windgenerator blades, and V = wind speed (velocity) (see note).

Note* This expression is derived from the equation of kinetic energy $KE = 1/2 mV^2$, where m = mass and V = velocity. The _rate_ of energy delivery (power) thus depends on the _rate_ at which air mass passes the blades. The rate at which mass having a density β and a velocity V passes a swept area A is βAV. Thus $P = 1/2 mV^2 = 1/2 \beta AV^3$.

It should be emphasized that this is the power in the **<u>wind</u>**, not the power output from a **<u>windgenerator</u>**. From this expression it can be shown that even small variations in wind speed have a large effect on wind power (See Figure 10). A 12 mph wind, for example, has eight times the power of a 6 mph wind ($12^3/6^3 = 8$), and over 70% more than a 10 mph wind ($12^3/10^3 = 1.73$). As a result, a site where winds average 12 mph has **<u>much</u>** better potential for wind energy development than a site where winds average 10 mph. This is a very important point about wind energy, and one which is not intuitively obvious.

Equation (1) also shows that the power is proportional to the area swept by the **windgenerator** blades. For a typical propeller-type horizontal axis **windgenerator** this area is a circle with a radius equal to the blade length. Since the area of a circle equals πr^2, Equation (1) can be rewritten as

$P = 1/2\ \pi \beta r^2 V^3$ where r = blade length **Equation (2)**

From this we can see that the area - and the wind power - are proportional to the **<u>square of the blade length</u>**. A **windgenerator** with 20 foot blades, then, has the potential to produce four times the power of one with 10 foot blades. The actual power output, of course, depends on the efficiency of the **windgenerators** as well as their size.

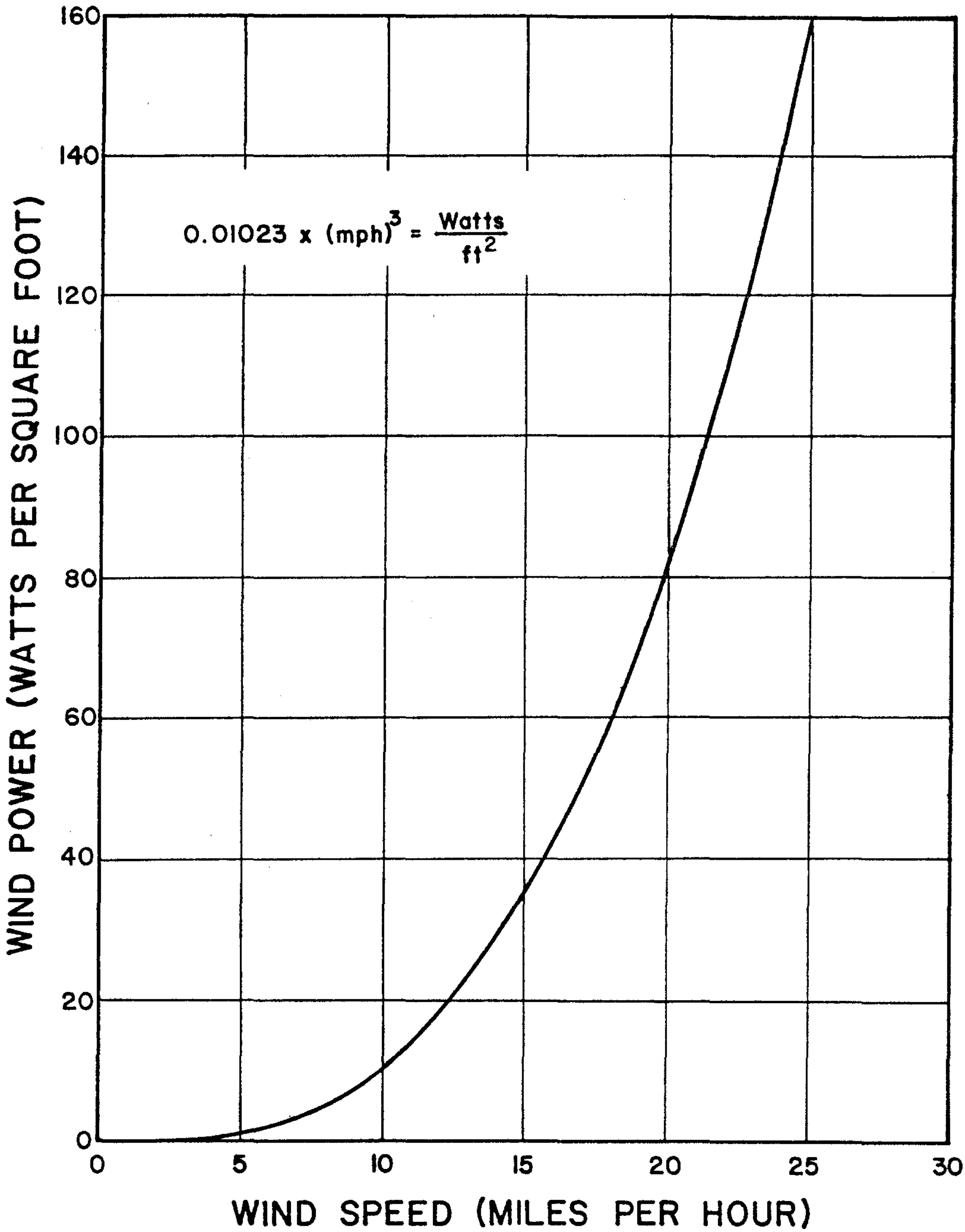
The density of the air is also a factor in wind power, but one which doesn't vary greatly from site to site. Lower elevations, cooler temperatures, and high humidities all tend to increase air density and thus wind power. Descending from 5000 feet to sea level increases air density about 15%, as does a drop in temperature from +60°F to -20°F (other factors being equal). This factor, then, is of much less importance than either wind speed or blade length. The effect of air density may be noticeable, however. When a recently installed **windgenerator** in Kotzebue was found to be generating more power than predicted for a given wind speed, it was reasoned that the greater air density of cold, sea-level air was the reason. Normal air density is about 0.0765 lbs/ft^3 (or, in metric terms, 1220 $grams/m^3$).

Using the standard figure for air density and Equation (1), we can state the following:

P/A (watts per square foot) = $0.01023\ V^3$ (mph) **Equation (3).**

This is plotted in the graph of Figure (1-10).

Fig.1-10: Wind Power vs. Wind Speed graph



Notes: Air density is assumed to be 0.0765 lbs/ft^3

The graph represents wind power, not windmill output

The graph cannot be used to determine average wind power from average wind speed

1:B:3 THE RELATIONSHIP OF HEIGHT AND WIND SPEED

The higher above the ground one goes, the higher the average wind speed will be (this may not be true if one goes up thousands of feet, but it's almost always true at heights **windgenerator systems** designers are interested in). Since even small increases in wind speed yield large increases in power, this is of great importance to **windgenerator systems** users. In most cases, a designer will find that the cheapest way to get increased power at a given location is to install a higher tower, not a larger **windgenerator.**

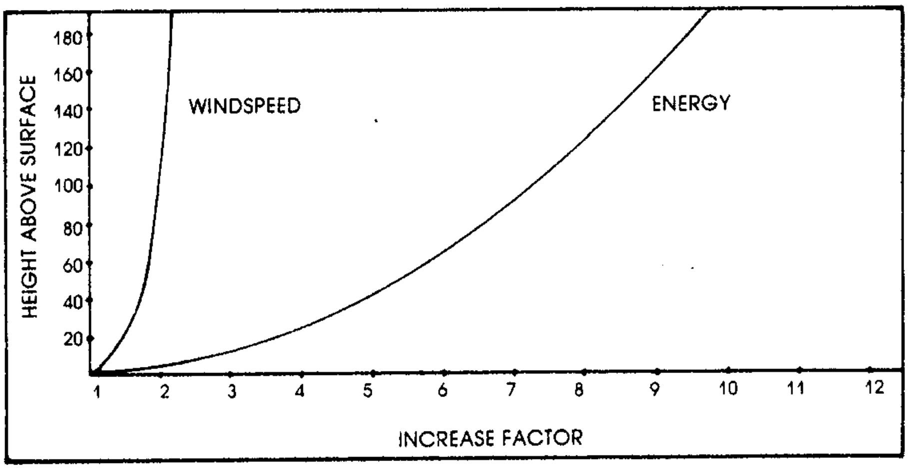


Fig.1-11: Height vs. Windspeed Plot (Source: Enertec)

Winds are not only faster at greater heights, they also tend to be less turbulent. This is another good reason for tall towers, because turbulence is very hard on **windgenerators.** A **windgenerator** which can operate for decades in laminar (smooth, even) winds with very little maintenance may be destroyed after just a few minutes in a turbulent location.

It is very helpful for a **windgenerator systems** designer to be able to estimate wind speed at a certain height from information he has about winds at a different height. During preliminary study of a site, for example, one may measure winds at eye level with a hand-held meter. What do these readings mean about winds at 60 feet where the **windgenerator** will be? How much power will be available at 80 feet compared to 60 feet?

A useful 'rule of thumb' for estimating these differences has been developed from measurements of winds at various sites and from theoretical studies of wind shear. This rule is expressed mathematically as

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{1/7}$$

where V_1 = wind speed at height h_1; and V_2 = wind speed at height h_2.

As an example of how this equation is used, assume that wind records have been kept at an airport from readings taken 30 feet above the ground. If you were interested in putting up a **windgenerator** at 60 feet somewhere nearby, you could estimate that the winds there would be $(60/30)^{1/7}$ as fast as those on record. If you had a calculator or were very good or patient at math, you would find this to be equal to about 1.10. This would mean that you could expect winds at 60 feet to be about 1.10 times those at 30 feet (in other words, 10% greater).

Neither calculator nor mathematical ability are needed, however, as these calculations have already been made. Finding the value 2 on the h_1/h_2 scale in Fig. 1-12, we can see that the corresponding value on the V_1/V_2 scale is about 1.10. This works for other values too; at 90 feet, h_1/h_2 would equal 90/30=3 (for our example), and V_1/V_2 would be about 1.17. Winds at 90 feet, then could be expected to be about 17% higher than at 30 feet.

The exponent 1/7 is not exact but rather an estimation. In some places, it is recommended to use 1/5 as the exponent; using this figure in the equation yields results showing greater differences between winds at different heights. (The reader is referred to "A Siting Handbook..." for a more detailed discussion). If greater accuracy is desired, actual measurements must be made at the site to establish the exact relationship.

1:B:4 LIKELY SITES FOR GOOD WIND

There are many promising locations in Alaska for wind power use; there are also many poor locations. Three general categories of places where high winds are likely are exposed coastal sites, hilltops or ridges, and passes through mountains.

Figure 1-13 shows sites with promising wind speeds along most of Alaska's coastline. The figure also shows, however, that certain coastal areas are not so good. These are usually sheltered areas; much of the Cook Inlet region, for example, and many of the south east Alaskan townsites.

Hilltops and ridges are often exposed to good winds, particularly if they are somewhat distant from other mountains. They act more or less like very high (and inexpensive) towers,

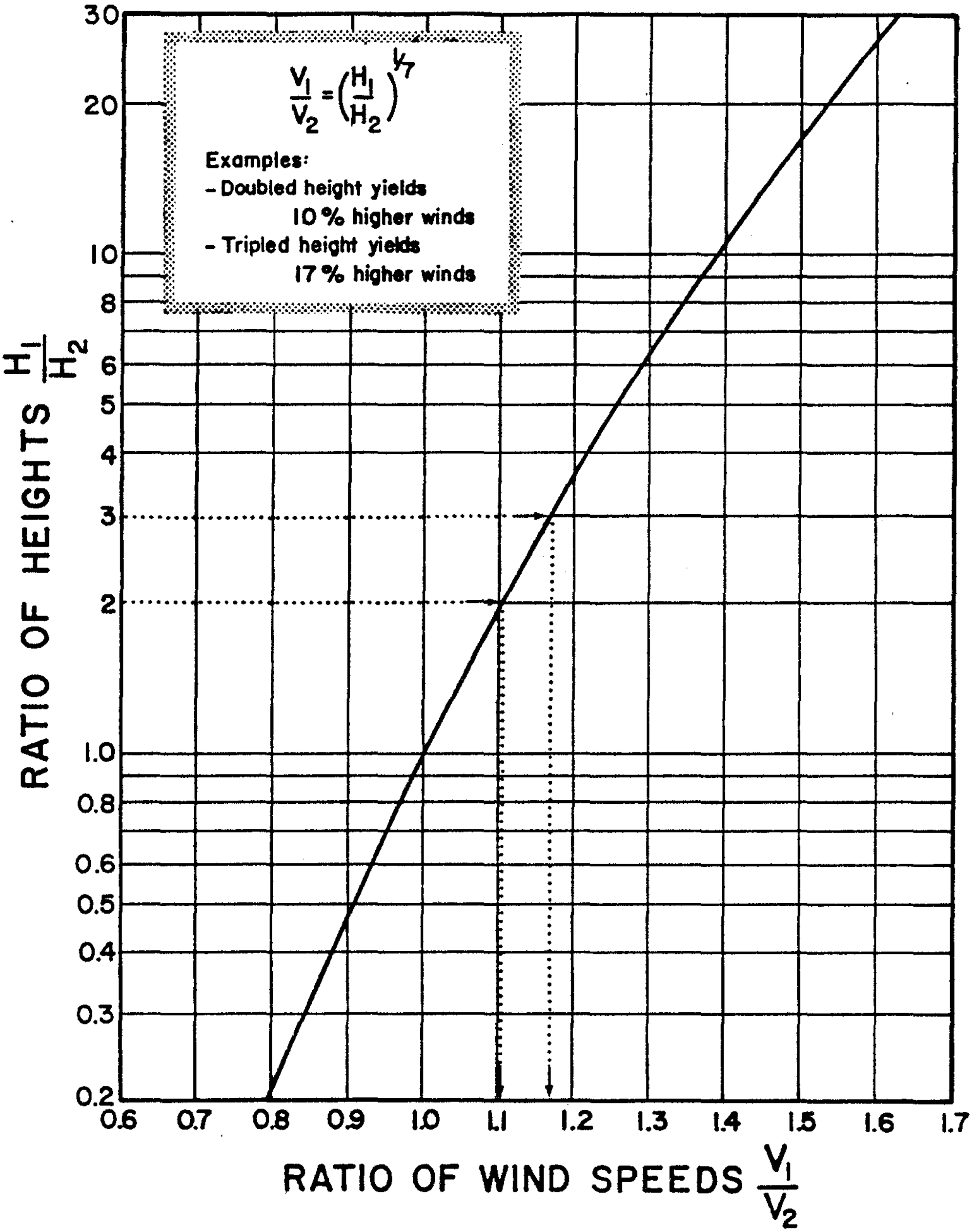


Fig.1-12: Ratio of Height vs. Windspeed Plot

reaching up into high wind regimes. Examples of this sort can be found in the Fairbanks area, where low-lying areas have very low winds, yet isolated domes have potentially useable wind resources.

Mountain passes and narrow valleys are often windy areas. When different weather systems lie on opposite sides of a mountain range, these passes can act as 'funnels' through which air rushes from a high pressure zone to a lower pressure. Well-known high wind areas of this sort are found in the Broad Pass - Healy area along the Parks Highway and in the Delta River Valley (both in the Alaska Range.)

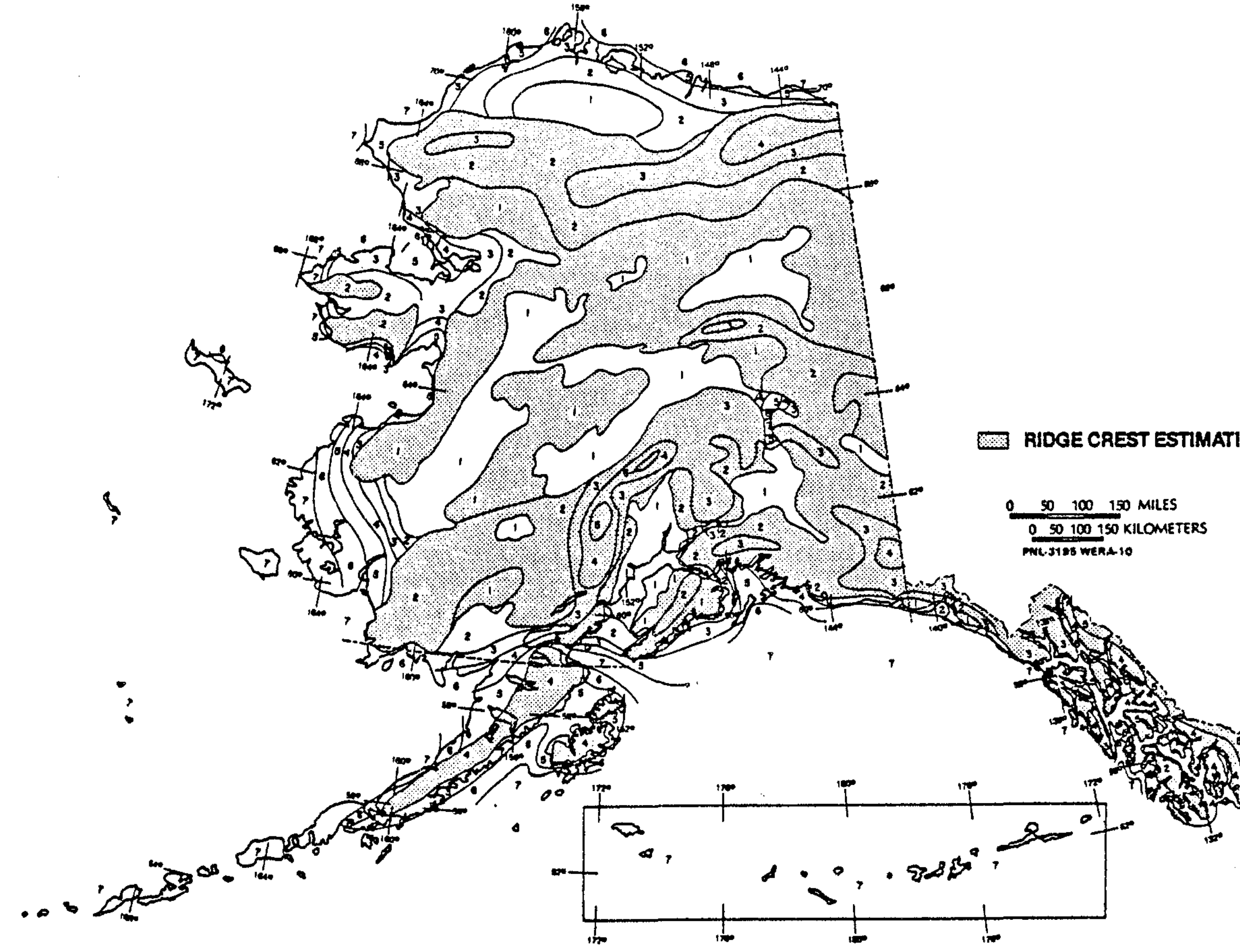


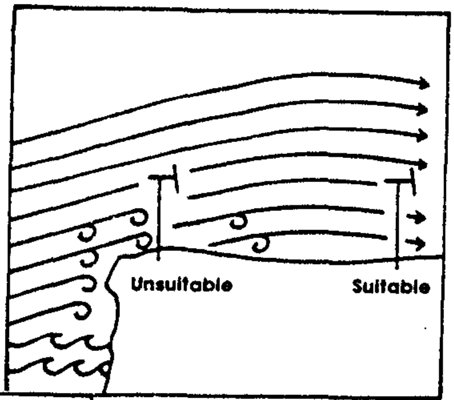
Fig.1-13: Map of annual average wind power in Alaska (Source: Wise,et.al.)

Classes of Wind Power Density at 10 m and 50 m[a]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, watts/m^2	Speed,[b] m/s (mph)	Wind Power Density, watts/m^2	Speed,[b] m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.



1:B:5 TURBULENCE

It is important to recognize that a good wind site is not only one with high winds, but also one with steady winds. Turbulence at high wind speeds is hard on **windgenerators,** producing stresses which can destroy machines which could survive much higher winds if they were steady. Turbulence also lowers **windgenerator** output, since the machine cannot react instantly to rapid changes in wind direction (this last point is not as critical for some vertical- axis wind machines, which do not need to be pointed to the wind),

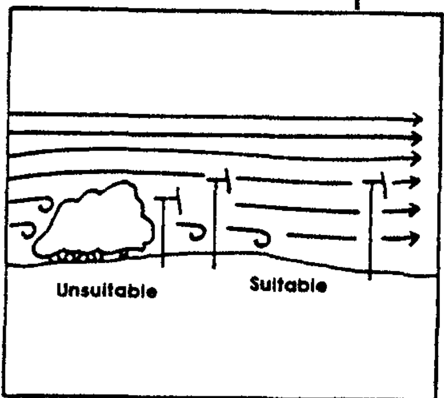
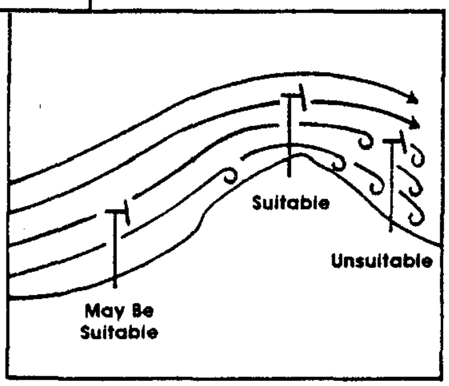


Fig.1-14: Siting considerations for turbulence (Source: Enertech)



For this reason **windgenerators** should be placed in areas away from obstructions such as trees and buildings, or at least high enough above them to avoid their effects on the wind. A 'rule of thumb' here is that the blades of the **windgenerator** should be above any object within 100 yards by at least 30 feet. Even greater clearances may be required to avoid turbulence that can occur on hilltops or on bluffs overlooking the sea or a large valley. These are often high wind areas, and can make excellent **windgerator** sites, but only if a tower is built high enough to raise the machine out of the area of turbulence.

Another area where potentially destructive turbulence may occur is where there is a junction of two or more valleys. Here a steady wind blowing along one valley may be interrupted by abrupt gusts from the other.

Some drawings illustrating some of these siting considerations are shown in Figure 1-14.

1:B:6 HOW MUCH WIND IS ENOUGH ?

The amount of wind necessary to make a wind electric system worthwhile depends to a large extent on the available alternatives. Wind-generated electricity is not cheap under any circumstances, and it can compete economically only when alternatives are also expensive.

As a general rule, a site with average wind speeds of 10 mph or greater merits serious consideration, and a site with wind speeds of 12 mph or greater is probably a good one. If wind average is below 10 mph, a **windgenerator** probably won't produce enough electricity to be worthwhile.

Many people overestimate wind speeds at their location, and for an accurate picture of the wind regime it will be necessary to measure and record wind speeds unless you can find existing records at a nearby site. Even at a site where "the wind always blows" it is rare for winds to average as much as 15 mph. At Barrow, for example, average wind speed is about 12 mph, at Nome airport the figure is about 10 mph (both measured at 30 feet).

Average wind speed is not sufficient alone to make a judgment, however. A wind system is obviously more advantageous at a remote site where diesel fuel delivery is both expensive and unreliable than at a site where relatively cheap and reliable electric company power is available. In some areas, wind speeds increase seasonally at the same time power demand increases (usually winter); this too is clearly advantageous.

For all but the smallest wind systems, the investment required is quite large. A decision to install a wind system, then, is not one that should be made lightly.

1:B:7 AVAILABLE WIND DATA

Table (1-1) presents average annual wind speed data for 77 Alaskan sites. This information was developed by Dr. Tunis Wentink, Jr. of the University of Alaska's Geophysical Institute. Wind speeds have been adjusted (using the methods described in Section 1:B:3) for three different heights.

Table 1-1

ANNUAL AVERAGE WIND SPEED AT THREE HEIGHTS FOR 77 ALASKAN SITES

(Listed in decreasing order)

LOCATION	NOTE	AVERAGE ANNUAL WIND SPEED At h = 10 m MPH	m/s	At h = 30 m MPH	m/s	At h = 50 m MPH	m/s
OS PAPA*	1, 2	26.7	11.9	33.3	14.9	36.8	16.5
Amchitka Isl.	2	23.9	10.7	29.8	13.3	33.0	14.8
Cape Thompson		22.6	10.1	28.1	12.6	31.2	13.9
Amchitka Isl.		20.8	9.3	25.9	11.6	28.7	12.8
Tin City		20.5	9.2	25.5	11.4	28.3	12.7
Shemya Isl.		20.4	9.1	25.4	11.4	28.2	12.6
Cold Bay		19.0	8.5	23.7	10.6	26.2	11.7
Wales		18.6	8.3	23.2	10.4	25.7	11.5
Kiska Isl.*		18.3	8.2	22.8	10.2	25.2	11.3
Gambell		17.9	8.0	22.3	10.0	24.7	11.1
Nikolski		17.3	7.7	21.5	9.6	23.8	10.6
Cape Sarichef		16.8	7.5	20.9	9.3	23.2	10.4
St. Paul Isl.		16.5	7.4	20.5	9.8	22.7	10.2
Cape Romanzof		16.0	7.1	19.9	8.9	22.0	9.9
Nunivak Isl.		15.9	7.1	19.8	8.9	22.0	9.8
Umnak/Cape AFB*		15.6	7.0	19.5	8.7	21.6	9.6
Chuginadak Isl.*		15.6	7.0	19.5	8.7	21.6	9.6
Port Heiden		15.2	6.8	19.0	8.5	21.0	9.4
Pt. Spencer		15.1	6.7	18.8	8.4	20.8	9.3
St. Matthew Isl.*		14.8	6.6	18.5	8.3	20.5	9.1
N.E. Cape		14.6	6.5	18.2	8.1	20.2	9.0

Table 1-1 (Cont'd)

		AVERAGE ANNUAL WIND SPEED					
		At h = 10 m		At h = 30 m		At h = 50 m	
LOCATION	NOTE	MPH	m/s	MPH	m/s	MPH	m/s
Pt. Lay		14.5	6.5	18.0	8.1	20.0	8.9
Cape Lisburne		14.3	6.4	17.8	8.0	19.8	8.9
Adak Isl.		14.4	6.4	17.9	8.0	19.8	8.9
Platinum		14.4	6.4	17.9	8.0	19.8	8.9
Middleton Isl.		14.1	6.3	17.6	7.9	19.5	8.7
Barter Isl.		14.0	6.2	17.4	7.8	19.3	8.6
Oliktok		13.8	6.2	17.2	7.7	19.0	8.5
Solomon*		13.3	6.0	16.6	7.4	18.4	8.2
Kotzebue		12.9	5.8	16.1	7.2	17.8	8.0
Prudhoe Bay		12.9	5.8	16.0	7.2	17.7	7.9
Pt. Hope		12.8	5.7	15.9	7.1	17.7	7.9
Moses Pt.		12.7	5.7	15.8	7.1	17.5	7.8
Atka Isl.		12.5	5.6	15.6	7.0	17.3	7.7
Cape Newenham		12.5	5.6	15.5	6.9	17.2	7.7
Bethel		12.4	5.5	15.4	6.9	17.1	7.6
Barrow		12.0	5.4	15.0	6.7	16.6	7.4
Wainwright		12.0	5.4	15.0	6.7	16.6	7.4
Attu (Alex. Pt.)*		11.7	5.3	14.6	6.5	16.2	7.2
Lonely Pt.		11.7	5.3	14.6	6.5	16.2	7.2
Golovin		11.4	5.1	14.2	6.4	15.7	7.0
Dutch Harbor	3	11.0	4.9	13.7	6.1	15.2	6.8
King Salmon		11.1	4.9	13.8	6.2	15.3	6.8

Table 1-1 (Cont'd)

LOCATION	NOTE	AVERAGE ANNUAL WIND SPEED At h = 10 m MPH	m/s	At h = 30 m MPH	m/s	At h = 50 m MPH	m/s
Koyuk*		10.9	4.9	13.6	6.1	15.1	6.7
Annette Isl.		10.8	4.8	13.4	6.0	14.9	6.6
Unalakleet		10.7	4.8	13.3	6.0	14.8	6.6
Port Moller		10.8	4.8	13.5	6.0	14.9	6.7
Driftwood Bay	4	10.4	4.7	13.0	5.8	14.4	6.4
Attu (NUU)	4	10.4	4.7	13.0	5.8	14.4	6.4
Skagway		10.3	4.6	12.8	5.7	14.2	6.4
Nome		9.8	4.4	12.2	5.5	13.6	6.1
Kodiak		9.9	4.5	12.4	5.5	13.7	6.1
Yakataga		9.7	4.3	12.0	5.4	13.3	6.0
Big Delta		9.6	4.3	11.9	5.3	13.2	5.9
Craig	4	8.2	3.7	10.2	4.5	11.3	5.0
Juneau		8.1	3.6	10.0	4.5	11.1	5.0
Kaltag		8.1	3.6	10.0	4.5	11.1	5.0
Ft. Yukon		8.0	3.6	10.0	4.5	11.1	4.9
Ketchikan		7.8	3.5	9.8	4.4	10.8	4.8
Yakutat		7.6	3.4	9.4	4.2	10.4	4.7
Kenai		7.5	3.4	9.3	4.2	10.3	4.6
Indian Mt.		7.4	3.3	9.2	4.1	10.2	4.5
Bettles		7.4	3.3	9.2	4.1	10.2	4.6
Umiat		7.0	3.1	8.7	3.9	9.6	4.3
Gulkana		6.8	3.0	8.5	3.8	9.4	4.2
Aniak		6.5	2.9	8.1	3.6	9.0	4.0

AVERAGE ANNUAL WIND SPEED

LOCATION	NOTE	At h = 10 m MPH	m/s	At h = 30 m MPH	m/s	At h = 50 m MPH	m/s
Homer		6.6	2.9	8.2	3.7	9.1	4.1
Sparrevohn		6.4	2.9	8.0	3.6	8.8	4.0
Nenana		5.9	2.7	7.4	3.3	8.2	3.7
Sitka	3	5.9	2.7	7.4	3.3	8.2	3.7
Tatalina		5.9	2.6	7.3	3.3	8.1	3.6
Galena		5.8	2.6	7.3	3.3	8.0	3.6
Anchorage		5.7	2.5	7.1	3.2	7.8	3.5
McGrath		5.5	2.5	6.9	3.1	7.6	3.4
Cordova	3	5.2	2.3	6.4	2.9	7.1	3.2
Northway		4.9	2.2	6.1	2.7	6.7	3.0
Valdez*	4	4.8	2.2	6.0	2.7	6.7	3.0
Fairbanks		4.8	2.1	5.9	2.7	6.6	2.9
Wiseman*	4	4.4	2.0	5.4	2.4	6.0	2.7
Eielson AFB		3.7	1.7	4.7	2.1	5.2	2.3

NOTES:

1. *Height unknown; 10 m assumed for measured data
2. Ocean Station PAPA not an Alaskan site, but 6 months $\overline{V}$ (Oct.-March) compared with Amchitka for same period.
3. Severe shielding of anemometer site known.
4. Probable shielding; details unknown.

The Wind Energy Resource Atlas -Volume 10 - Alaska is a good compendium of the available wind data in the State. Jim Wise, the State Climatologist, at Arctic Environmental Information and Data Center has this document and any other wind data available in Alaska.

Arctic Environment Information and Data Center
University of Alaska
707 A Street
Anchorage, AK 99501
(907) 279-4523
ATTN: Jim Wise, State Climatologist

If there is a wind speed recording station near a prospective **windgenerator** location, the people running the station should be contacted to find the best way to get access to records. Wind speed records are normally available from the National Weather Service Anchorage, Alaska. Most records are also available from the State Climatologist, at the University of Alaska (Anchorage) Arctic Environmental and Information Data Center. In many cases, the data have not been analyzed, and you may have to go through the (tedious) work of finding wind speed averages and distribution from the raw data yourself.

Wind speed records are available for a large number of Alaskan locations, due primarily to the large number of airstrips throughout the state. These records can be invaluable, as they have usually been kept for a much longer period than would be practical for a wind system designer to find himself. It is important to remember that these records can only act as a guideline to what wind speeds will be at a specific wind site; at least a short program of wind speed recording should be done at the actual site for comparison to established records. This is critical in locations where the available data indicates marginal winds. Since wind is such a localized phonomena your winds can be significantly different from those at a nearby airport (since airports are usually sited to avoid winds).

1:C The Nature of Windgenerators

1:C:1 WHY ONLY WIND ELECTRIC SYSTEMS ARE DISCUSSED

Wind power conversion to electricity is the only wind use discussed in this handbook. **Wind Power** can be used, of course, for purposes other than the making of electricity. The question then arises as to why these other uses are not discussed.

The first reason for this is that wind electric systems are what most people are interested in. The second reason is that even if non-electric demands are to be served, the intermediate conversion to electricity will usually prove to be the most cost effective method in any case. The strictly mechanical **windmills** of Holland were (are) much less efficient than modern electricity-producing **windgenerators.** Therefore even if all you wanted power for was to grind grain or saw wood, it could be cheaper to use an electricity producing windgenerator unless the less efficient mechanical mills were vastly cheaper - which they aren't.

The 'American fanwheel' **waterpumpers** serve their purpose very well, but only under limited conditions. These conditions are that first, the well cannot be very deep, and second, the best wind site should also be the best well site. This occurs frequently in the American Mid West, where the flat terrain makes **windpumper** sites all about the same. In more rugged topography, however, one would probably do better to place an electricity-producing **windgenerator** on a hill in the higher winds, and transmit electricity to an electric pump at the well site. A final consideration is the maintenance requirements of windpumpers and their aversion to freezing temperatures.

This does not imply that there are never any applications for non-electric wind machines. Their applications in Alaska, however, are felt to be limited enough that a thorough discussion of them is unwarranted.

1:C:2 COMMON PROPELLER TYPE WINDGENERATORS

Nearly all **windgenerators** in production or use today are of two or three bladed propeller type, a fairly simple machine not drastically different from those built 50 years ago. The wind turns a rotor, which is connected to a generator either directly or through some mechanical speed increaser, such as a gearbox.

Efficiency

The theoretical maximum efficiency of a wind turbine rotor was shown by the German, A. Betz (in 1927) to be 16/27, or 59.3%. In other words, a 'perfect' **windgenerator** would produce 59.3% as much power as was in the wind blowing past it. The derivation of this proof can be found in **Golding** and in many physics textbooks. In practice, many modern propeller type rotors come fairly close to this in developing shaft power; and efficiency of about 40-45% may be typical for normal operating wind speeds. The gearbox and generator have their own inefficiencies, however, and the overall efficiency of the propeller type **windgenerator** is thus less; 35-40% is closer to the maximum efficiency of these machines at normal operating wind speeds (and less in very low or very high winds). An overall efficiency of 15-30% should be considered reasonable for most **windgenerators** by the time you get the power to the ground. It is, however, important to note that efficiency is of little consequence in a **windgenerator** since you are not paying any fuel bills. Efficiency can be useful however, in determining if a manufacturer's rated output at a given wind speed is reasonable.

Blades

A schematic drawing showing the major components of a propeller type **windgenerator** is shown in Fig. 1-15. **Windgenerators** of this type have been built with blade lengths as small as two feet and as great as 200 feet (Hamilton Standard is building even larger ones). For small machines the blades are usually simple in design, and are often made of Sitka spruce or hardwoods with a metal strip fastened to the leading edge for protection against wear. Composite blades using fiberglass, foam, or wood laminates are becoming increasingly popular with many manufacturers. For large machines the blades can become quite complex (much like a large airplane wing), with elaborate framing covered with a metal skin, having a changing cross section and pitch along the length of the blade, and perhaps hydraulic lines to operate feathering devices. In the DOE/NASA large Wind Energy Conversion Systems program the best performance from a blade design has interestingly enough been from the MOD-OA 200 kw unit at Kahuka Hills, Hawaii; it uses wood laminated blades.

The blades are joined at the rotor hub, which is mounted on the rotor shaft. The relatively slow speed of the rotor shaft can be stepped up in a gearbox enough to drive a generator. Since the rotor turns more slowly on larger **windgenerators**, the gear ratio tends to be larger for them. The 200 kw **windgenerator** built by WTG Energy Systems (*), for example, has 40 foot blades and is designed to turn at 30 rpm; the gearbox increases this 40 times to the 1200 rpm generator speed. On the other hand, the 200 Watt Winco 'Wincharger' (*), with 3 foot blades, turns at 900 rpm and uses a specially wound alternator to generate power at low rpm's with no gearbox used at all.

* does not indicate product endorsement

A

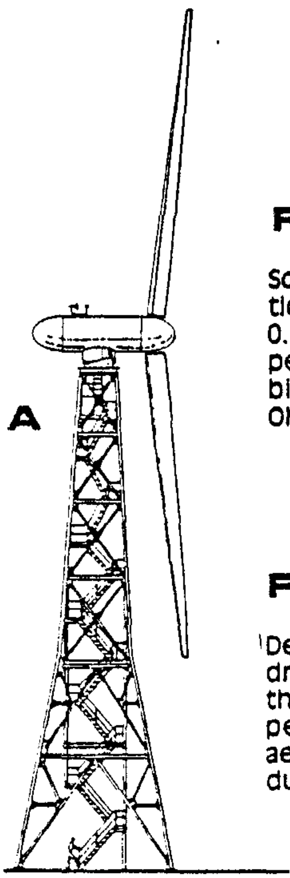


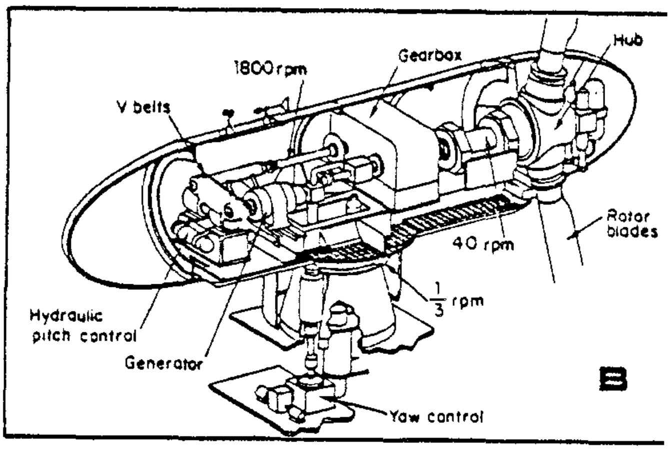
FIG. 15A

Schematic representation of the 0.1-megawatt experimental wind turbine near Sandusky, Ohio.

FIG. 15B

Design details of the drve train assembly of the 0.1-megawatt experimental aerogenerator at Sandusky, Ohio.

Fig.1-15: Schematic diagram & components of a Windgenerator



Generator

A **windgenerator** can be fitted with just about any kind of electric generator, depending upon the application. The old **windgenerators** used in the 1930's such as the old **Jacobs**, used a direct drive brush-type DC generator. These units were very heavy because of the amount of heavy gauge copper wire needed and required periodic replacement and adjustments on the brushes. Most new built **windgenerators** now use an AC alternator and rectify the AC to DC power (as done in automobile electric systems). The conversion from AC to DC is quite simple, inexpensive, and reliable, although the reverse operation - DC to AC inversion - is neither simple nor cheap.

In locations where utility power is available, an intertie with the AC power lines may be desirable. This can be done one of three ways:

1) The induction generator is actually an induction motor. With no input from the blades, and the system connected to a utility power source, the induction motor would try to spin the blades. On the other hand, with the wind blowing at a velocity that causes the rotor to turn faster than the induction motor's rated rpm, the device acts like a generator and produces energy. The most important part is that the energy produced will be "synchronized" with the local utility power (AC).

The relationship between the utility and the induction generator is that of master and slave. The "master", (utility power source) provides the signal or reference, and the "slave" has the duty of mirroring the master.

2) **Windgenerators** utilizing synchronous alternators are capable of 60 cycle, alternating current with or without a utility grid. This capability is possible because of the controls necessary to make the synchronous alternator generate electricity. The "master-slave" relationship found in the induction machines is modified for the synchronous machine with the addition of a "middle man" who translates the master's instructions. This middle man is usually a micro-processor. Because micro-processors have the capability of generating for their own reference, the utility grid is not necessary for machines to generate electricity at 60hz.

3) **Windgenerators** which generate DC power are typically used for charging batteries in remote sites. Either a brush-type DC motor or an alternator rectified to DC is generally used. The DC power can be used directly, charge batteries, and/or inverted to AC power. A **synchronous inverter** is a device which can take the DC power and invert it to AC synchronized with the utility, thus using the "master" for a reference.

Yaw Control

Yaw (directional orientation in the wind) is controlled in several ways on different **windgenerator** designs. Many use a tail vane, which keeps the rotor pointing into the wind on the **upwind** side of the tower; these machines are known as **upwind windgenerators.** Some **windgenerators** have no tail vane, and the machine turns in the wind so that the rotor remains **downwind** of the tower; these are **downwind machines.** On large machines yaw is controlled by means of a motor drive, controlled by a wind direction sensor. These motor driven **windgenerators** are usually **upwind** to avoid tower shadow problems. Tower shadow is the wake produce by the wind blowing through the tower and causing turbulence.

Overspeed Control

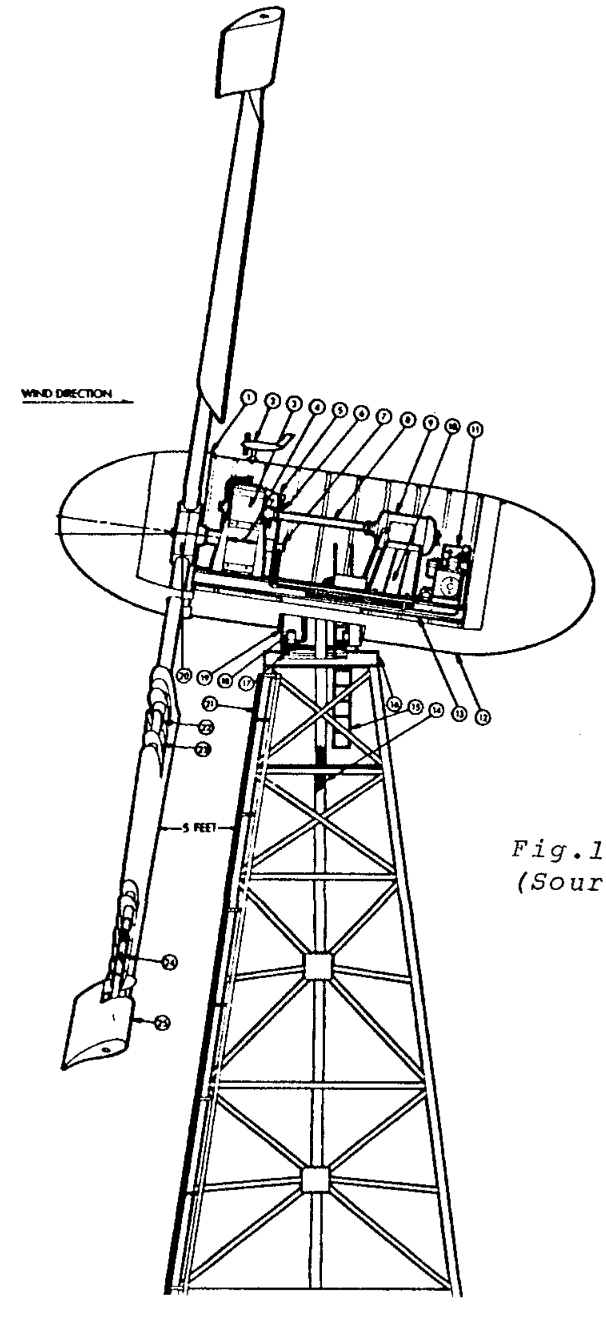
Windgenerators rotors must be prevented from turning too rapidly, or else broken blades or bearings can result. A number of devices are used on different machines to provide overspeed control (see Figure 1-16). On some, 'brake flaps' or 'wind scoops', located at the rotor tips, are actuated either by centrifugal force (on smaller machines) or by electric or hydraulic motors (on larger ones). These create a drag which slows the rotor speed. On other machines the blades themselves can pivot, changing their angle of attack and, again, reducing rotor speed. This type of control can also be actuated either by centrifugal force or by means of motors and is called "feathering". On machines with a tail boom, overspeed control can be effectively achieved by cocking the tail somewhat, thus turning the rotor partially or fully out of the wind.

Brakes

In addition to overspeed controls, **windgenerators** must have a brake system to stop them completely in times of very high winds and when maintenance is required. The brake is usually automatically activated for protection in very high winds; manual operation must be possible, of course, for maintenance and emergency purposes. A disc brake on the rotor shaft is frequently used. Another method possible of stopping the blades if the **windgenerator** has a tail vane is to turn the tail boom parallel to the rotor - 90 degrees from its operating position - thus keeping the rotor turned out of the wind.

Nacelle Assembly:

The entire rotor-gearbox-generator assembly is mounted in a housing which, in turn, is mounted on a turntable base, which allows the **windgenerator** to yaw (pivot in a horizontal plane) to follow changes in wind direction. The turntable is fitted with devices to level the machine precisely on top of the tower. Slip rings allow the **windgenerator** to yaw while maintaining electrical contact with the stationary cables leading to the ground.



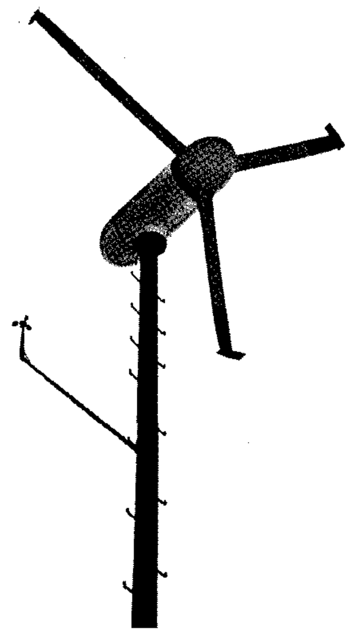


Fig.1-16: Blade tip brake flaps (Source: WTG & Enertech)

1:C:3 OTHER WINDGENERATOR TYPES

Numerous types of wind-electric devices have been demonstrated or proposed other than the propeller type. The vast majority of **windgenerators** available, however, are propeller types, and the prospective wind power user will most likely decide to use one of these. Because of this, less detail is presented here on other **windgenerator** types, although short descriptions of some are presented below. The reader is encouraged to do his or her own research on these machines if they are of interest.

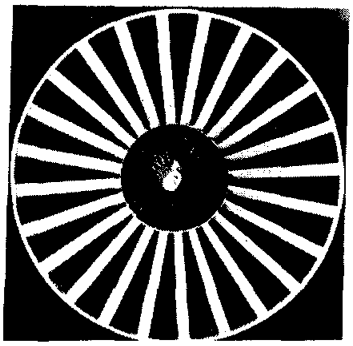


Fig.1-17: Bicycle wheel turbine (Source: American Wind Turbine)

<u>Bicycle Wheel Turbine</u>: This new **windgenerator** design is reminiscent in appearance to the multi-bladed 'fanwheel' **water pumping** machines (see Figure 1-17 & 1-18). It is constructed much like a bicycle wheel, with wire spokes holding an outer rim in place around a central hub. A large number of narrow blades are attached to adjacent spokes. The pitch of these blades is determined by the placement of the ends of the spokes on the rim and hub. At least one manufacturer of these machines, rather than gear up the rotor speed, runs a drive belt around the outer rim and over a small drive wheel on the generator shaft in order to achieve the increase in speed. They are light in weight, relatively inexpensive, and simple in design. The little bit of testing that has been done on them at the DOE/Rockwell Rocky Flats Test Center has shown that they do not hold up well in high winds (greater than 30 mph). None of the bicycle type generators has been tested in Alaska, but past experience does not suggest that this type of turbine has a lot of promise here.

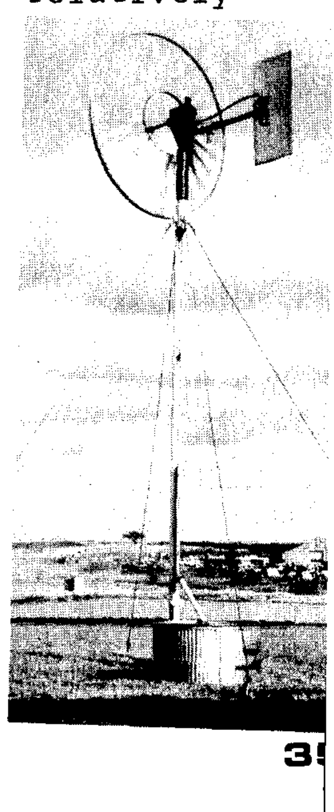


Fig.1-18: Bicycle turbine water pumper (Source: same)

<u>Darrieus Turbines</u>: These machines, invented by Frenchman G.J.M. **Darrieus** in 1926, are **vertical axis** machines (as opposed to propeller types whose rotors turn on a horizontal axis). They consist of two or three long, thin airfoils like those used for helicopter rotors, bent in a bowed 'troposkein' shape, and attached at each end to a vertical shaft (see Figure 1-19). The result looks something like an oversized **eggbeater**, and this has become the nickname of the design.

One great advantage of these machines is that they do not need to be turned to face the wind. The generator is mounted at the bottom of the vertical shaft in a stationary position, and thus no slip rings are needed. Several of these machines can be mounted, one atop another, on the same shaft to increase power output. (See Figure 1-19).

A major drawback of these machines is that they are usually not self-starting, even in high winds. This is overcome by running the generator as a motor in order to start the blades spinning.

There are several firms making **Darrieus windgenerators** but as yet they have not proven themselves as a commercial machine. They do however hold a lot of promise and given a little more time will be a machine worth considering for Alaska.

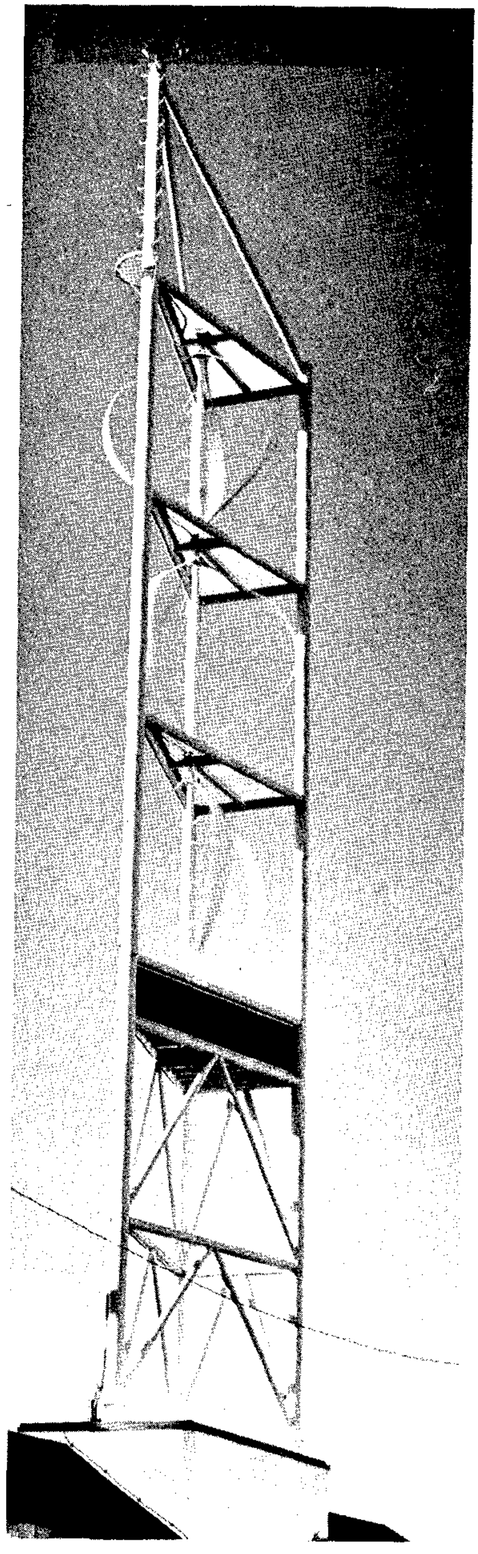


Fig.1-19: Stacked Darrieus (Source: Dynergy)

Savonius Rotors: This **windgenerator** design, named after the Finn, S.J. Savonius, who developed it in 1931, is a modern version of the 'carousel' **windgenerators** (see Figure 1-20). Like the **Darrieus,** it is a **vertical-axis** machine. It makes use of the drag presented by its curved shape, much like a cup anemometer. The rotor consists of half cylinders mounted in a fashion around the axis. In this configuration, some of the wind hitting one half-cylinder spills into the other, yielding more power than would otherwise be produced. Because it uses the drag force exerted on its surface, rather than aerodynamic lift (like the propeller and **Darrieus** types), the speed of the **Savonius** rotor is low and is best used in mechanical applications such as pumping water. It does possess the virtue of simplicity, however, and can be built cheaply.

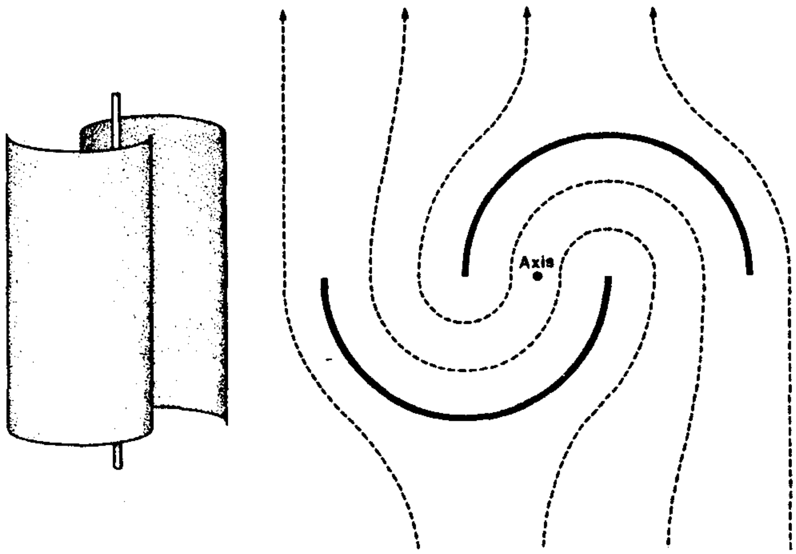


Fig. 1-20: Savonius Rotor (Source: Inglis)

At present there are no commercially available **Savonius** rotors and as such should not be considered a machine for anybody but the experimenter. There are several good how-to books on the construction and design of a homebuilt **Savonius** rotor listed in the Bibliography.

1:C:4 THE RESPONSE OF WINDGENERATORS

The amount of power produced by a **windgenerator** varies with the wind speed. Figure (1-21) shows a graph of this for a typical machine; this is known as the 'machine response curve' or the 'power characteristic'.

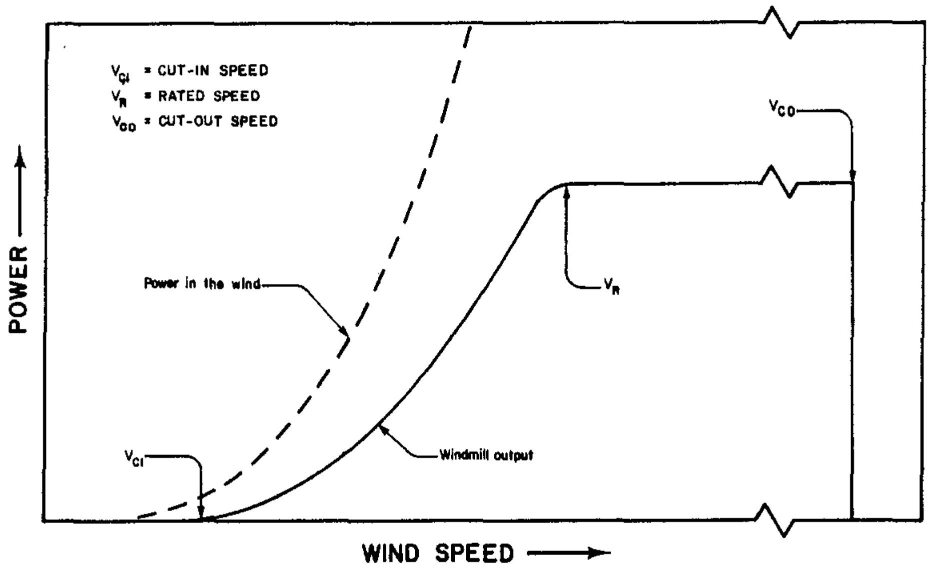


Fig.1-21: Power vs. Wind speed graph

At very low wind speeds, the **windgenerator** doesn't turn at all (or at least not fast enough to produce noticeable power). The wind speed at which the **windgenerator** begins to produce power is known as the cut-in speed (V_{CI}). This is usually around 7 mph for propeller type machines, although it may be as low as 5 mph or as high as 15 mph.

As the wind speed increases beyond cut-in speed, the power output of the machine increases rapidly until the generator reaches its rated output. The speed at which this occurs is known as the rated wind speed (V_R). For different models of wind machines, V_R varies from as little as 16 mph to as high as 40 mph, and is typically between 20 and 30 mph.

As the wind speed increases above V_r the rated wind speed, the machine's overspeed controls begin to operate. This prevents damage to the machine, and keeps power output at about rated capacity, even though the power in the wind itself is still increasing rapidly, as shown in the graph (Figure 1-21).

As winds become very high it may become dangerous to operate the **windgenerator** at all. In some units, at a certain speed, a brake is automatically applied (or the blades turned completely out of the wind), and power output drops to zero. This is known as the cut-out speed (V_{CO}). The V_{CO} varies between models of **windgenerator** between as little as 30 mph to as great as 65 mph. A few **windgenerators** are designed to have no cut-out speed and will operate in any wind up to 150 mph.

Each model of **windgenerator** will have a different machine response curve which the manufacturer can usually supply; these will be similar to the one shown in Figure 1-17. The efficiency of the machine at any wind speed can be determined by comparing the machine's output at that speed (from the machine response curve) with the power of the wind at that speed (which can be calculated from the blade length as described in Section 1:B:2).

1:C:5 COMPARING WINDGENERATOR POWER RATINGS

A great deal of confusion can arise when comparing the 'rated power' of different models of **windgenerators.** This is due to the fact that the rated power refers to output at a given maximum output of the generator. A generator fitted to a large set of blades or a greater number of blades will reach rated power in lower winds than if it were fitted to a small set of blades. The performance of the two **windgenerators,** even though both would have the same rated power, would be quite different. It should be noted here that no **windgenerator's** output ever averages anything close to the rated output, unless you live in a location which has 20 mph winds constantly.

There can be advantages to these variations in the sizes of **windgenerator** blades (relative to generator size). A **windgenerator** with a large set of blades (or a greater number of blades) will begin to turn - and generate power - in very low winds. It will also reach rated output at a relatively low wind speed. Above rated speed, the output remains constant (up to cut-out speed), even though the energy in the wind is still increasing. Conversely, a **windgenerator** with relatively small blades will not begin producing power in very low winds, but can take full advantage of the wind's energy up to its (higher) rated wind speed. Because of this, it is advantageous to use a **windgenerator** with a relatively large set of blades (and low rated speed) in a low wind regime, since such a **windgenerator** can take better advantage of light winds. In a wind regime with frequent high winds, however, a relatively small set of blades would be recommended, since it would more effectivley harness the energy in higher winds.

The 'rated power' of **windgenerators,** then, is not by itself enough information with which to compare models. A certain machine may "peak" at a relatively low wind velocity where another may have its output rise to a certain value and then remain at that level even if the wind velocity continues to increase (up to its rated maximum winds anyway). These operating characteristics are machine specific. As a result, the wind electric system designer must calculate the estimated power output of each model under consideration in whatever wind regime his site presents; simple comparison of rated power - which is to say generator size - is not adequate. If these principles are understood, they can greatly aid in the choice of the best **windgenerator** for a particular system; if not, they can create a lot of confusion and lead to systems which do not produce power as expected.

1:C:6 CHOOSING A WINDGENERATOR

It is important to understand at this point that there are many factors which must be taken into consideration before one purchases a **windgenerator.** A good analogy is buying a car; the various makes and models are all designed with a different use in mind. Unlike the auto industry however, the **windgenerator** industry is still very young and there are many manufacturers in the business which won't be around five years hence. In addition very few machines have been proven to work well in Alaska. Thus it is imperative to select a generator which is backed by a conscientious manufacturer and a reputable dealer and preferably one with a good deal of field experience in an environment similar to yours.

A thorough discussion of the design factors involved in a **windgenerator** selection is left to **Part Two.** Service is an important consideration in the purchase of a product with a 20 year life. Even the best engineered system will fail unless the necessary support infrastructure (related businesses) is present.

1:D Other Wind System Components

1:D:1 TOWERS AND FOUNDATIONS

The tower and its foundation must provide a stable platform for the **windgenerator** - not an insignificant feat, since the **windgenerator** is intentionally placed in the highest winds practical. There are three basic types of towers commonly used in wind electric systems; each has advantages and disadvantages. Towers, regardless of type, must be fitted with a cap which will match the mountings of the **windgenerator**, and should be well grounded for lightning protection.

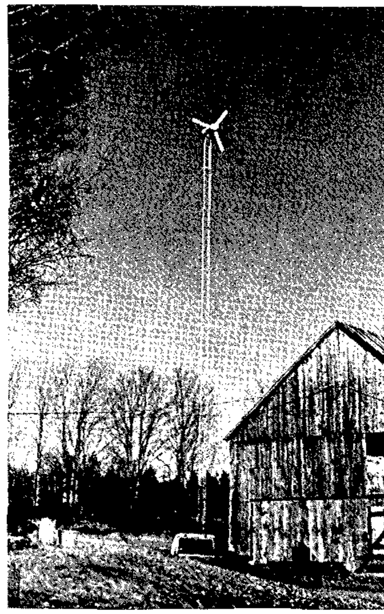


Fig.1-22: Guyed towe
(Source: Enertech)

TOWERS

The most common (and usually the least expensive) type of tower is the guyed mast. For smaller systems (less than 2kw) the mast can be a wooden telephone pole. Metal radio or telecommunications masts are also common. The mast and each guy wire has a foundation. The foundation for the mast is built mainly to take the downward force exerted by the weight of the machine and tower and the reactions to guy wire tension. The guy wire anchors are designed to resist the upward pull of the guy wires caused by the tension they are under and the wind loads on the machines. Sometimes guyed masts are built with a hinge at the base so that the entire tower and **windgenerator** can be lowered for servicing.

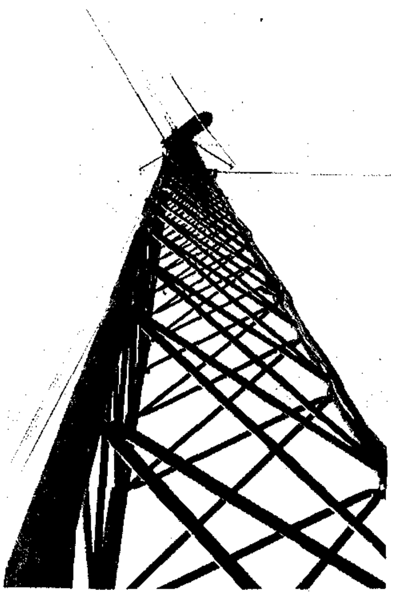


Fig.1-23: Tubular steel guyed tower
(Source: same)

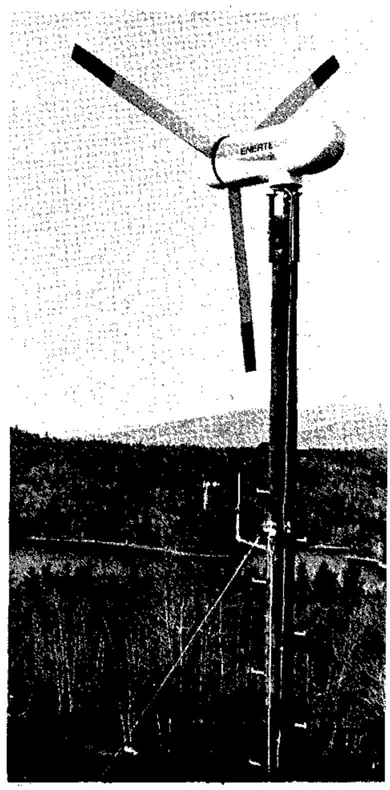


Fig.1-24: Pole towe.
(Source: same)

The next most common form of tower is the three or four legged <u>truss type</u> tower similar to transmission line towers. These <u>free standing</u> towers are a little easier to maintain than the guyed masts since in the latter the guy wire tension must be checked and adjusted periodically. The free standing type of tower requires a footing for each leg or a massive footing for the entire base. These footings must alternatively support downward loads or resist uplift, depending on the wind speed and direction.

The third type of tower is the <u>free standing mast</u>. These must be more rigid than their guyed counterparts, since they have no guys to help resist the loads, and are heavier and more expensive as a result. The single foundation these require must also be very strong, since it not only has to support the weight of the tower and **windgenerator** but also resist the large moment forces (twisting) created at the base of the mast by the wind loads on the machine.

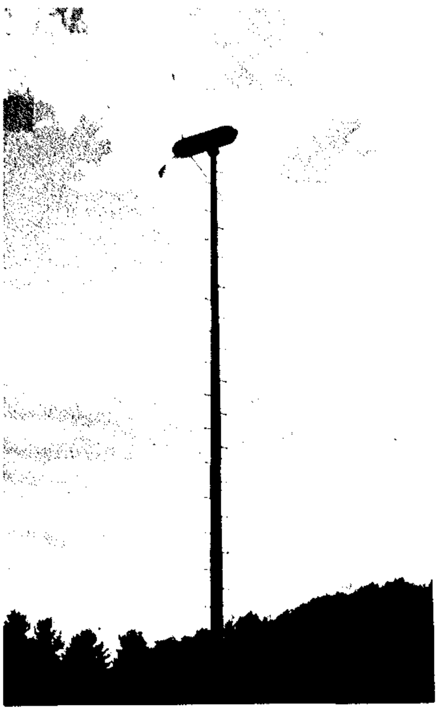
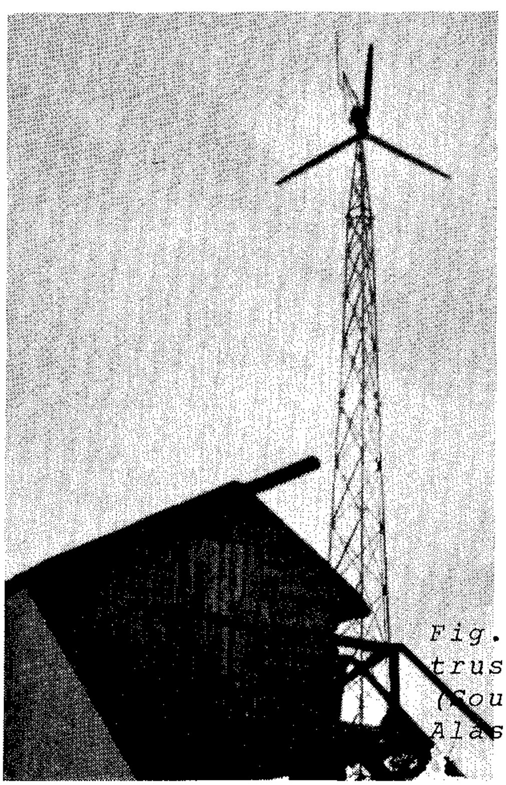


Fig.1-25: Free standing mast tower (Source: Enertech)



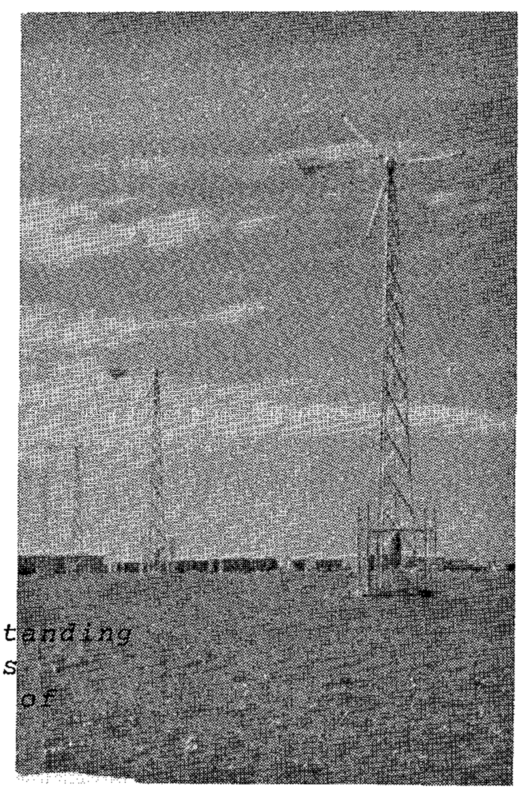


Fig.1-26: Free standing truss type towers (Source: 4 Winds of Alaska & Newell)

FOUNDATION

The type of soil the tower base is surrounded by is as important as the tower itself. Concrete is usually used for tower bases in the "lower 48" but in most of Alaska this can be very expensive. In frost susceptible soils, the freezing and thawing action can force a tower base out of the ground and destroy a **windgenerator.** Pilings can make good foundations if properly designed and installed. Foundation design in Alaska is much too complex to cover in any detail here. The reader is best advised to consult an engineer or soil mechanics textbook for more information.

1:D:2 BATTERIES

Lead-acid batteries are by far the most common type of energy storage device for wind electric systems. Batteries also perform a less obvious role, which is to stabilize the voltage in the electric system (the **windgenerator's** output fluctuates as the wind speed changes).

'Deep cycle' batteries are almost always used in wind systems. These batteries are designed to sustain repeated deep discharge without damage, and are commonly used in forklifts, golf carts, and the like. They are both heavier and more expensive than the batteries used in automobiles and trucks. It is possible to use automobile type batteries for wind system storage, but this is <u>not recommended</u>. If they are allowed to discharge very often, their lifetime will be short; if they are not allowed to discharge (in order to lengthen their service life) much of their capacity is wasted.

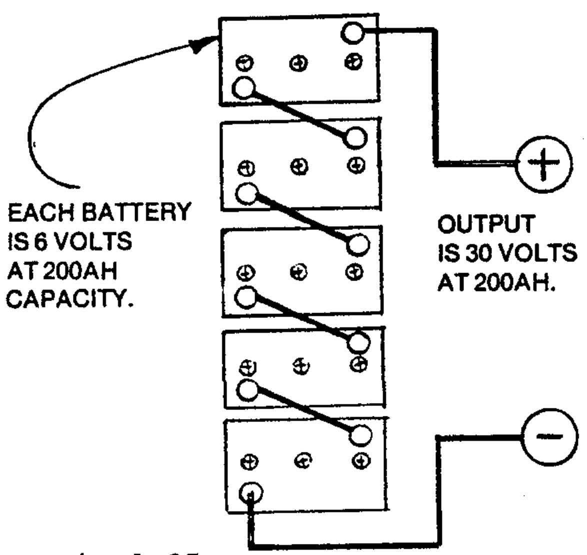


Fig.1-27:

BATTERIES CONNECTED IN SERIES (POSITIVE TO NEGATIVE)

(Source: Hackleman)

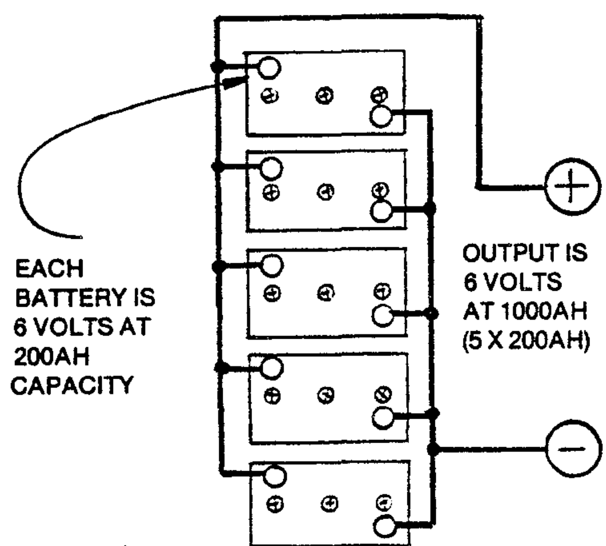


Fig.1-28:

BATTERIES CONNECTED IN PARALLEL (NEGATIVE TO NEGATIVE, POSITIVE TO POSITIVE)

(Source: same)

Batteries have a rated capacity in ampere-hours and a rated voltage (usually 2, 6 or 12 volts). If several batteries are connected in parallel, the resulting battery system will have a capacity equal to the sum of the individual batteries' amp-hour ratings; the voltage will be the same as for the individual batteries (see Figure 1-28). If connected in series, the voltages are additive while the amp-hour rating remains the same as the individual batteries (see Figure 1-27). In either case, the total stored energy (measured in watt-hours) is the sum of the individual batteries.

The battery storage system must be of the same voltage as that generated by the **windgenerator**. Thus if a 48 volt **windgenerator** is used, enough batteries must be connected in series to yield a 48 volt battery system (i.e. four 12 volt batteries or eight 6 volt or twenty-four 2 volt). If the total energy storage of this series is insufficient for the system, additional sets of series-connected batteries identical to the first can be hooked up in parallel.

Batteries for wind electric systems can be very expensive, so it is worthwhile to use them under conditions which will result in their most efficient operation and longest life. Aside from keeping cells full of water, the two basic requirements for optimum battery operation are, first, don't charge or discharge them too fast and , second, keep them from freezing. Battery sets should also be fully charged periodically to equalize the charge on the individual cells. Keeping batteries too hot can also be a problem, but this will rarely be of concern in Alaska. These requirements are discussed in more detail in Sections 2:D:1, 2:D:2 and 4:C.

1:D:3 OTHER FORMS OF STORAGE

Batteries are not the only means of storing energy produced by a **windgenerator**, although they will in nearly all cases prove to be the cheapest and most reliable means for storing electricity, especially in small systems. Other forms of storage which have been used or proposed include compressed air storage, pumped-hydroelectric storage, hydrogen storage, flywheel storage, and thermal storage.

Compressed air storage involves using all **windgenerator** power not immediately needed for other uses to operate an air compressor. To retrieve the power, the process is reversed; a compressed air driven 'motor' powers a generator. For some uses the reconversion to electricity would be unnecessary; compressed air tools, for example, are commercially available. The principle drawback to compressed air is its low efficiency, and large volumes of storage required.

Pumped-hydroelectric storage is accomplished by pumping water uphill to a reservoir, and later using this stored water to drive a turbine-generator. In most pumped-hydro systems, the 'pump' and the 'turbine' are one and the same machine whose operation is reversible. There are a number of pumped-hydro stations operated by electric utilities in the U.S. and other countries. Finding a favorable hydro storage site is difficult, and finding one in proximity to a favorable **windgenerator** site is even more so. In addition, these systems tend to be very expensive. For a system with numerous large **windgenerators** (such as an electric utility might buy) it is possible that pumped-hydro storage would be practical.

Hydrogen Storage involves electrolyzing water into hydrogen and oxygen gas, and storing the hydrogen. The flammable hydrogen can then be used as a fuel for a (more or less) conventional motor-generator system or a fuel cell system. The fuel cell is a device which converts the chemical energy of the hydrogen-oxygen reaction directly into DC electricity with higher efficiency than conventional methods of power generation. In operation it is similar to an electrolyzer working in reverse.

Hydrogen storage appears to be a reasonably good storage method in theory although it wouldn't match the efficiency of a conventional battery. At the present time, few, if any of the major components - electrolyzers, hydrogen storage systems, fuel cells, or hydrogen-fueled motors - are readily available. Even if these components could be specially made, they would be very expensive.

Flywheel storage is done by using excess power in an electric motor to spin a flywheel; the energy is thus stored as kinetic energy. Later, the spinning flywheel can be reconnected to the motor, which will then generate electricity again. Like hydrogen systems, flywheel storage is in a developmental stage. Research is being done for applications in many fields, but no practical systems are commercially available.

In order to store significant amounts of energy in a flywheel, large masses must be spun at very high speeds; this creates two major problems. One of these is that a heavy flywheel must be perfectly balanced so that the bearings will not be destroyed; the other is that special materials must be used or else the centrifugal forces on the flywheel will cause it to literally tear itself apart. In addition to these problems, the flywheel bearings need to be nearly perfect if the energy is to be stored for long periods (otherwise the flywheel would just slow down and eventually stop).

Thermal storage can be done by simply using electrical resistance heaters or a heat pump to warm up a material in a heavily insulated container. This hot material can then be used later to boil a fluid (water, ammonia, etc.); the steam (or ammonia vapor)can then be used to drive a conventional turbine-generator. A thermal storage system would have a low efficiency for electrical power production.

Thermal storage is a more practical idea if heating will be the final use of the energy, because in that case reconversion to electricity is unnecessary. A system has been designed and built based on the principle that surplus power be used to heat water, which can later be used for domestic hot water uses or for a hot water space heating system. This, of course, is just indirect electric heating, which is almost always more expensive than any other means of heating. As a result, this is not usually a cost-effective idea unless your **windgenerator** is generating power which otherwise would be wasted.

Another form of thermal energy storage which is being demonstrated on a commercial basis and is useful in some cases is to store cold, not heat, and use it for cooling purposes. Surplus electricity could be used to run an icemaker, for example, and the ice stored for use in an icebox (which would substitute for a refrigerator). This could well be advantageous to a wind system owner in a hot climate or for a community freezer in a village in the summer time.

1:D:4 DC/AC INVERTERS

An inverter is a device which converts direct current (DC) electricity to alternating current (AC). Batteries store DC only, but most appliances are designed for AC (which is what electric companies supply); this results in the need for an inverter in many remote wind systems.

The oldest type of inverter is called a 'rotary inverter'. This device is basically just a DC motor connected to an AC alternator, which produces AC electricity. Rotary inverters are reliable and can sometimes be bought cheaply as military surplus material. They are not highly efficient (around 50%), however, and have a sizeable no-load power drain (i.e. they use power to keep spinning even when no AC power is being drawn off them).

Solid state inverters are generally much more efficient (80-95%) than rotary inverters. Efficiencies vary between models, as does the amount of no-load power drain and the quality of the AC wave produced. Less expensive models produce a 'modified square wave' which may not be suitable for the operation of televisions, stereos, and similar electronic equipment; the more expensive models produce a 'pure' sine wave.

Inverters can be an expensive part of a remote wind electric system. If AC power is needed only occasionally, the most economic choice may be to install a small inverter and convert lights and appliances to DC power. For continuous use, the solid state inverters are advisable.

1:D:5 BACK-UP SYSTEMS

Due to the intermittent nature of the wind and the expense of storage batteries, most wind electric systems include a backup power source. In some cases this backup source is an electric utility (such as the utility intertie systems). The backup in a system remote from a utility is a gas or diesel generator set, which is used to charge batteries when they run low on charge during periods of low wind (or when the **windgenerator** is broken). Backup generators can also be used to supplement the battery system if at some time extraordinarily large amounts of power are needed which are too great for the batteries alone to handle.

1:D:6 CONTROLS

The control components of wind electric systems are nearly always sold as a package with the **windgenerator** itself. The complexity of the controls varies between models of **windgenerators**, and is usually greater for larger and more expensive machines. Automatic controls are usually mounted in a single panel, which also has meters to display wind speed, **windgenerator** output, and perhaps other items of interest (such as battery voltage).

One control common to all **windgenerators** is a manually operated shut down system. This allows for the **windgenerator** to be shut down for maintenance, for emergency situations, or merely when power won't be needed (e.g. when owners will be gone for an extended period). All commercial machines designed for use with batteries have a voltage regulator, like those used in automobile electric systems, which unloads the **windgenerator** when the batteries are fully charged. This is done by sensing the battery voltage, which increases slightly with increasing levels of charge. Nearly all machines also have (or should be retrofitted with) a control device to automatically brake the machine (or turn it out of the wind) when wind speeds reach a dangerous level (the cut-out speed). This can be accomplished by connecting the controller to an anemometer mounted on the tower which senses wind velocity and its signals are sent to the controller which shuts the machine down at some pre-set wind velocity.

There are many other control functions which may or may not be included with a **windgenerator** (or may be optional equipment). One useful control is one which will restart a **windgenerator** which has been shut down due to high winds after the winds drop to safe operating levels. In models without this control, restarting the machine must be done manually.

In most larger **windgenerators**, overspeed control is accomplished by hydraulic or electric drives which feather the blades or turn the machine out of the wind. This control is actuated by a tachometer on the rotor shaft, by a high voltage or high current sensor, or by combinations of these. In most smaller machines, overspeeding is prevented by completely mechanical means and is actuated by centrifugal force (see descriptions of these in Section 1:C:2). This, of course, is a control device too.

Most wind machines do not use a tail vane to point them into the wind. Instead, yaw control is performed by a wind direction sensor (electronic wind vane) which actuates a drive mechanism to rotate the **windgenerator**.

Other **windgenerator** control functions can include automatic braking of the machine when excessive vibrations are sensed, and automatic disconnection of the load to prevent excessive discharge of the batteries (like overcharge control this is done by measuring battery voltage).

On utility intertie machines, controls are built into the design so that when the utility power is off the **windgenerator** is not producing power. This is to prevent backfeeding the power lines when a utility repairman is working on them. Also, some machines have controls which sense the frequency of the sine wave output and other power quality characteristics to prevent the windgenerator from providing bad power to the utility or the utility from harming the **windgenerator** with brown-outs and the like.

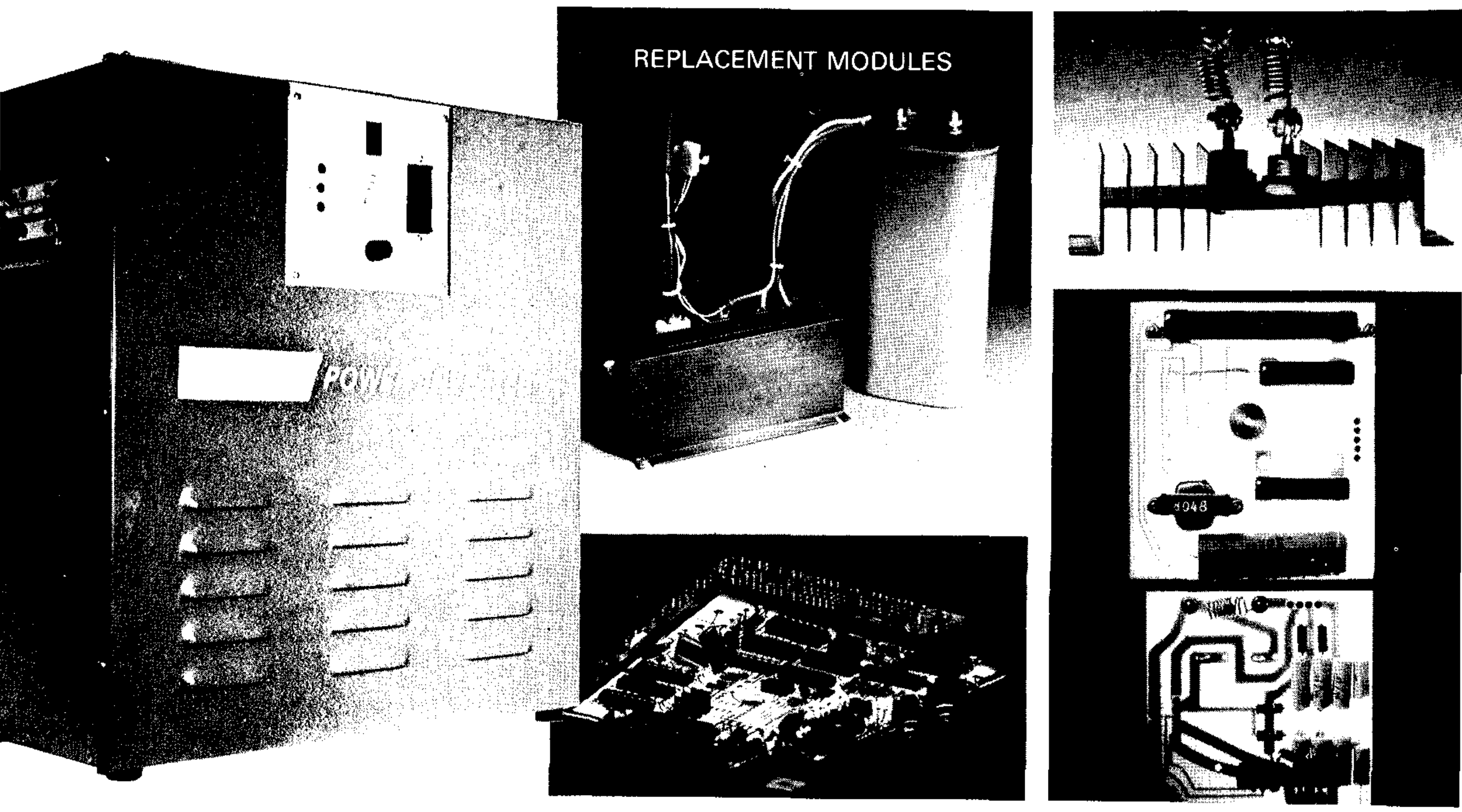


Fig.1-29: DC to AC Inverter: 12 KW (Source: 4 Winds of Alaska)

1:E System Configurations

1:E:1 INDEPENDENT SYSTEMS

The equipment requirements of a wind system depend upon the type of application in which it is to be used. Most current systems can be divided into three general classes of application. These include independent ('stand alone') systems, private systems with utility (grid) interface, and utility-owned systems. The utility-owned systems are not discussed in any detail in this report since this handbook was not designed for large systems nor utilities.

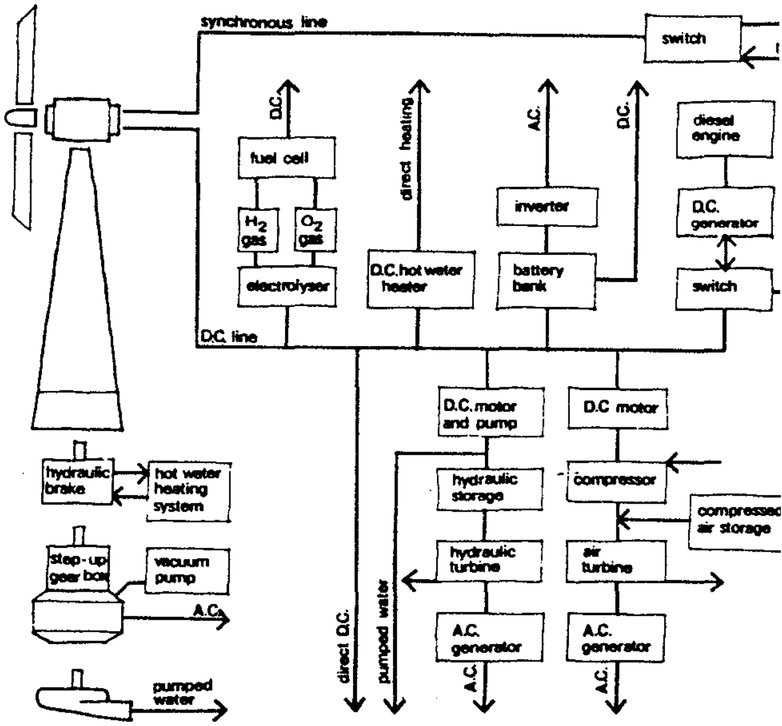


Fig.1-30: Possible Wind systems configurations (Source: Walker)

Most independent (or remote) wind electric systems are not unlike the electrical system on automobiles. A schematic representation of such a system is shown in Figure (1-31). The **windgenerator**, like a car alternator, provides intermittent levels of power supply to charge a battery; a voltage regulator prevents overcharging. The battery is used as a reservoir of charge, from which power can be drawn as required.

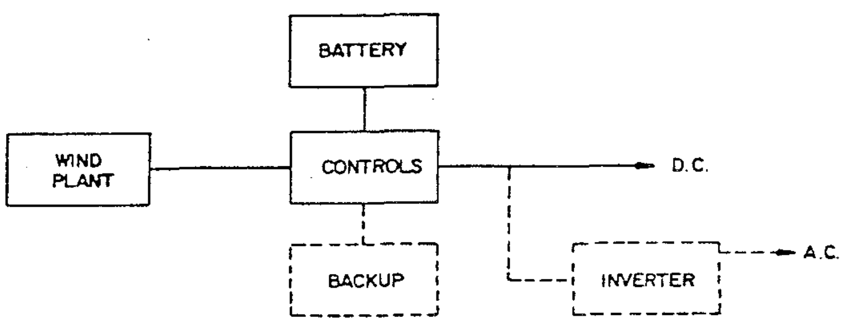


Fig.1-31: Independent Wind electric system

This is the basic system configuration, although many variations are possible. Frequently an DC/AC inverter is employed so that some or all of the power can be supplied as AC. This is done because many devices are difficult to find which operate on the batteries' direct current.

Another addition to the basic system which is sometimes employed is an automatic 'power dumping' device. When the batteries are fully charged in such a system, excess power generated is dumped to a non-critical use, often resistive heaters such as a hot water tank or baseboard heaters. In a system without such a device, the **windgenerator** is unloaded when the batteries are fully charged, and so some power is wasted.

Another common addition to an independent system is a backup generator for use during periods of low wind. The generator is used as a battery charger, and can be hooked up, with proper controls, to start up automatically when low battery voltage is sensed. They can, of course, be operated manually, too.

There are some system applications for which no battery storage is necessary. Notable among such applications is water pumping for domestic or irrigation purposes, where outages of several days may be acceptable (for domestic purposes this assumes a large holding tank). Historically, **windmills** used for grinding grain, sawing lumber, etc. were not provided with storage, and operated only on windy days. In modern applications, however, most people would find such limitations on their operations unacceptable.

1:E:2 GRID-INTERFACED SYSTEMS

In a grid-interfaced (or utility intertied) system, any surplus power generated is fed into utility lines, while power is drawn from the utility whenever insufficient power is produced by the windplant. A schematic diagram of such a system is shown in Figure (1-32). The great advantage to such a system is that it eliminates the need for storage batteries and backup generators.

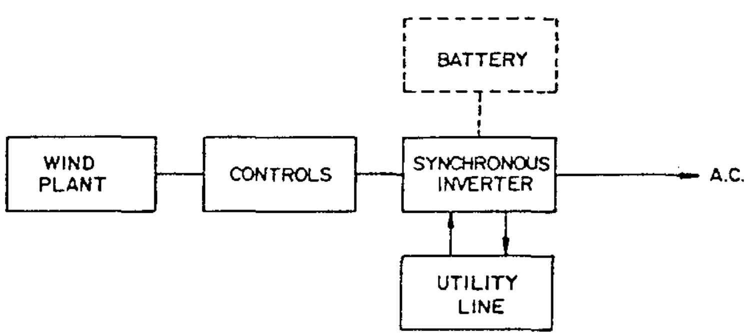


Fig.1-32: Grid-interfaced Wind system

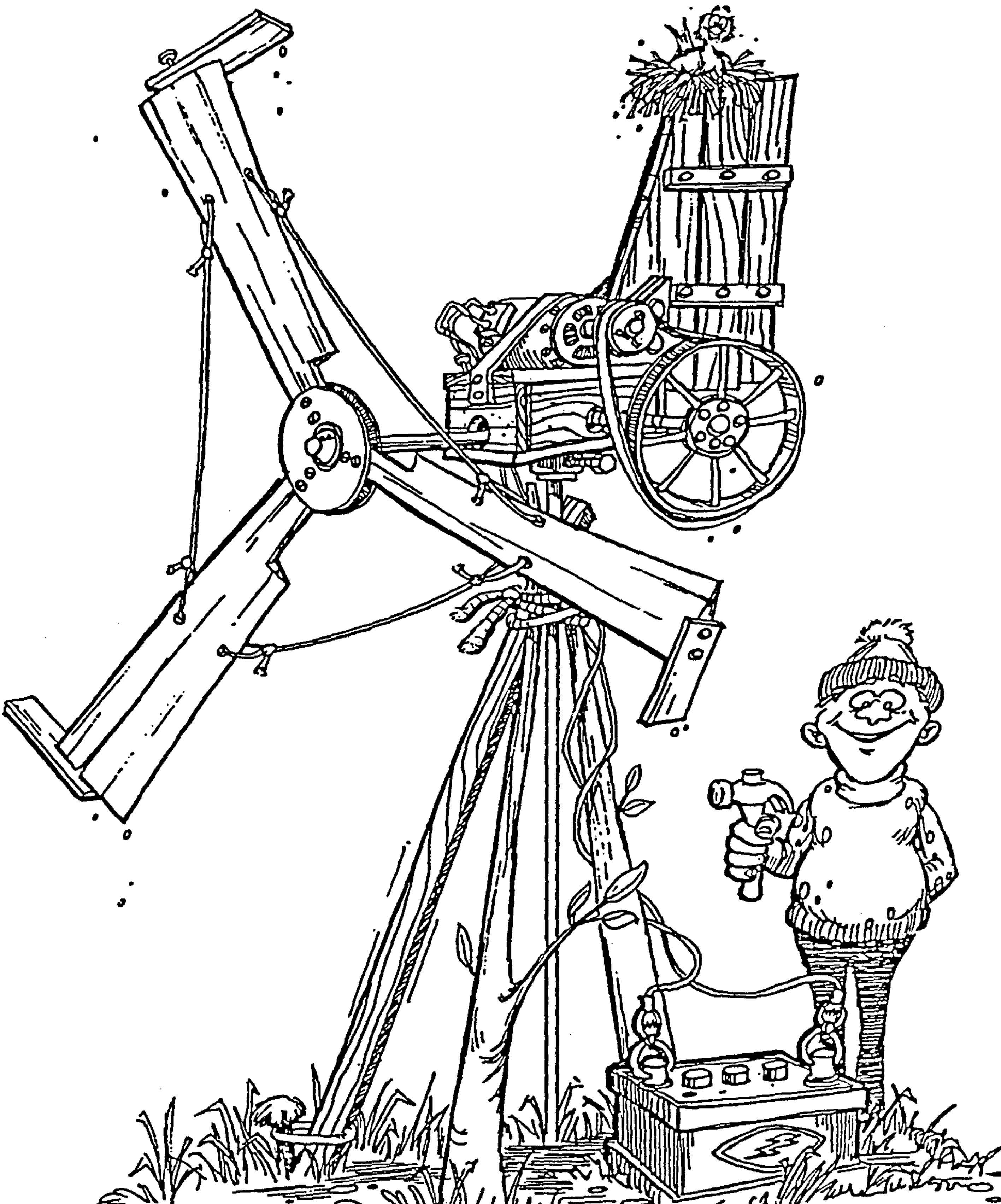
AC power fed into utility lines must be in phase with the utility's power, as well as at the same voltage.

An interfacing system of this sort requires the approval of the utility. While utilities are required by law (Public Utilities Regulatory Policy Act, PURPA) to accept such a connection, they will often buy power generated by the wind system for only 1/2 to 1/3 the price for which they sell power to the system. The reasoning behind this rate structure, which is valid, is that the utility has to build - and pay for - the same amount of transmission and distribution equipment, and probably the same amount of generating capacity, whether or not you export power to them. As a result, your export of power saves them only fuel costs, not equipment or maintenance costs.

The owner of a grid-interfaced system, then, is likely to be faced with continuing monthly electric bills, even if he generates more power than he uses (the electric bill should of course be smaller than if he had no wind system at all). The grid-interfaced system may still be worthwhile, since the lack of a need for batteries and backup generator means the capital (first) costs for the system are less than for an independent system.

A sometimes cold realization for an owner of a utility intertied system is that when the utility power is down (as during or after windstorms) their **windgenerator** will not produce power (by design). It will then be necessary for the owner to disconnect from the utility, start-up his own stand-by generator and provide the "signal" for the **windgenerator** to work. There are ways to design a system so that your system can go "on" and "off-line" automatically but that can get expensive quickly. The important point here is that a utility-intertie wind system does not give you freedom from a utility nor freedom from utility bills, rather it gives you reduced electric bills at a reduced capital cost when compared to an independant battery system.

PART TWO



WIND SYSTEM DESIGN

Introduction

This part of the handbook is included to give the user an idea of some of the important design considerations. No engineering design texts have been written to date which include all the disciplines required to put a wind system together. The type of professional assistance you could have might be a Geotechnical or Soils Engineer to help you with the foundation design. A Structural Engineer to assist with tower design and structural modification to any buildings. An Electrical Engineer could do the design and interfacing of all the electrical components. A Systems Analyst to scope out the entire project and perform an energy audit. Or you could hire a Wind Energy Engineer (a hybrid of all the above) who could additionally help you select a specific wind generator for your application.

This handbook is not intended to take the place of professional assistance, rather it should provide a strong background from which you can ask the right questions.

2:A Electrical Demand Survey

One of the first steps in the design of a wind electric system is to accurately determine the energy demands that the system is to supply.

2:A:1 DC VS. AC ELECTRICITY

Most utility independent wind systems use batteries, and since batteries store only direct current (DC) power, any alternating current (AC) power requirements will need to draw their power from a DC/AC inverter. These are expensive (and less than 100% efficient), so to reduce system costs it is important to be able to select the smallest inverter which will handle the AC needs. As a result, it may be necessary to divide electrical demands between those which can use DC power and those which will need AC.

Most appliances are designed to operate on 110 or 220 volt, 60 cycle per second AC electricity. Some electrical devices will also work on DC. Among these are most kinds of resistive heating elements (ranges, hot water heaters, irons) and incandescent light bulbs. Many appliances which run on DC power are available (they were designed for used in recreational vehicles); these include radios, tape decks, televisions, even small refrigerators. Many power tools are available with "universal" motors, which can operate on either AC or DC. It may be difficult to find DC versions of some things, however, like large refrigerators or freezers, automatic washing machines, and electric typewriters.

Some wind electricity users attempt to maximize the use of DC equipment, and minimize or eliminate the need for AC. The necessity of having both DC and AC circuits in the same system - the same building - adds to the cost and complexity of the system. In some cases this may not be worthwhile; it may be easier just to buy a large inverter and handle all loads with AC. This is one of the earliest design decisions which must be made.

Some wind system designers may want to consider using only DC wiring. Some major AC appliances which cannot be found commercially in DC models might be converted to run on DC power. The AC compressor/ motor in a refrigerator, for example, might be replaced by a similar DC motor. DC ballasts can be found which will allow flourescent lights to operate on DC power. A small DC/AC inverter might be kept for such a system which could be plugged into any of the DC outlets. Small appliances not worth converting to DC operation (such as electric typewriters or calculators) could then be operated if needed.

A few points about DC wiring should be noted. The first is that you should make sure that all electrical equipment (switches, circuit breakers, etc.) is rated for DC use; some equipment is not. Another point to consider is that DC shocks are generally considered more dangerous than AC ones - it's harder to let go of the source of the shock. Finally, if low voltage (less than 50 volts) DC is to be used, it will be necessary to install heavy wiring. The wire size determines the amount of current which can be safely drawn from a system, irrespective of its voltage. Power (measured in watts) is equal to the current (measured in amperes or 'amps') multiplied by the voltage; thus if the voltage is cut in half the current must be doubled if the same amount of power is to be supplied. If your system is designed to handle any more than about 1000 watts you should go to a higher voltage system such as 48 volts or 120 volts DC.

2:A:2 AVERAGE POWER REQUIREMENTS

The amount of electricity required, on the average, will be the basis for deciding how large a windgenerator is required. The power requirements may change during the year, so the demand estimate should be made on a monthly or seasonal basis. This can then be compared with wind speeds - which also vary seasonally - to determine the 'match' between expected energy supply and demand. For most Alaska users, the demand for electricity will be greater during the winter than during the summer.

If electricity from a utility is already being used at the site, an examination of old electric bills will show how much electricity has been used in the past; this is the easiest way to determine demands. If a diesel generator is presently being used, demands may be estimated from fuel use by assuming a conversion efficiency for the generator. This will probably be in the neighborhood of 7 to 10 kwh for every gallon of fuel used.

If demand estimates cannot be made by these methods, or if you want a check for them, demand estimates can be made by determining what electrical devices will be used, and how long they will be on. Appendix B lists a large number of appliances, with typical power requirements and monthly hours of use. From information such as this, a total demand estimate can be added up, as is done in the example shown in Table 2-1.

2:A:3 MAXIMUM INSTANTANEOUS POWER DEMAND

It will also be necessary to determine what the maximum rate of electricity use will be, again for both AC and DC requirments. The maximum AC power demand will determine how large an inverter will be needed, and the maximum total power use at any time (AC plus DC) may have a bearing on what size battery is required.

A maximum demand estimate can be made up in a manner similar to the one used for estimating average power, except that instead of figuring how much will be used over a month or a season, you will have to decide how many electrical devices will be turned on <u>at the same time</u>. This has also been done in the example in Table 2-1.

2:A:4 REDUCING ELECTRICITY DEMAND

It will be useful at this point to review your estimated electrical needs. Electrical power is expensive, and it may well be that you can save a great deal of money by reducing demand,without giving up too much in the way of convenience.

Electrical heating elements in particular use large amounts of power, as can be seen from the ratings of the water heater, range, and clothes dryer in Appendix B. Even the smallest iron available uses as much power as the largest TV or refrigerator. This may not be too important in some cases; an iron isn't used for very many hours in a month. It may well be worthwhile, however, to switch from electric water heating and cooking to another type, and to minimize (or eliminate) the use of heavy power users such as headbolt heaters for automobiles. You may also decide - once you examine the costs - that you can do without many 'convenience' appliances (hair dryers, electric can openers, and the like).

You may also be able to save money by reducing the instantaneous power demands, particularly for AC. This will lessen the size required of your inverter. This reduction could be achieved by simply remembering not to use too many AC devices at once. It could include a load sequencer which will prevent two motorized appliances (a water pump and a refrigerator, for example) from switching on at the same time. This will reduce the surge loads which these devices draw when starting up.

APPLIANCE	POWER (WATTS)	MONTHLY USE (HOURS)	ENERGY DEMAND (KWH/MONTH) DC	AC
a. lights: 3 @ 75 W	225	120	27	
b. refrigerator	300	150		45
c. water pump	500	30		15
d. washing machine	250	6		1.5
e. sewing machine	100	10		1
f. circular saw (1 HP)	1000	6		6
g. record player	100	100		10
h. vacuum cleaner	600	5		3
i. toaster	1250	4	5	
j. coffee pot	700	10	7	
k. television	200	45		9
l. electric drill	250	2		0.5
m. miscellaneous			6	19
		SUBTOTAL	45	110
n. electric range, 2 burners avg	3000	30	90	
O. water heater	2000	90	180	
p. clothes dryer	4000	15		60
		TOTAL	315	170

WITH n,o,p:

MAX. SIMULTANEOUS AC LOAD: b,c,d,f,g,p .... = 6150 Watts

MAX. SIMULTANEOUS TOTAL LOAD: a,b,c,d,f,g,j,n,o = 8075 Watts

WITHOUT n,o,p

MAX. SIMULTANEOUS AC LOAD: b,c,d,f,g .... = 2150 Watts

MAX. SIMULTANEOUS TOTAL LOAD: a,b,c,d,f,g,j ... = 3075 Watts

Table 2 - 1:
Demand Calculations

2:A:5 BATTERY AND INVERTER LOSSES

Batteries and inverters use power (or, if you prefer, lose power) while in operation. Modern solid state inverters operating at full load are very efficient, with losses on the order of 10%. Their efficiency drops off at lower load levels, however, and they use power even on standby, when there is no AC load at all. Because of this you may want to be able to switch the inverter off when no AC is being used. Even so, you'll have to plan on an average efficiency of perhaps of 75%. This means that for every unit of AC power you plan to use, you will require 1/75% = 1.33 units of DC power to supply the inverter.

Batteries too are less than 100% efficient; actual values will probably be between 75% and 90% depending on their age. If 80% is assumed, then for every unit of electricity you want to draw out of the battery system, you will have to put 1/80% = 1.25 units of electricity in.

As an example of how to put this all together, assume that you are planning to use the amounts of electricity shown in Table 2-1, without the electric range, water heater, and clothes dryer. The basic demand will then be about 45 kwh of DC and 110 kwh of AC each month. To get 110 kwh of AC at a 75% inverter efficiency, you'll need 110/75% = 147 kwh of DC. Added to the DC demand, you need 192 kwh of DC out of your batteries. If the batteries are 80% efficient, you'll need 192/80% =240 kwh of DC electricity total. This is the amount that your **windgenerator** - or **windgenerator** plus backup generator - will need to supply.

2:B Wind Speed Measurement

2:B:1 WHAT WIND INFORMATION IS NEEDED?

For a complete assessment of wind power potential at a site, a number of different things must be known. These include the following (a more complete presentation can be found in "A Siting Handbook for Small Wind Energy Conversion System" which should be consulted prior to site selection).

Average Wind Speed: This will be the most important information in the prediction of system performance. Since the winds - and your energy demands - may vary during the year, average wind speeds for each month (or at least each season) are needed. If average wind speeds and the response characteristics of a particular windgenerator are known, a rough estimate of expected electricity production can be made.

Wind Speed Distribution: For more accurate performance predictions, wind speed distribution must be measured. As with average wind speeds, this should be on a monthly or seasonal basis. This information is a tabulation of how much of the time the wind blows at a certain speed - so many hours a month at 7 mph, so many at 8 mph, etc. Obviously, this requires frequent recording of wind speed (hourly in most cases) usually done by automatic equipment.

Highest Winds: This information is valuable, not for predicting power output, but rather for designing a tower which won't be blown away. A windgenerator is usually designed to operate for 20 or 30 years, and there is no reason why it shouldn't if the system is designed and erected correctly. But if the system hasn't been designed for the occasional extreme storms - the 'once in a century event' - the entire windgenerator, and your investment, can be lost.

Longest Periods of Calm : This information is helpful in deciding how much battery capacity is required. If you know how often periods of calm occur, and how long they last, you can estimate how frequently you'll run out of power with different sizes of batteries. If it takes too many batteries to provide the reliability you require, you may decide to buy a backup generator. This information not only helps to make that decision, but it will also allow you to estimate how often you'd have to run the generator, and how much fuel it would use. Obviously, this information is of less importance if you'll be hooked up with an electric utility or other continuous backup supply of electricity.

Directional Stability (Turbulence) : This point will not help to tell you how much power your windmill will generate. Instead it will tell you whether your machine will survive or not. Turbulent winds put large, transient loads on the machine and induce vibrations. Often, turbulent winds are more dangerous than higher speed steady winds, and they have probably caused more damage to **windgenerators.** Turbulent wind sites are to be avoided as **windgenerator** locations.

Wind Speed to Height Relationship: In order to choose the best height for a **windgenerator** tower, it is desirable to measure at least the average wind speed at more than one height at your location. The relationship between windspeeds at different heights can be estimated without these measurements (as discussed in Section 1:B:3). The accuracy of your design will be greater, however, if you can use measured data from your location rather than 'educated guesses'.

2:B:2 SITE CHOICE AND PRELIMINARY WIND ESTIMATES

Before starting an elaborate wind measurement program or a detailed design study you first need to do some 'rough cut' work to determine the best possible wind site available and the approximate magnitude of the winds there. 'Wind prospecting', as it is sometimes called, is important except in very flat terrain. Since even small increases in wind speed yield much greater power, finding the best site in your area is worth a lot of effort. Obstructions and changes in topography of any kind - valleys, hills, isolated groves of trees, etc. - can alter both the speed and the turbulence of the wind regime for a surprising distance. In figure 2-1 the cropping of the trees at the top indicated a high wind regime at greater than 80 feet which was not present at ground level

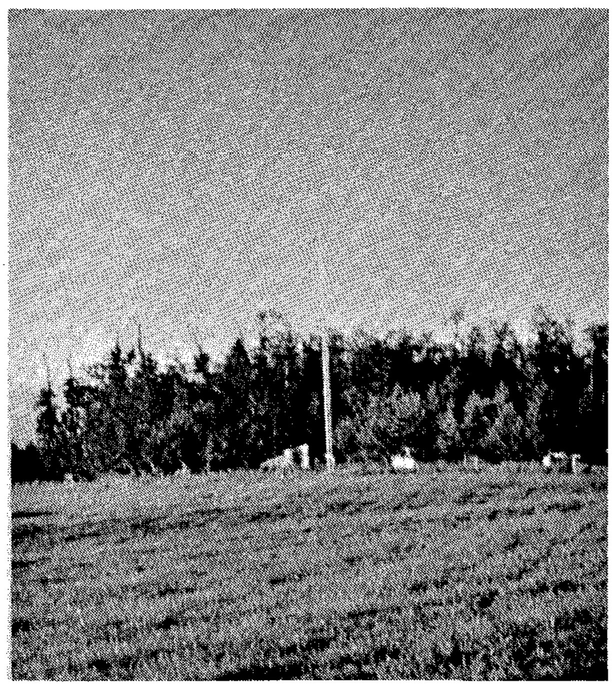


Figure 2 - 1: Windgenerator in Palmer located above surrounding trees and turbulence. (Source: 4 Winds of Alaska)

The type of site conditions where high winds (which are desirable) are likely are outlined in Section 1:B:4. The type of site conditions where winds may be turbulent (which is undesirable) are outlined in Section 1:B:5. If you live in the area, of course, you probably will already have a pretty good idea of where the winds are highest. Other area residents can also be helpful, there's no substitute for experience. You should be suspicious of judgments such as 'it's always windy where I live', however, since people usually overestimate wind speeds, especially average ones. If wind records are kept at a nearby site (an airport, for example) these can be very valuable too, of course.

As a first crude step to estimate wind speeds, you can use the 'Beaufort Scale', which is explained in Table 2-2. This will allow you to determine the approximate wind speed from physical effects such as whether tree branches sway, whether ground snow or dust is blown around, etc. A more accurate method is to use a hand-held wind gauge; these are inexpensive (less than $20). Eye level readings - which is what you'll get with a hand-held meter - can be adjusted to estimate wind speeds at greater heights using the method described in Section 1:B:3. It should be cautioned that these height adjustments work more accurately in smooth terrain than in rugged, broken ground.

BEAUFORT SCALE OF WIND FORCE

Beaufort Number	Miles per Hour	Knots	Descriptive Term	Beaufort Number	Miles per Hour	Knots	Descriptive Term
0	Less than 1	Less than 1	Calm	7	32 - 38	28 - 33	Near Gale
1	1 - 3	1 - 3	Light Air	8	39 - 46	34 - 40	Gale
2	4 - 7	4 - 6	Light Breeze	9	47 - 54	41 - 47	Strong Gale
3	8 - 12	7 - 10	Gentle Breeze	10	55 - 63	48 - 55	Storm
4	13 - 18	11 - 16	Moderate	11	64 - 72	56 - 63	Violent Storm
5	19 - 24	17 - 21	Fresh	12 or More	73 or More	64 or More	Hurricane
6	25 - 31	22 - 27	Strong				

Table 2 - 2

A rough idea of turbulence can be gained easily just by observation. A better idea can be had by attaching a streamer of some sort to a long pole and raising the pole into the air. If the winds are steady the streamer will blow out evenly and straight, in turbulence it will flap around in different directions.

Using these simple techniques, you can get a pretty good idea of the wind regime at your site - good enough, in any case, to decide whether or not it's worth the time and expense needed to get more accurate data. The criteria for further work are pretty simple: you should be pretty sure that winds 40 or 50 feet in the air average 10 mph or more, and you should be sure that you're not in an area with severe turbulence during high wind periods.

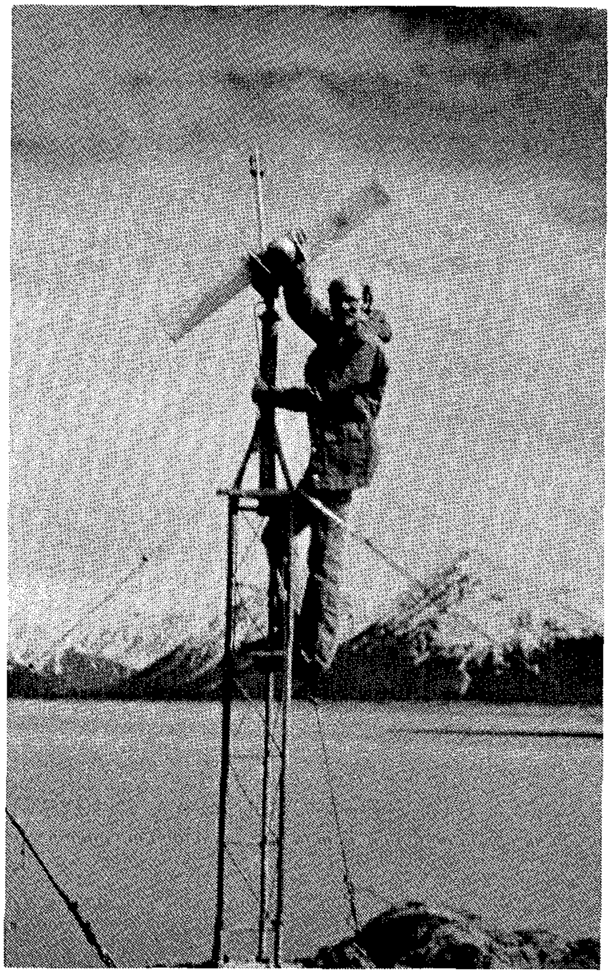


Figure 2 - 2: Lack of adequate tower height can cause severe turbulence

(Source: Newell)

2:B:3 GATHERING DETAILED WIND DATA

A detailed and fairly accurate assessment of a wind regime can be made easily if you can find wind speed records for a nearby site - an airfield, weather station, or the like. In a case like this, you can take wind readings at your site for a short period - a month, perhaps - and compare them with the records for the same period taken at the airfield (or whatever). You can then try to find a consistent relationship between your winds and theirs. Perhaps your winds will always be 10% higher; perhaps your west winds will be 10% higher but your north winds 10% lower. If you can establish a consistent relationship, you can adjust the figures for the nearby site to your location, remembering to include an adjustment for the difference in height between your windgenerator and their instruments (see Section 1:B:3). In this way you can get the benefit of years worth of wind measurements with little of the trouble or expense.

If you aren't lucky enough to have a nearby recording station, you will have to set up your own, and run it for a considerable period - preferably at least a year. The amount of time and expense needed for this program - how frequently and for how long you measure wind speeds - will vary from project to project. The amount of detail you might want for the design of a large and expensive wind system for a school or village (for example) may be more costly and troublesome to get than it's worth for a little system designed to power a few lights in a hunting cabin.

If you are going to measure wind speeds, it is worthwhile to try to get your instrument set up on a guyed pole at the height where you think the windgenerator will go (at least 60 feet, or 30 feet above any trees or obstructions nearby). Height adjustments can be made, of course, if you don't measure at that height, but this sacrifices some accuracy.

The simplest measuring device is a 'run-of-the-wind' or 'totalizing' anemometer. These measure windspeed and also the total miles of wind that pass them, just like the odometer on a car. If you take readings an hour apart, and find the meter has advanced ten miles, then the average windspeed for that hour was 10 mph. Similarly, if read every day (24 hours), your average windspeed in miles per hour will be the number of miles divided by 24. These devices can produce very accurate results, but are dependent on the conscientiousness of the people reading the meter. If you can read the meter every hour you'll get very detailed results; if you read it once a day they'll be less detailed; once a month and you'll get the monthly average. As previously mentioned, the size and expense of the planned wind system will determine to some extent how much trouble it's worth getting detailed wind readings. This type of wind measuring equipment will probably cost in the neighborhood of $150-$200.

*Fig. 2 - 3: Run-of-the-Wind Anemometer**
(Source: Aeolian Kinetics)

**Not a product endorsement*

A step up from the 'run-of-the-wind' anemometer is a recording anemometer. Instead of giving total miles of wind, these give readings of instantaneous wind speed. This can be recorded on a strip chart recorder. Some recording anemometers will measure and record wind direction as well as speed; this information may be helpful, especially if you are trying to correlate your winds with those recorded at a nearby weather station. Recording anemometers have two advantages over the run-of-wind anemometers; they provide more detailed information, and the operator is freed from the chore of making frequent readings. Their main disadvantages are their greater expense and the trouble it takes to average all the individual values to find average wind speeds. The greater difficulties in analyzing the results, however, are the price you pay to get more detailed - and accurate - predictions of wind power production.

Increasingly wind power site studies use devices which combine an anemometer with a microprocessor to simulate a particular windgenerator response. Instead of just measuring windspeeds, these machines calculate the actual amount of power you could expect to get from a particular windgenerator model. They then integrate these amounts and tell you how much total energy (in kwh) you would have gotten if the windgenerator had been there over the period. This is by far the easiest and most accurate way to estimate power production at a prospective wind site. It is also the most expensive. A wind power simulator/recorder like this costs at least $1000, but may well be worth it if it ensures the best design of a wind system that will cost many thousands of dollars.

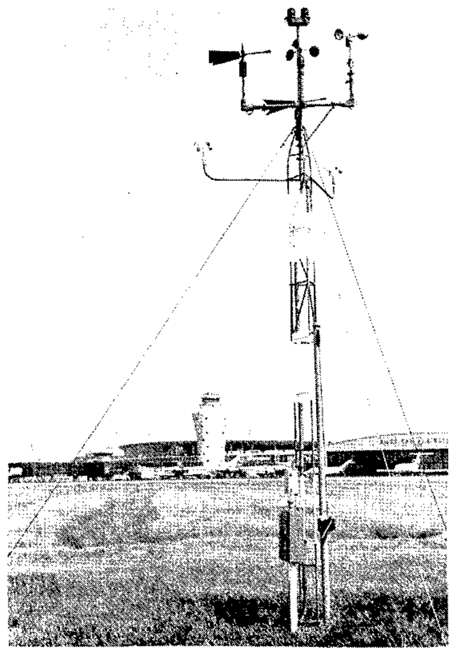


Figure 2 - 4: Data Logger with microprocessor (source: Aeolian Kinetics)

2:C Electricity Production Estimates

2:C:1 MACHINE OUTPUT:

ROUGH ESTIMATES USING AVERAGE WIND SPEED

Most **windgenerator** manufacturers and distributors can supply information giving estimated power production for their machines at sites with different average wind speeds. These estimates of power output will - or should - show a wide range for any particular wind speed. These estimates may, in certain cases, be sufficiently accurate for design purposes. Better estimates can be made, but perfect accuracy in power estimates is never necessary. Real power output from a **windgenerator** will vary from average figures, because the winds themselves vary from their average speeds.

Even if the manufacturer provides only a machine response curve (showing instantaneous power output at various wind speeds) you can make a very crude estimate of average power output. For sites with average wind speeds between 10 and 15 mph, the average power (P) produced by many **windgenerators** is from 20% to 100% greater than the instantaneous power (P) produced at the average wind speed (V). The lower figure (20%) is likely to be more accurate for higher wind regimes (V = 15 mph), the higher figure (100%) more accurate for lower wind regimes (V = 10 mph).

Figures derived this way are very rough, however, and should only be used for gaining a rough idea of output, not for final design.

Exact figures for average power output cannot be given by the manufacturer or calculated by the designer using only average wind speed figures. This is because there is no set relationship between average wind speed and average power output. To clarify this point, consider two imaginery sites. At one site, the wind always blows 10 mph; at the other site, winds are 20 mph half of the time and calm the other half.

In both of these cases, the average wind speed V is 10 mph. The average power P produced will not be the same, however. At 10 mph most wind machines are barely starting to produce power at all, so at the first site very little power will be produced (although the supply will be steady). **Windgenerators** produce large amounts of power at 20 mph, however (many are at maximum power at this windspeed). Much more power will be produced at the second site, therefore, even though it only operates half of the time.

As this example shows, the effect of the wind speed distribution can be very important. This distribution is taken into account in all detailed estimates of wind power production.

2:C:2 MACHINE OUTPUT: DETAILED ESTIMATES USING WIND SPEED DISTRIBUTION AND MACHINE OUTPUT CURVES

If you have both a machine response curve (described in Section 1:C:4) and wind speed distribution data (described in Section 2:B:1), you can make a detailed estimate of power production from a **windgenerator.** The machine response curve should be available from the manufacturer or distributor of the particular machine you are interested in. Wind speed distribution data (preferably on a monthly or seasonal basis) will have to be gathered at your site or adjusted for your location from wind speed distribution figures from a nearby site.

The wind speed distribution information tells you how long each month the wind blows at a certain speed - a number of hours (or a percent of the time, which can be converted to a number of hours). The machine response curve tells you how much power is produced at that speed - a number of kilowatts. These two figures multiplied together tell you how much electricity is produced at that wind speed each month - a number of kilowatt hours. If this is done for all the wind speeds and all the figures are added together, the result is the total electricity output of the machine for that month.

2:C:3 ESTIMATING THE EFFECTS OF TOWER HEIGHT ON ELECTRICAL OUTPUT

The wind speed distribution information used in the previous section to calculate **windgenerator** output was based on a certain height above ground level. This information can be adjusted to allow you to calculate output based on different heights. In this way you may find, for example, that a machine which appeared to be too small for your needs (in the first calculation) will be adequate if placed on a higher tower.

Wind speed distribution information is adjusted by using the method described in Section 1:B:3, and using either the 1/7 exponent suggested there, or a more accurate one derived from measurements made at your site. Once the windspeed distribution is adjusted, the output calculation is repeated as before. You may find after making a series of these calculations that either a small **windgenerator** on a tall tower or a larger one on a shorter tower will serve your needs. A cost comparison between the two systems can then determine the one that is best for your situation.

2:D Batteries

2:D:1 BATTERY CAPACITY REQUIREMENTS

If you plan to have electricity on demand, and do not plan to be continuously connected to an electric utility, you will need to store energy. In the vast majority of cases, this means you will need batteries. This is an expensive part of a wind electric system; in some cases batteries can cost more than the windgenerator itself.

It is almost always impractical to buy enough batteries to supply power through the longest possible lull in the winds. If you decide to use a backup gas or diesel generator during these long, windless periods, you are faced with a tradeoff between spending more on batteries at the start or more for fuel and maintenance of the backup later. If you decide to do without a backup system, you are faced with a tradeoff between spending more on batteries and getting by with little or no power for longer and more frequent periods. In most cases however, the back-up generator is already in place and in use.

Most wind power systems include enough batteries to store two days to a week's average use of electricity, with three or four days most common. Calculating the needed capacity for this is straightforward if your daily demand has been estimated. One potentially confusing point is that battery capacity is often rated in ampere-hours (or 'amp-hours'), while demands have been calculated in watt-hours (or kilowatt-hours, which are thousands of watt-hours). If you remember in a DC system watts equals volts times amps (W = V x A), though, there should be no problem: multiply the amp-hour rating of the battery by its voltage and you will have the watt-hour capacity. For example, a 12 volt battery with a 400 amp-hour rating will store 12 x 400 = 4800 watt-hours = 4.8 kilowatt-hours.

You will also have to make sure that your batteries can accept the maximum expected rates of charging and discharging without damage. For deep-cycle batteries most often used with wind systems, it is frequently recommended that these rates not exceed 10% of the battery capacity per hour (you should check with your battery supplier on this). If a 10% figure is used, then for a 3 kilowatt windgenerator (or backup generator), 30 kilowatt-hours of batteries whould be the minimum. With such a system, 3 kilowatts should also be the maximum sustained discharge rate (i.e. the greatest sustained demand).

2:D:2 BATTERY STORAGE AREA

Batteries will require a heated and ventilated storage area. Heat is required to prevent the batteries from freezing - which can happen at temperatures not much below 32°F if the battery is discharged. Batteries also have less storage capacity at lower temperatures; the maximum charge at freezing is only about 3/4 that at room temperature. Ventilation is required for safety, since batteries can emit flammable hydrogen gas. For the same reason, batteries should not be stored in a room with an open flame, nor in the same room as a backup generator. Caps for batteries can be bought (for under $10.00 each) which turn the hydrogen and oxygen back into water using a catalyst. They are called "hydrocap" and essentially provide a "closed" system which decreases battery maintenance and eliminates hydrogen gas build up except when the batteries are manually equalized (see Section 4). It is preferable, of course, to store batteries on sturdy racks in part of a heated building. If this is not possible, however, the batteries can be put on, or preferably in, the ground in a box heavily insulated from the outside. This should keep the batteries near ground temperature. The batteries 'help themselves' keep from freezing, since they give off small amounts of heat.

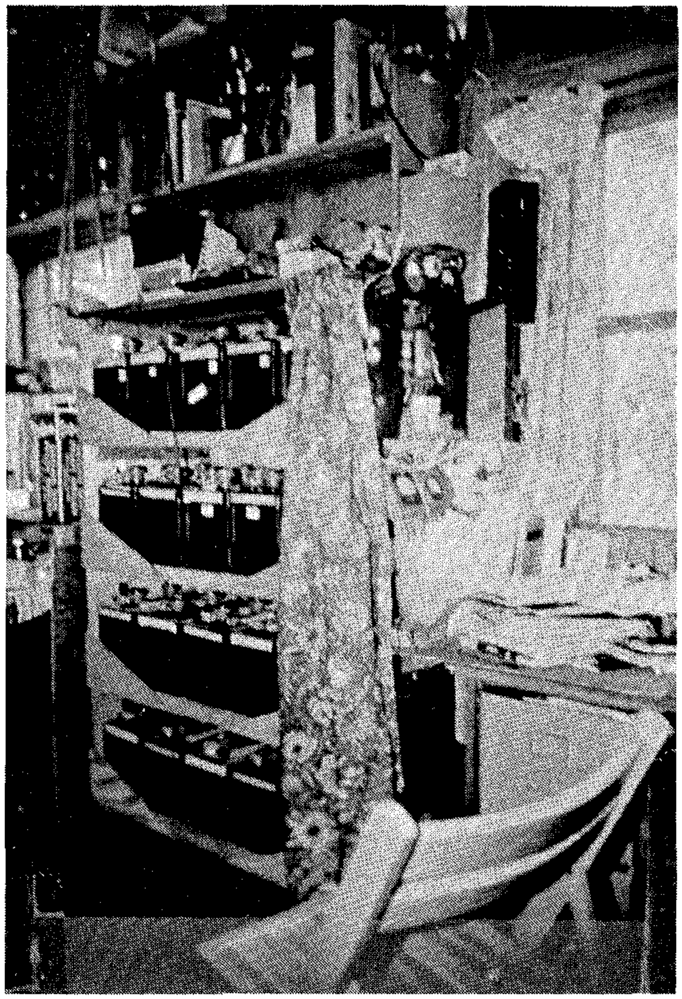


Figure 2 - 5: Batteries stored in living space in system built in the Arctic Region (Source: Newell)

Batteries kept at too high a temperature - over 80°F - will have a shorter lifetime. You should avoid storing batteries either next to a heater or anywhere they will be in sunlight for extended periods for this reason. Another factor that should be considered in designing battery storage is that they are very heavy, you should ensure that your rack or floor is strong enough to support this weight.

Batteries contain acid and spills can occur which can destroy unprotected wood, metal, floors, and people. An acid burn first-aid kit is recommended equipment in a battery room, with an eye wash bottle being imperative.

2:E Capacity Requirements: Inverters and Backup Generators

<u>Inverter</u>: The inverter should be sized to provide power for the maximum AC load as found in the system demand calculations (remember that it's worth your while to minimize this load). It should be noted that many appliances draw a surge of power when first starting up which can be several times as great as their normal operating demand (you may have noticed how lights dim in some houses when the refrigerator goes on). Most inverters are capable of handling these greater, transient loads for the short time they last, but you should check this.

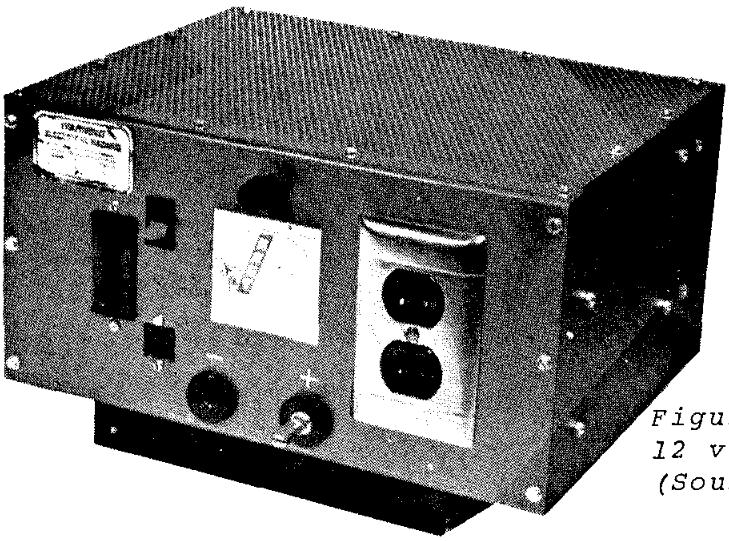


Figure 2 - 6: 1000 watt-12 volt inverter (Source: 4 Winds of Alaska)

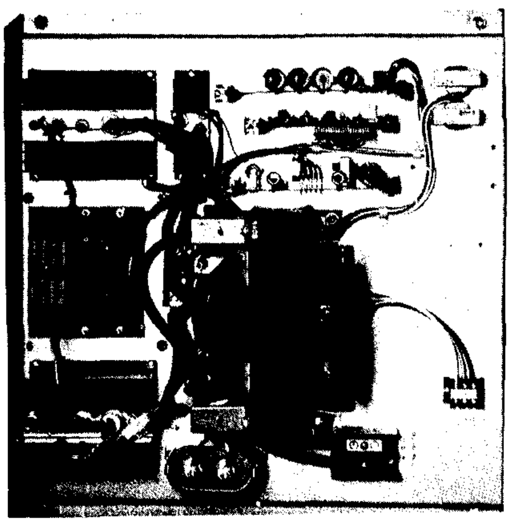
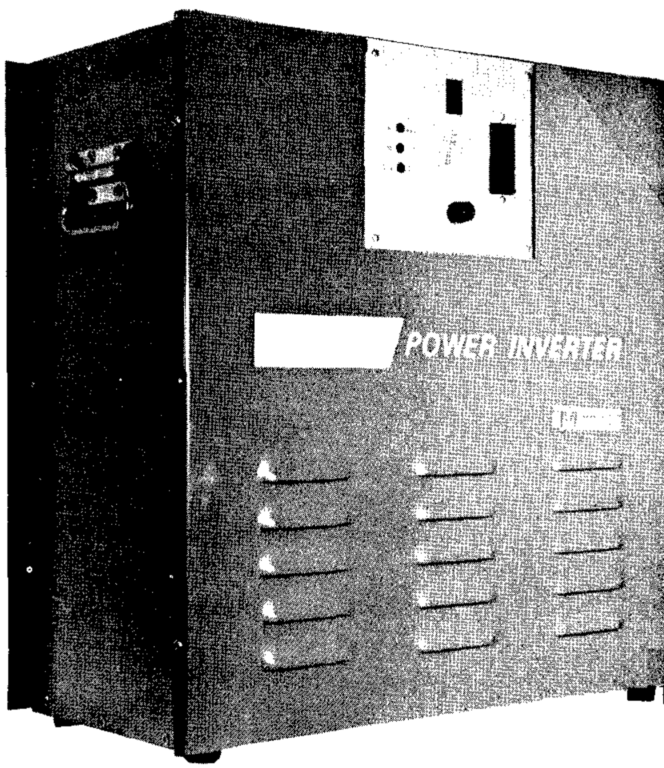


Figure 2 - 7: 12,000 watt-120 volt modularized solid state inverter (Source: 4 Winds of Alaska)



Backup Generators: These will be used as battery chargers during periods of low wind. Because of this, they do not have to be large to meet peak demands (batteries can do that). The generator should not be so big that it exceeds the maximum charge rate for batteries, nor should it be smaller than the average load. Between these limits, you are free to choose. A larger unit tends to be more fuel efficient, and since it will charge batteries faster you won't have to operate it as often, however, a smaller capacity unit would cost less to purchase.

You may decide to operate a system without a backup generator. This may require you to ration your use of electricity during long windless periods, or do without altogether.

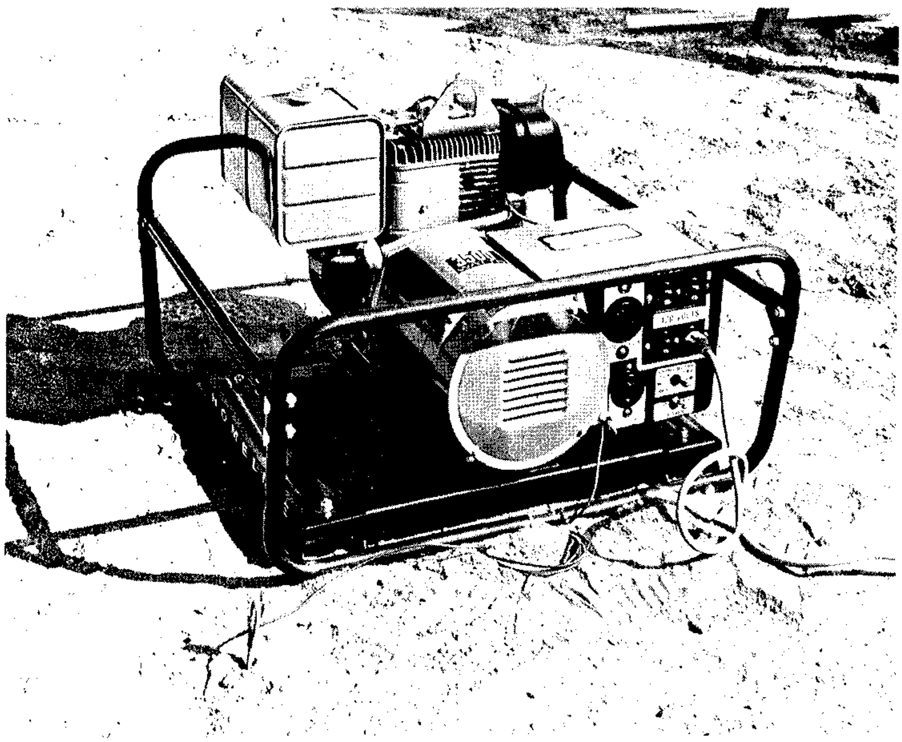


Figure 2 - 8: 3500 watt standby generator (Source: Homelite)

2:F Tower and Foundation Design

This is an area which deserves careful attention, because inadequate tower or foundation design is a fast and effective way to turn an expensive investment into a heap of scrap metal. Prospective wind system buyers without the necessary knowledge in structural design should ensure that they consult someone who is qualified.

Guyed pole towers - either wooden 'telephone' poles or metal 'telecommunications' towers - are usually the least expensive type of tower, and will perform adequately in many locations. If there are poor foundations conditions, however, frequent maintenance may be necessary in order to keep proper tension on the guys. This is due to frost heave, thaw at breakup, or melting of permafrost, all of which can cause differential settlement of the guy anchors. At sites with conditions like these, free standing truss-type towers (similar to electric transmission line towers) may be preferable. Free standing poles (without guy wires) are the most attractive type of tower, but are the most expensive and require the most massive foundation.

The **windgenerator** supplier often has tower designs available for each model of **windgenerator** (the supplier usually sells towers as well as **windgenerators**). If tower designs are not available from the supplier, design criteria should be. The most critical design factors are the weight of the machine and the maximum horizontal wind load; the latter is usually at least twice and sometimes more than four times as great as the former. With this information the tower manufacturer, structural engineer, or perhaps a utility contractor can probably recommend a tower design.

Nobody can adequately design tower foundations until a thorough soils investigation is made. This is a very important step in the design process, and a bad place to try to 'cut corners'. If it is found that foundation conditions are relatively favorable (i.e. your site is located on bedrock or clean gravel or sand) the **windgenerator** or tower supplier may well be able to provide an adequate tower foundation design. Greater care should be taken if less desirable foundation conditions are found, such as the presence of massive ice or frost susceptible soils (generally any soil with more than about 5% of silts, clays, or organic material). In these cases you should ensure that the designer of the foundation is familiar with construction in Alaskan conditions.

Another costly mistake is to assume a used tower is a bargain. In many cases old FAA towers were blasted down and have stress induced cracks which in high winds can cause system failure as was the case in Nelson Lagoon (figure 2-9, as shown in the next page).

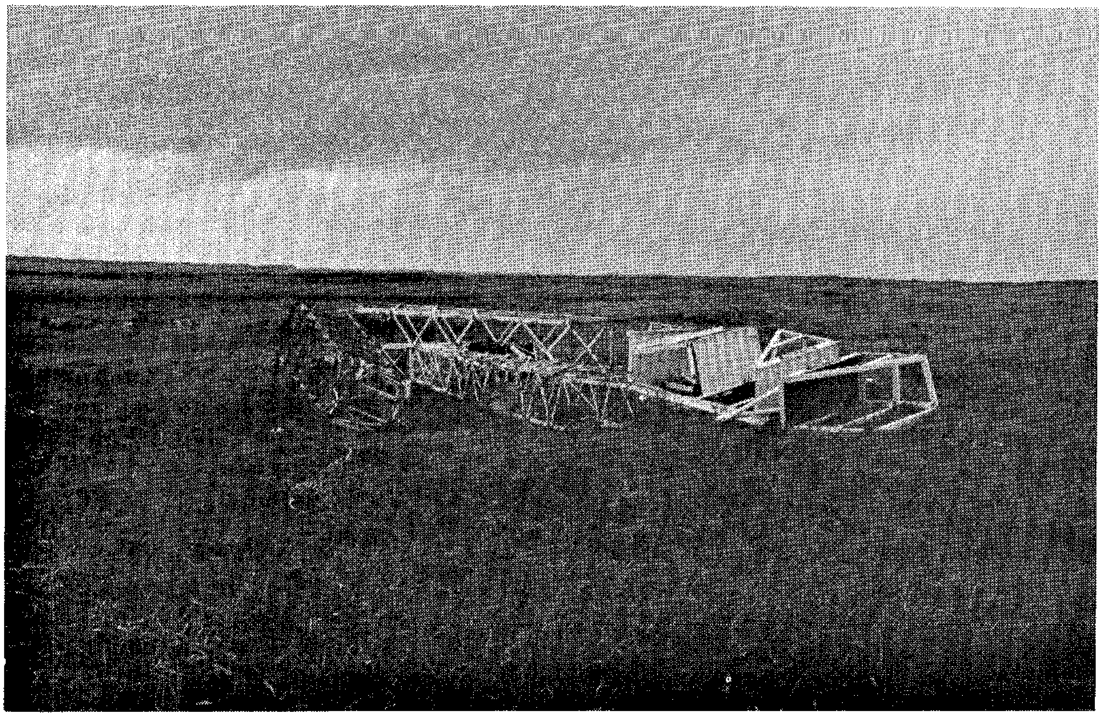
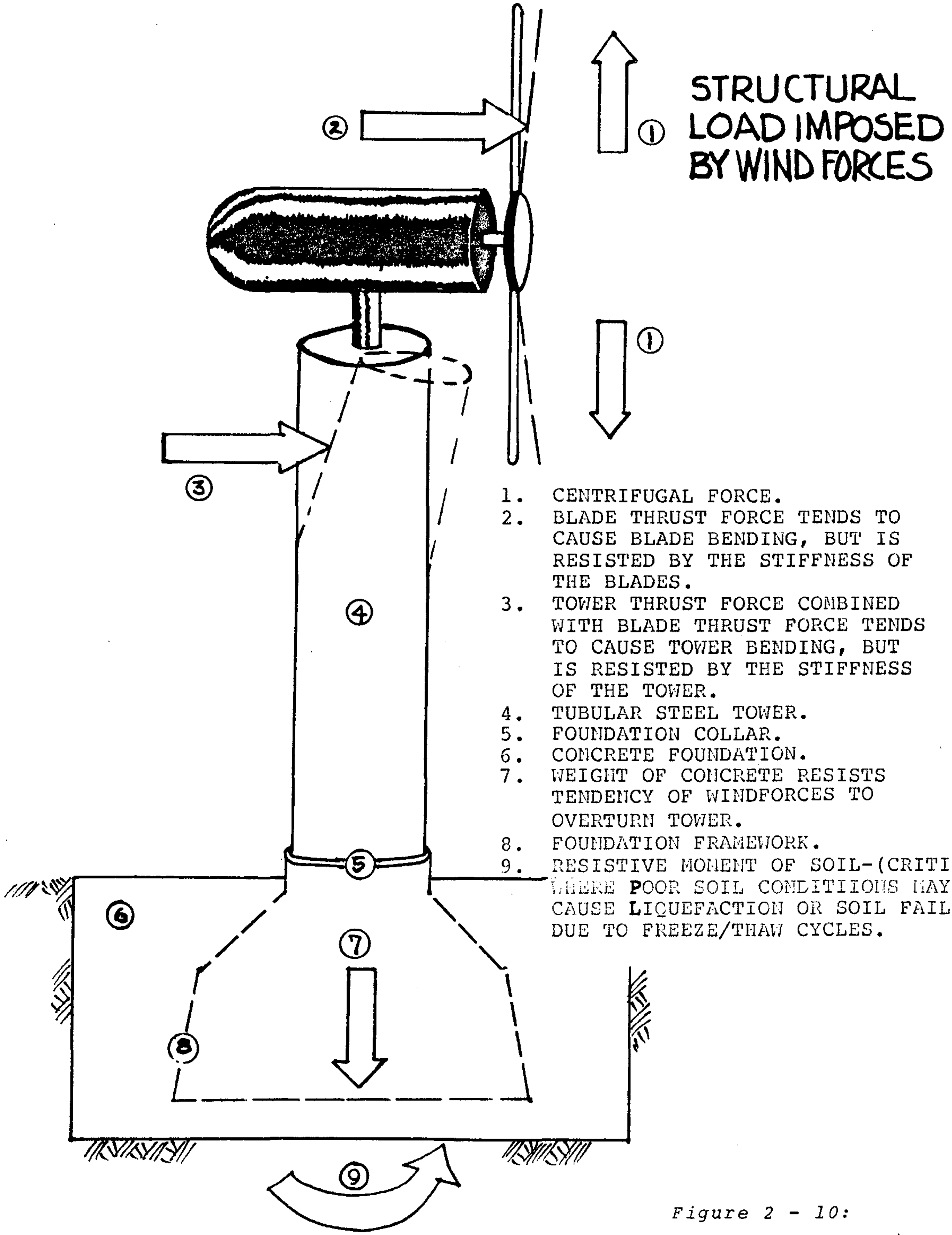


Figure 2 - 9: Remains of tower which was not designed for use with windgenerator (Source: Sherman Photo Serv.)

If you plan on erecting a tall tower, aircraft warning lights might be considered if planes fly nearby. FAA does not require them on any tower under 200 feet but they many times serve a very useful purpose as a navigational aide.

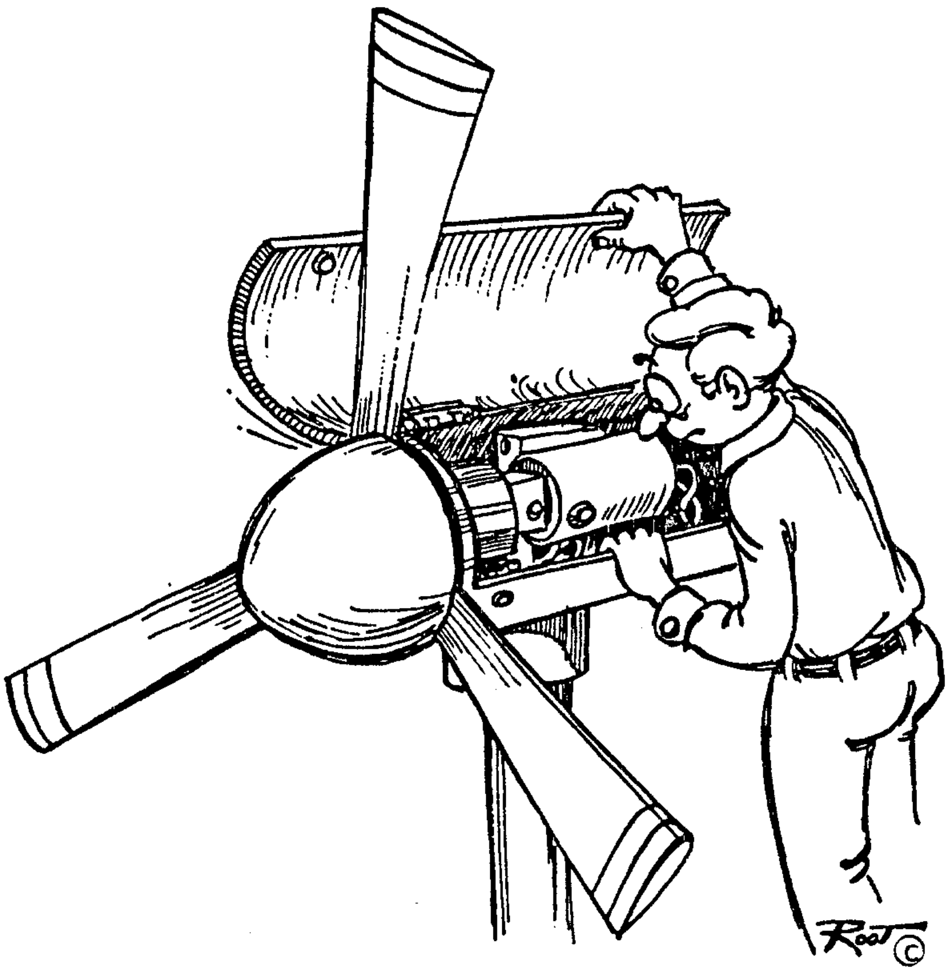
Also for safety reasons, fencing off the base of a tower and placing warning signs might deter any unauthorized people from climbing the tower and hurting themselves.



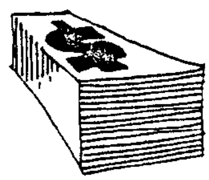
1. CENTRIFUGAL FORCE.
2. BLADE THRUST FORCE TENDS TO CAUSE BLADE BENDING, BUT IS RESISTED BY THE STIFFNESS OF THE BLADES.
3. TOWER THRUST FORCE COMBINED WITH BLADE THRUST FORCE TENDS TO CAUSE TOWER BENDING, BUT IS RESISTED BY THE STIFFNESS OF THE TOWER.
4. TUBULAR STEEL TOWER.
5. FOUNDATION COLLAR.
6. CONCRETE FOUNDATION.
7. WEIGHT OF CONCRETE RESISTS TENDENCY OF WINDFORCES TO OVERTURN TOWER.
8. FOUNDATION FRAMEWORK.
9. RESISTIVE MOMENT OF SOIL-(CRITICAL WHERE POOR SOIL CONDITIIONS MAY CAUSE LIQUEFACTION OR SOIL FAILURE DUE TO FREEZE/THAW CYCLES.

Figure 2 - 10:

PART THREE



WIND SYSTEM ECONOMICS



3:A Factors in Economic Analysis

Analysis of the economics of wind electric systems compared to alternatives can be a complex and confusing task. There are many variables which can affect the overall economics of systems. These include:

SYSTEM OUTPUT

This, of course, affects the cost of power. A given machine will produce electricity for less cost per kilowatt-hour in a faster wind regime than a slower one. Estimation of machine output is described in Section 2:C.

CAPITAL COSTS

These are the 'up front' costs for purchasing and installing the system. It is important, for comparison, that the capital costs of alternatives be determined, as well as those for the wind system.

FUEL COSTS

For independent systems, this cost usually represents the cost of gasoline or diesel fuel. Fuel requirements for backup generators must be accounted for, as well as those for the all-diesel (or gasoline) alternative. For grid-connected systems, the price that the utility will pay for power exported to them must be known, as well as the price they will charge for power they provide.

OPERATION & MAINTENANCE COSTS

This factor includes not only routine maintenance costs, but also the cost of unexpected breakdowns. The latter, of course, can only be guessed at. Here again, it is important to estimate the operation and maintenance costs not only for the wind system, but also for the alternatives (such as the cost of periodic overhaul of diesel generator sets).

INTEREST RATES

This is important for any high capital cost item. If you take out a loan or issue bonds to pay for the wind electric system, it is obvious that the interest rate will affect the cost of your power. If you pay cash for the system, the influence of interest rates is less obvious, but no less important. In this case, you don't pay interest on a loan or bonds, but you do lose the interest you could have made if you still had your cash. The availability of low interest loans for wind systems can significantly affect system costs, and this possibility should be investigated.

TAXES

A wind system purchase may affect taxes. On one hand, there may be investment or income tax credits for such systems. On the negative side, it's possible that a wind system will lead to a greater assessed value on your property, and thus higher taxes. Insurance requirements of the wind system should also be considered.

INFLATION

The rate of inflation affects the maintenance and fuel costs of a system (wind-driven or otherwise), and this should be recognized. One of the advantages of a wind system is that, once it is purchased and installed, it is relatively 'inflation-proof'; the major costs (repayment of the loan) are fixed, while only the relatively small costs of maintenance and backup fuel will rise with inflation.

3:B Wind System Capital Costs

It is no easier to state offhand how much a wind system costs than it is to state how much a car or a school costs; it will depend on size, quality and other factors. Anyone designing a system will have to decide for himself what particular equipment might be suitable, and what the requirements will be for transporting the system to the site and erecting it. The designer will then have to obtain prices for his specific application.

Due to this, the following sections are not meant to substitute for a detailed cost analysis. They are intended, instead, to give a general idea of the range of costs which can be anticipated for certain kinds of equipment.

3:B:1 WIND TURBINE-GENERATOR COSTS

Figure (3-1) shows an estimate of the range of wind turbine-generator capital costs as a function of size. This range was developed from prices obtained for commercially available machines, and includes the cost of standard controls, but not towers, parts, shipping, or installation. A review of prices has shown that costs for domestically manufactured wind plants has stayed relatively constant over the last couple years (and has dropped in some cases). Because of this the range indicated should be reasonably up-to-date as of the publication of this report. Foreign made wind plants appear to have risen in price in the last three years, perhaps due to changes in currency exchange rates.

Shipping costs must be added to these prices, and the designer will have to determine these costs himself. For wind plants of 1 kilowatt or less, shipping weights of 150 to 350 pounds can be expected. Machines in the 1 1/2 to 3 kilowatt range may run from as little as 250 to as much as 800 pounds; a 6 kilowatt machine's shipping weight may be 1000 pounds. Exact figures will be available from the supplier.

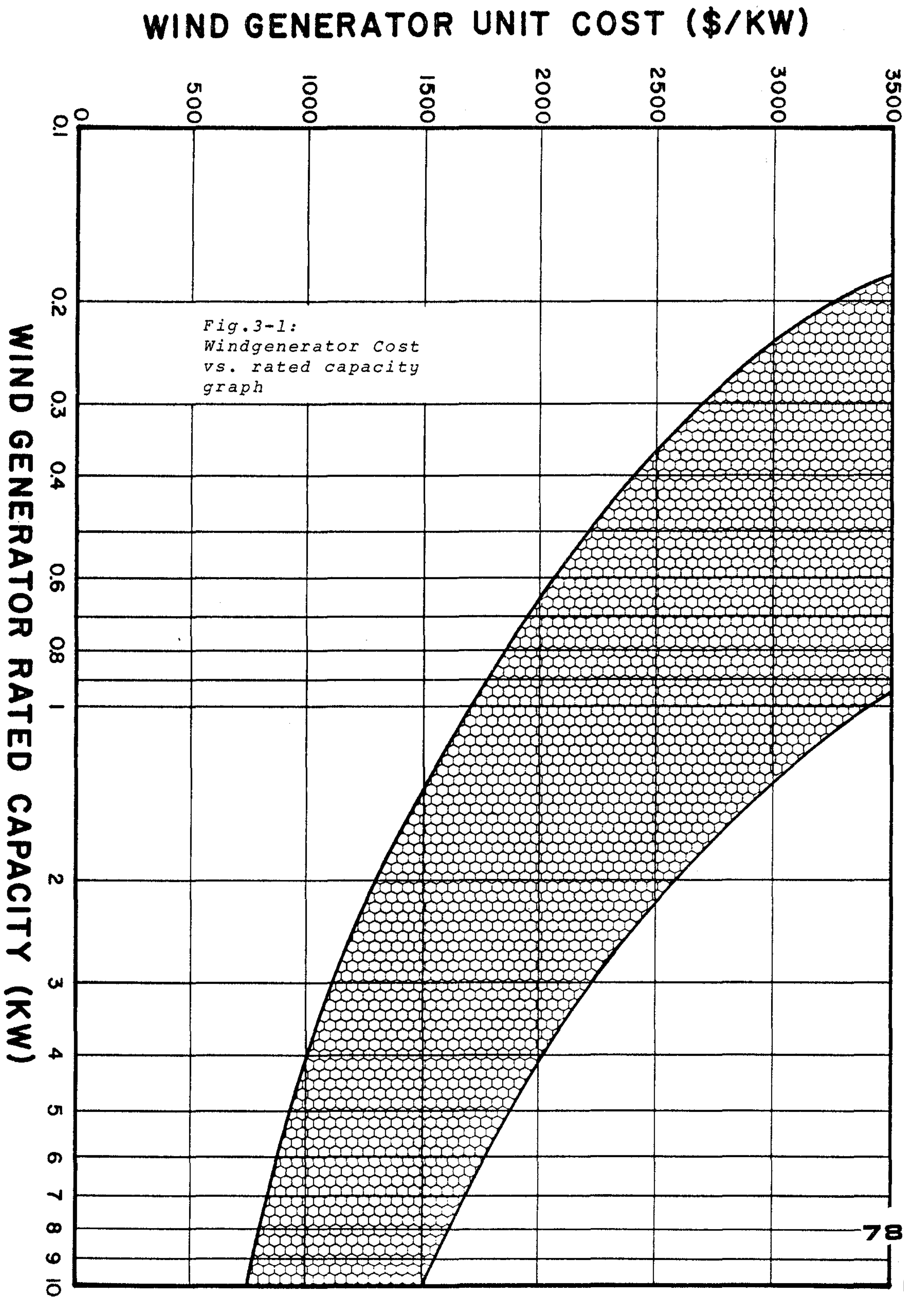


Fig.3-1: Windgenerator Cost vs. rated capacity graph

3:B:2 TOWER AND FOUNDATION COSTS

Towers can be a large cost item for a wind system, and one which it usually does not pay to minimize. Due to higher winds found at higher elevations, it is often worthwhile to build towers as high as 100 feet or even more. This point is discussed in Sections 1:B:3 and 2:C:3.

Guyed metal telecommunications type towers vary in cost, but will normally be between $20 and $35 per foot of height for small machines (up to 4 kw capacity). Free-standing truss-type towers for windgenerators of this size are more expensive; they will probably fall in the range of $35 to $50 per foot.

Wooden telephone poles, if locally available, will probably be cheaper than either of the above alternatives but should only be considered on machines smaller than 2kw. The designer may be able to find exact costs from a local utility. It may also be that local trees can be found - perhaps even on the owner's property - which will be suitable. Unfortunately many of Alaska's best potential wind power locations are treeless, eliminating this last possibility.

Free standing masts (unguyed poles) are the most expensive alternative. Costs for these are unpredictable, and they may have to be specially made. It isn't likely that they'll be worth the money unless there are peculiar space limitations for the tower at the site.

Towers should be selected carefully to comply with manufacturers recommendations. Using an unauthorized tower may invalidate your **windgenerator** warranty.

It is very difficult to estimate foundation costs, since the design of the foundation can vary a lot due to soil conditions. For small machines in favorable locations, a few 55 gallon drums filled with concrete, placed within a few feet of the ground surface, have been used. The cost of this, particularly if the owner provides his own labor, may be only a few hundred dollars. In permafrost areas with poor soils, 'ad-freeze' piles placed in predrilled holes may be the best alternative. The cost of these will depend to a large extent on the availability of drilling equipment, and will run anywhere from several hundred dollars on up. In very poor conditions in remote areas (such as the thawed, wet, unstable soils often found in the Aleutian Islands) foundation costs can be more than the cost of the **windgenerator** itself, which could well make the entire project prohibitive in cost.

Any foundation design should be checked by an engineer who will need good soil information. The cost of an engineer and possible soil test should be included in the foundation costs.

Shipping costs for towers and foundations materials will vary depending upon the site location. The weight of towers will probably be somewhere near 25 to 30 pounds per foot.

3:B:3 UTILITY INTERTIE SYSTEM COSTS

If you choose to intertie with a utility (either a public utility or a small private diesel grid) you can avoid the cost of batteries and an inverter. You will still need the tower, wiring, controls, installation, engineering, and safety gear however. The avoidance of the capital costs associated with storage and converting to AC power is usually significant. The operation and maintenance costs can be expected to be cut by at least half in an intertied system.

3:B:4 BATTERY COSTS

Battery costs are another major part of wind system costs. The most commonly used type, the lead-acid, deep-cycle battery, costs in the neighborhood of $90 to $140 per kilowatt-hour capacity as of this writing (April 1981). Battery costs have been rising rapidly in the last few years (in contrast to **windgenerator** costs), so the designer will need to check this figure.

A great deal of research is going on in the field of battery storage. Much of this, however, is not primarily an attempt to reduce costs, but rather to get higher energy to weight yields to make electric cars more practical. Some progress has been made in improving batteries, but no major breakthroughs should be expected in the near term.

Battery systems require a place to store them and racks to put them on (see Section 2:D:2). If the owner already has space available, and can knock together storage racks, the cost of this will be negligible. If a new room or a separate building must be constructed, however, this may require considerable expense, even though the space requirements are modest. The designer is probably the best judge of what these costs will be.

Battery life depends upon the care taken in their maintenance and in the way they are charged and discharged. New deep cycle batteries, with minimum care, will probably last at least 10 years; with careful attention they may last twice this long. Even so, their lifetime may be shorter than that expected of other system components. In the system cost analysis, then, the designer should count on replacing the battery system at least once during the system's lifetime.

Batteries are very heavy and can be one of the most expensive parts of the system to transport to the site. Deep cycle lead-acid batteries generally weigh between 50 and 100 pounds per kilowatt-hour of energy storage.

3:B:5 INVERTER COSTS

Small capacity inverters suitable for use in wind systems have a wide range in costs and operating efficiencies. The highest quality inverters - solid state models producing a pure sine wave - usually range in cost from $1000 to $2000 per kilowatt (continuous) capacity. Solid state inverters producing a modified square wave are less expensive, usually between $500 and $1200 per kilowatt (continuous) capacity.

Rotary inverter costs are in approximately the same range as for solid state modified square wave inverters. Their wave form is of higher quality (a pure sine wave), but their efficiency is much less.

It is possible that a wind system owner could construct his own rotary inverter (a DC motor driving an AC alternator). In this case, he will be the best judge of costs, which will depend on his own particular circumstances, the availability of motors and alternators, and his knowledge of electrical systems.

3:B:6 BACK-UP GENERATORS

Internal combustion generators (either gasoline or diesel) are widely available in a broad range of sizes. Prices vary considerably, depending upon quality and size. For backup duty in an independent wind system, where the generator will seldom be used, lightweight and inexpensive models will probably be adequate. Even in very small sizes they are available for as little as $200/kw.

These generators have low operating efficiencies. The highest efficiencies, found in the larger models, are about 25% to 30%. In very small sizes, efficiencies may be much less. The efficiencies for these generators are generally the highest when operating at full load, and drop off dramatically at part load.

If a backup generator is used to charge the batteries a major expense may be a good "taper charge" battery charger. The cost of these depends on the voltage and amp rating desired. The smaller 12 volt models are cheapest but impractical for charging banks of batteriess which are connected in series at higher than 12 volts.

3:B:7 CONTROLS

The most important component of a wind system is the controls. Controls will be very specific to each system and owner as to how much he desires to do manually or automatically. Today with inexpensive microprocessors, load management is becoming very practical and efficient for wind systems. The cost will vary from several dollars for some relays, sensors, and alarms to several thousand for a computer-based fully automatic system. However with a good load management system the cost of other components (generator, inverter, back-up system, batteries) will be reduced because of lowered peak load requirements.

3:B:8 WIRING, CONNECTORS, AND MISC.

These are the most often neglected costs, yet can be significant. The cost of wire to get the power from the **windgenerator** down the tower, buried in the ground (or run overhead) to the battery room can be a critical cost item. Wire (depending on the type and size) could run $1 to $2/foot/strand, which in a typical 3 to 5 wire generator at 500 feet from the source could run up to $5000. An electrical engineer or good electrician should be referred to for the proper type of wire and connectors, and an electrical supply house for current price.

Battery connectors, hydrocaps, vents, explosion proof lights, first aid kits, voltmeter, hydrometer, tools, climbing belts, hardhat, safety gear, ground rod, anemometer, battery acid crates, and spare parts are just a few of the miscellaneous items which should accompany each purchase of a wind system. You may also need a library of maintenance manuals and how-to books to repair your equipment when it breaks.

3:B:9 INSTALLATION COSTS

Most major **windgenerator** manufacturers now require (even on the small machines) that a factory representative either inspect or install the wind system in order to validate the warranty. Usually the dealers are very anxious to help and will provide this service for the cost of a plane ticket and a nominal per diem. Unless you are experienced at installation of the unit you are buying, it is strongly recommended you consider this a necessary capital cost. If a crane is available the cost per hour should be included. If not, a gin pole (see section 4:A:3) will be required, which can usually be rented from the dealer.

3:B:10 ENGINEERING AND DESIGN COSTS

Getting good advice on your system before you purchase the components can save you a lot of money and heartache. Retaining a competent Engineer to help with the system's design could be considered a necessary capital cost.

3:C Energy (fuel) Costs

These costs will in most cases be the cost of fuel for a gasoline or diesel generator, or the cost of electricity from a utility.

Gasoline or diesel fuel requirements for backup generators are based on the amount of backup electricity needed and the efficiency of the generator; this is discussed in Section 2:E. Fuel requirements for generators such as a primary source alternative are calculated in the same manner. Once the quantity of fuel needed is calculated, the cost of this fuel for the first year of operating can be found using current fuel prices. For other years it is necessary to guess what the rate of inflation for fuel prices will be.

If you assume 12% inflation rate, the cost the second year will be 1.12 times the first year's amount; the cost the third year will be 1.12 x 1.12 = $(1.12)^2$ = 1.254 times the first year's amount; the fourth year it will be 1.12 x 1.12 x 1.12 $(1.12)^3$ = 1.405 times the first year's amount, etc. In general, the cost for any year will be

$$C_n = C_1(1+i)^{n-1}$$

where: C_n = Cost in the nth year

C_1 = Cost in the first year

i = inflation rate (expressed as a decimal, not a percentage; e.g. 10% = 0.10, 8% = 0.08, etc).

The values given by this equation, for various rates of inflation and number of years, is shown in the graph of Figure (3-2).

If you use a utility's electricity as a backup source, the cost is computed in the same manner unless you use a utility intertie machine. If you use a utility intertie, you'll have to figure out both how much electricity you'll buy from the utility (and how much they'll charge you for that) and how much electricity you'll sell to the utility (and how much they'll pay you for that).

The amount of power you sell will be everything that is generated which is not used immediately. This cannot be calculated exactly, since it depends on the unpredictable levels of the winds and on your demand for power. If you have a small **windgenerator** and a large demand, you may never generate more power than you use, and therefore never export any power. On the other hand, if you have a **windgenerator** large enough that its <u>average</u> output is equal to your <u>average</u> demand, it would not be surprising if 3/4 of your generation will not coincide with your demands, and will be exported. The amount of electricity you import will be your total demand minus whatever you generate and use immediately.

Once you figure out the export and import quantities, you can figure costs in the same manner as before. Remember, though, that the price you sell electricity for will probably be less than what you buy it for; you'll have to establish these prices by talking to a utility representative.

3:D Non-Fuel Operating and Maintenance Costs

Operating and maintenance costs for wind systems, if properly installed at a good (i.e. non-turbulent) wind site, are quite small. A figure of 1% to 2% of the system's cost each year is often used; you may want to review the maintenance section of this manual and then make your own estimate. Operating and maintenance costs for gasoline or diesel generators are much higher than those for wind systems. An operator's manual for your particular gas or diesel engine should be consulted for maintenance and overhaul intervals.

The cost of maintenance is subject to inflation, although perhaps this will occur at a slower rate than that for fuel costs. Again, the graph of Figure 3-2 can be used to calculate the amount of cost increases due to inflation.

3:E Low Interest Loans

It should be noted here that the State of Alaska, as of this writing, has a limited amount of money available in the Alternative Energy Revolving Loan Fund. The maximum loan amount is $10,000; the interest rate is 5%, and the maximum repayment period is 20 years. Information regarding this fund can be obtained from:

Alternative Energy Systems Revolving Loan Fund

★ Division of Business Loans, 675 7th Ave., Station A
Fairbanks, Alaska 99701, (907) 452-8182

★ Division of Business Loans, Pouch D
Junear, Alaska 99811, (907) 456-2510

★ Division of Business Loans 2600 Denali, Suite 401
Anchorage, Alaska 99503, (907) 274-6693

Provides loans up to $10,000 for the purchase and installation of alternative systems. This is for energy systems using fuel other than fossil or nuclear, including solar, wind and hydro devices. The rate of interest for Alternative Energy Loans is 5%.

3:F Tax Credits and Grants

You may be able to receive tax credits or grants for installing a wind system. As of this writing, the federal government allows a 40% tax credit on the first $10,000 spent on a wind system by individuals to serve their principal residence. For businesses, an additional 15% investment tax credit is available with certain restrictions. In addition, businesses can get a 35% tax credit (with a maximum of $5,000) from the State of Alaska. Additionally, the wind system is a depreciable asset and can be depreciated over a seven year period and written off as a deduction. Tax policies can change overnight, so you should make sure to get up-to-date information of these programs and any restrictions they may have. For more detailed information regarding the credits, contact your local tax office for Publication 903, "Energy Credits for Individuals."

Internal Revenue Service
310 K Street, 2nd Floor
Anchorage, AK 99501
Tel. (907)277-8715
Toll-Free Taxpayer-Zenith 3700

Two Grant Programs which may fund wind systems are:

Appropriate Technology Small Grants Program
Division of Energy & Power Development
338 Denali Street
8th Floor, Mackay Building
Anchorage, Alaska 99501
(907) 276-0512
This program, sponsored by the U.S. Department of Energy, offers grants up to $50,000 to individuals, small businesses, native groups, non-profit groups and local agencies for energy conservation and alternative energy products.

Northern Technology Grants Program
Alaska Council on Science and Technology
Pouch AV
Juneau, Alaska 99811
(907) 465-3510
Offers grants up to $5,000 for the development of technologies that may be more efficient, less costly and less energy-intensive than those methods which presently are appropriate to the Alaskan environment.

To adjust the economic analysis for any grants or tax credits you may get, simply deduct the amount from the price tag of the system.

3:G Wind System Optimization

The first task in the economic analysis is to determine what the most economical wind system will be. This can be done by comparing different wind system designs, using the same methods as are used to compare wind systems with conventional systems. The most important design factors which should be examined are listed below.

Windgenerator Model: The model of **windgenerator** that you choose will affect the cost of the power generated. In general, a larger and more expensive **windgenerator** costs more initially, but will produce more power (and thus will have a lower cost per kwh). This will result in lower costs for backup fuel. Your problem is to determine which model results in the lowest average cost of power. Additionally the small units (less than 4 kw) are more proven and thus more likely to last longer.

Tower Height: This factor is similar to the one above; a higher and thus more expensive tower will generally result in increased power output of the system, thus reducing backup power costs. Alternatively, a higher tower may allow you to use a smaller, less expensive **windgenerator** and still get the same amount of power. Again, the problem is to find which size of tower results in the lowest cost of power.

Battery Size: A larger battery bank will allow you to go through longer periods of low wind without using a backup system. You must examine the tradeoff between higher initial (capital) costs and higher operating (backup fuel) and maintenance costs.

Inverter Size: If you install an inverter large enough to handle all your power demands, you can wire the building (or buildings) to be served in a conventional manner and use any kind of conventional equipment in it. A larger inverter, however, is expensive, and the conversion of DC electricity stored in a battery to AC electricity lowers the efficiency of the system. A smaller inverter will be cheaper and may result in a more efficient system, but will probably require that you install both DC and AC wiring circuits in the buildings served. In addition, you may have to purchase special DC equipment, or pay for converting conentional AC equipment to run on DC.

Utility Intertie: If utility power is available, you will almost certainly be able to lower capital costs by installing a generator capable of an intertie. With such a system, however, you will probably be faced with continuing electric bills. You will have to find out the rates which the utility will buy and sell power for to determine if a system with an intertie will save money in the long run over a system using utility electricity strictly as a backup source (or over a system with no utility connection at all).

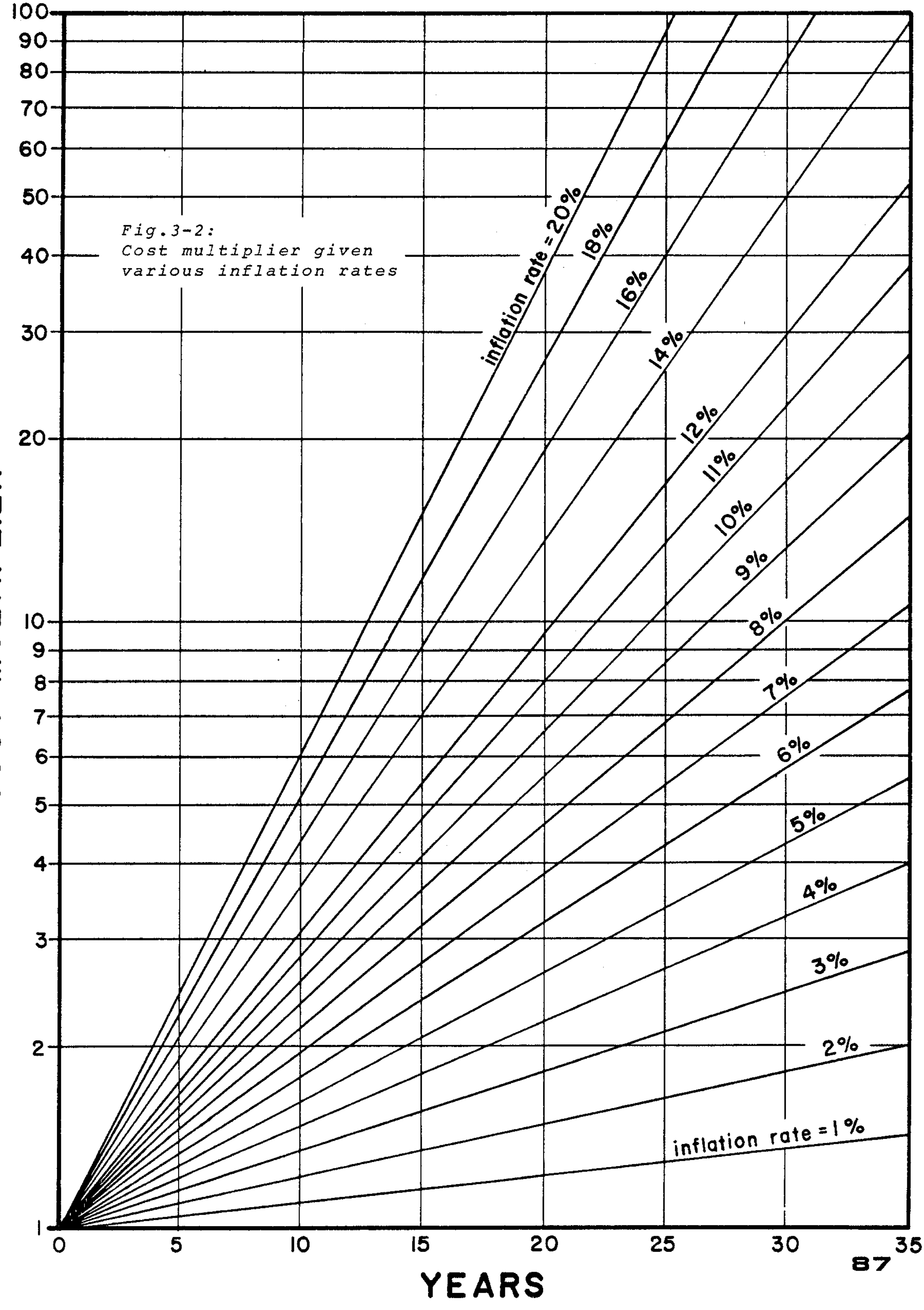


Fig.3-2:
Cost multiplier given
various inflation rates
inflation rate = 20%
18%
16%
14%
12%
11%
10%
9%
8%
7%
6%
5%
4%
3%
2%
inflation rate = 1%
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
YEARS

3:H Payoff Period Cost Analysis

The payoff period cost analysis isn't as good as the annualized cost analysis (presented later) for making decisions. But while an economist wouldn't like it as much, it is simpler and may be good enough for a prospective wind system owner. Basically, this method calculates how long it takes for a wind system to generate an amount of electricity worth what the wind system costs. This depends principally on two things; the cost of the wind system and the value of the electricity produced. The latter is usually determined by the cost of the alternatives to the wind system.

First of all, you must determine the cost of buying and installing the wind system. You should subtract from this amount the cost of setting up the alternative system, since you'd have to spend that much anyhow. If you're already hooked up to utility power, or already have a diesel generator, this cost is zero, of course. Otherwise, the cost of the alternative will be the cost of buying and installing the diesel generator and related equipment, or the hookup fee from the utility. The hookup fee can be very expensive if the installation is to be even a few hundred yards from existing power lines.

Next, you must figure out how much the annual costs would be for the gas or diesel generator system or the utility connection. For a generator, this cost is fuel plus maintenance; for the utility connection it is merely the electric bills. These costs, of course, will increase over time due to inflation. Subtract from this annual cost the fuel and maintenance costs of the wind system; this will give you the annual savings you get from the wind system (these savings should also increase over time due to inflation).

Having found these figures, you can easily calculate how many years it will take for the wind system's savings to equal the wind system's cost. This is the 'payoff period'; for an energy system like this, many people will decide the investment is worthwhile if the payoff period is six to ten years.

Example Calculation: What follows is a simplified example, but it should serve to illustrate the method of calculation. Assume that you have a need for 10,000 kwh of electricity per year, and that you have the following alternatives:

Wind System: Capital cost $30,000
Annual cost (backup fuel and maintenance) $600 per year. Inflation rate for annual costs 12% per year.

Electric Utility: Capital cost $4,000
Annual cost (electric bills) 30¢/kwh = $3,000 per year. Inflation rate for annual costs 12% per year.

The wind system costs $26,000 more than the electric utility hookup; Table (3-1) shows how to calculate the length of time needed to save this amount of money by using the wind system. As can be seen in the table, the $26,000 more that the wind system cost will be made up in savings on electricity bills in a little more than seven years. This example assumes no tax credits, low interest loans, or depreciation allowance which would all add to the economies of the wind system.

TABLE 3-1 : CUMMULATIVE WIND SYSTEM SAVINGS

1 YEAR	2 ANNUAL ELECTRIC BILL	3 CUMULATIVE ELECTRIC BILL	4 ANNUAL WIND SYSTEM COSTS	5 CUMULATIVE WIND SYSTEM COSTS	6 CUMULATIVE WIND SYSTEM SAVINGS (3-5)
1	$3,000	$ 3,000	$ 600	$ 600	$ 2,400
2	$3,360	$ 6,360	$ 672	$1,272	$ 5,088
3	$3,763	$10,123	$ 753	$2,025	$ 8,098
4	$4,215	$14,338	$ 843	$2,868	$11,470
5	$4,721	$19,059	$ 944	$3,812	$15,247
6	$5,287	$24,346	$1,057	$4,869	$19,477
7	$5,921	$30,267	$1,184	$6,053	$24,214
8	$6,632	$36,899	$1,326	$7,379	$29,520
9	$7,428	$44,327	$1,486	$8,865	$35,462
10	$8,319	$52,646	$1,664	$10,529	$42,117
11	$9,318	$61,964	$1,864	$12,393	$49,571
12	$10,436	$72,400	$2,087	$14,480	$57,920

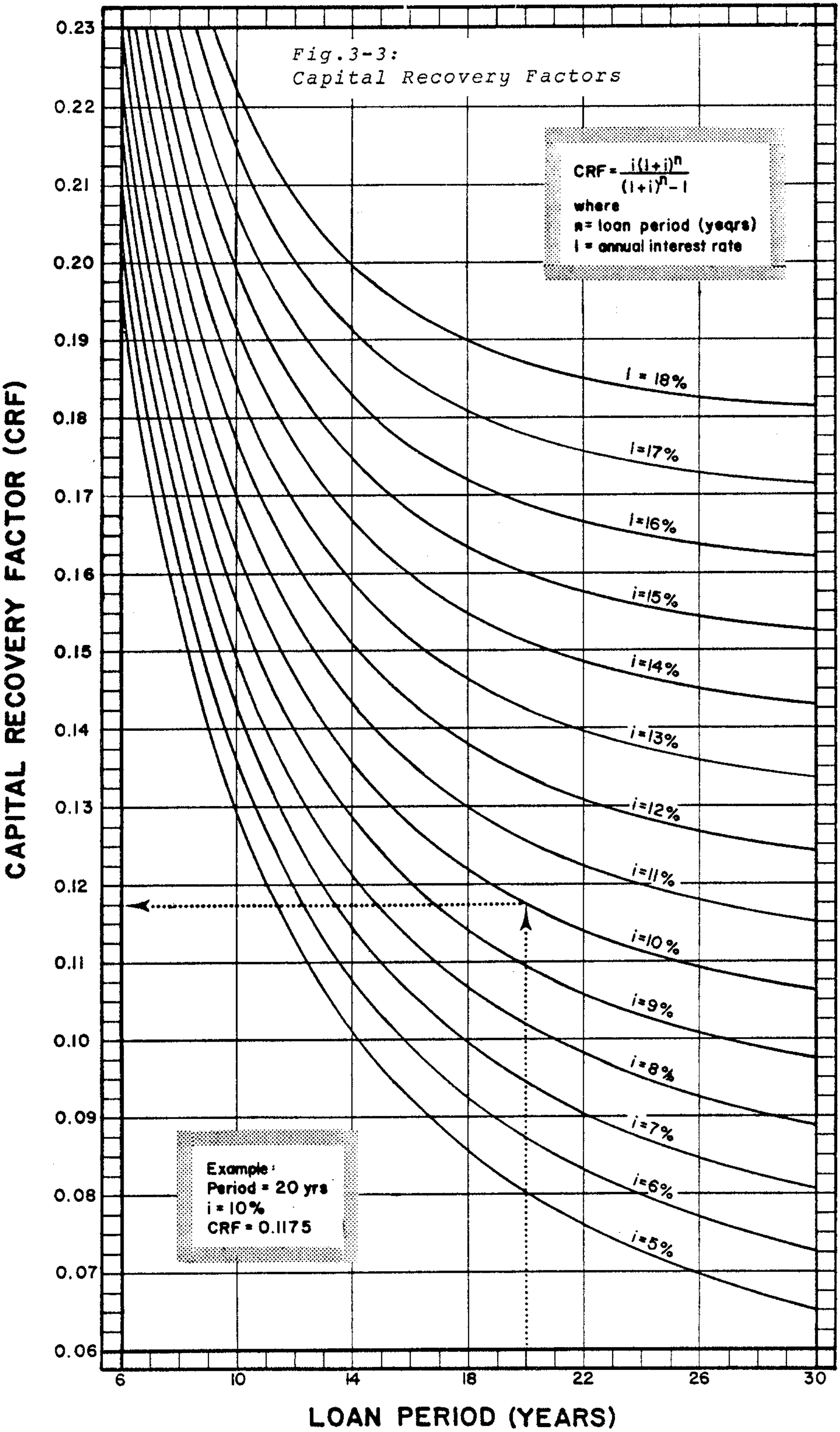


Fig.3-3:
Capital Recovery Factors
CRF = $\frac{i(1+i)^n}{(1+i)^n-1}$
where
n = loan period (years)
i = annual interest rate
Example:
Period = 20 yrs
i = 10%
CRF = 0.1175
i = 18%
i=17%
i=16%
i=15%
i=14%
i=13%
i=12%
i=11%
i=10%
i=9%
i=8%
i=7%
i=6%
i=5%
CAPITAL RECOVERY FACTOR (CRF)
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
6
10
14
18
22
26
30
LOAN PERIOD (YEARS)

3:I Annualized Cost Analysis

This method of cost analysis allows you to compare on equal footing a system with a high capital cost and low operating costs (like a wind electric system) with a low capital cost, high operating cost alternative (like diesel generating system or a utility hookup). Basically, in this analysis capital costs are converted to an equivalent annual payment, and this is added to the annual cost of fuel and maintenance. This is done for all the alternatives, and then these annual costs are compared.

Capital Costs: Converting a capital cost to an annual equivalent consists of calculating what the annual payments would be for a loan with a repayment period equal to the expected life of the system. This annual payment is then adjusted to account for the effects the interest payments will have on your income taxes, and the effect that the ownership of the system will have on your property taxes and insurance payments. It is, in essence, the same calculation as you would make to figure the annual cost of buying a home, a school, or any other major investment.

The annual cost of repaying a loan (principal plus interest) is equal to the loan amount multiplied by the factor:

$$CRF = \frac{i(1+i)^n}{(1+i)^n-1}$$

where: n = the number of years of the loan repayment period

i = the annual interest rate on the loan

The interest rate is expressed as a decimal number, not a percentage (e.g. 10% interest is expressed as 0.10, 8% as 0.08, etc.). The values given by this formula, for a number of interest rates and loan repayment periods, is given in Figure 3-3; these are known as 'Capital Recovery Factors'.

If you pay cash for a system, you must still figure in the cost of interest as this formula does. In this case, the interest is money you lose because you've taken your money out of a savings account (or stocks or some other investment). If you issue municipal bonds to finance a system, the bond interest rate applies in the formula.

These interest rates - those on a loan, on withdrawn savings, or on bond issues - can all be different. Because of this you should figure out two capital recovery factors if you put down a payment on a system and take out a loan (or issue bonds). One of these will use the interest rate you lose on your down payment money (and will apply to the down payment part of the capital cost), and one will use the interest rate on your loan or bonds (and will apply to the loan or bond amount). You should calculate capital recovery factors based on a loan period equal to the expected life of the system, even if your loan repayment period will actually be shorter; this simplifies the analysis.

Neither batteries nor diesel generators last as long as the 20 (or even 30) years expected of a **windgenerator** under normal circumstances. Thus, if you are calculating the cost of diesel-generated power as an alternative to a **windgenerator,** you should account for this by using a shorter loan repayment period - perhaps 10 years - in the formula. Similarly, you can divide the cost of a wind system into two parts, one for the batteries and one for the rest of the system. These costs can then be converted to annual equivalents using the appropriate expected lifetimes for each.

Taxes and Insurance: The interest rate you use for calculations should be adjusted to account for taxes and insurance. To illustrate the importance of this, imagine you've bought the system for cash, and you could have invested that money elsewhere at a 12% interest rate. If you did that, you'd have to pay taxes on that 12% interest. If income taxes took 1/3 of this, you'd really only see 2/3 of the interest, or 8%. Similarly loan interest can be written off of income taxes, again making the effective interest rate less than the apparent interest rate (as any homeowner with a mortgage knows).

You may also have to pay property taxes and insurance on your investment. You should calculate what these costs will be (if any) and add this amount to your annualized capital cost.

Capital Cost Example Calculations: Financing arrangements can vary widely, and this has a very large effect on the economic competitiveness of wind systems. The importance of this can hardly be underestimated; the examples below illustrate the point. In all cases, the expected life of the wind system is assumed to be 20 years.

Case 1: A wind system for a municipal community center costing $30,000.
Financing method: Municipal bonds, 20 year maturity, 9% interest.
Tax Credits and Grants: None
Marginal Income Tax Rate: 0
Property Tax and Insurance: 1% per year (insurance, no property tax)

Using the formula, the capital recovery factor **(CRF)** in this case is:

$$CRF = \frac{(.09)(1.09)^{20}}{(1.09)^{20} - 1} = 0.1095 = 10.95\%$$

The insurance cost of 1% per year must be added to this; thus the total capital related cost of owning the wind system will be 11.95% of the capital cost, or $3585, per year.

Case 2: A wind system for a non-profit village cooperative costing $30,000
Financing Method: Bank loan at 13% interest
Tax Credit and Grants: None
Marginal Income Tax Rate: 0
Property Tax and Insurance: 1.5% per year

Using the formula, the capital recovery factor (CRF) in this case is

$$\text{CRF} = \frac{(.13)(1.13)^{20}}{(1.13)^{20}-1} = 0.1424 = 14.24\%$$

Adding the property tax and insurance to this yields a total annual cost of 15.74% of the capital cost, or $4722 per year.

Case 3: A wind system for an individual costing $15,000
Financing method: $3,000 down payment from money market certificates at 12% interest, $10,000 from Alaska Alternative Energy Revolving Loan Fund at 5% interest
Tax Credits and Grants: $2,000 federal income tax credit (20% of the first $10,000)
Marginal Income Tax Rate: 35%
Property Tax and Insurance: 1.5% per year

This example is more complex than the other two (as most real cases will be). Two capital recovery factors must be calculated; one for the down payment, and one for the loan amount. The money for the down payment was earning 12% interest, but income taxes take 35% of this, so the effective interest rate is only 7.8%. Thus

$$\text{CRF} = \frac{(.078)(1.078)^{20}}{(1.078)^{20}-1} = 0.1003 = 10.03\%$$

The low interest state loan has a 5% interest; 35% of that will be saved on income taxes, so the effective interest rate is 3.25%. Therefore

$$\text{CRF} = \frac{(.0325)(1.0325)^{20}}{(1.0325)^{20}-1} = 0.0688 = 6.88\%$$

The 10.03% **CRF** applies to the $3,000 down payment; this amounts to $301 per year. The 6.88% **CRF** applies to the $10,000 loan amount, or $688 per year. The 1.5% property tax and insurance rate applies to the full $15,000 price, or $255 per year. The total annual capital related cost is therefore $301 + $688 + $225 = $1214 per year. This is only 8.09% of the cost of the system.

These are only isolated examples, and in different situations other results would be found. In case 3, for example, the individual would not qualify for the income tax credit if the wind system was not installed at the owner's principal residence. He also might not be able to get a state low interest loan. On the other hand, the village cooperative in case 2 might qualify for such a loan; they might find other financing methods as well. The important point here is that the annualized capital cost can vary a lot, and this can have a very important effect on the economic competitiveness of the wind system.

Total Annual Costs: Once you have computed the capital, fuel, and maintenance costs for the wind system and the alternatives, you can add them up to find the total annual costs for each and compare them. You can also find out how much each kilowatt-hour of electricity costs you, by dividing the annual costs by the annual kilowatt-hours used.

Since the fuel and maintenance costs rise over time, the comparison between the wind system and its alternatives may change too. It might turn out that the wind system costs more than a diesel generator the first year, but less after five years of rising fuel and maintenance costs. This may be enough information for you to decide which system to buy; if the wind system becomes the cheaper alternative within 7 or 8 years it's probably a good investment.

A more rigorous method of analyzing these costs is to find the 'discounted present value' of the comparitive costs or savings for each year of the system's expected life. These can then be added up to see if the wind system is the cheaper alternative. Basically, the discounted present value accounts for the fact that $100 savings ten years from now isn't as valuable as a $100 savings today (the $100 savings today could be invested and thus would be worth more than $100 in ten years). The discounted present value of a cost or savings in the future is given by the formula

$$C_o = \frac{C_n}{(1+i)^n}$$

where: C_o = present value of cost or savings

C_n = cost or savings in year n

i = annual interest rate

3:J Non-Economic Factors

Economic factors will probably be the most important ones in the decision to buy a wind system or not. Some factors, however, do not lend themselves to an economic analysis. Among these are questions of convenience, reliability, and aesthetics.

3:J:1 CONVENIENCE

There is no question but that an electric utility is a convenient way to get an electricity supply; all you have to do is mail a check occasionally and perhaps replace a fuse or two. On the other hand, a properly installed wind system may be more convenient than a comparable diesel generator. The relative costs of maintenance may not fully reflect the value of the convenience of competing alternatives; each system owner must determine the value of this for himself.

Convenience also enters into the question of whether to use DC or AC power. You may consider using an entirely DC system; even if you have to have some equipment converted to operate on DC power, this may well result in a much cheaper system. Yet there is some convenience lost in such an arrangement; if you have AC capability, you know that at any time you can buy almost any type of equipment and simply plug it in. This isn't true if you only have DC (or if you only have a small DC/AC inverter). To some, this may not be a significant drawback; to others this may be an important factor.

3:J:2 RELIABILITY

A properly installed wind system at a non-turbulent wind site can provide a fairly reliable long-term source of power. There is always a chance, however, that you will throw a blade in a storm, or that you'll develop a short in your controls. On the other hand, conventional systems can also have their problems. Utility power can go off for varying lengths of time; some utilities are more prone to this than others. Diesel generators tend to have more reliability problems than utilities. If a barge doesn't make it in before freeze-up, you may be faced with the high cost of flying in fuel. If your generator's bearings go out during a period of bad weather, you may have to wait for a long time to fly in spare parts (during this same period of 'bad' weather a **windgenerator** might be producing abundant quantities of power). These problems of reliability, both of wind systems and their alternatives, are important, but not easily quantifiable.

With a **utility intertie** system your windgenerator is only as reliable as the utility. When the power fails, an **induction generator** by design, will not put power in the lines. Thus in order to activate the generator you will need to provide a signal via a stand-by gas generator, which has to be sized properly to handle the "load" put on it by the windgenerator. A **synchronous invertor type** intertie will not produce any AC power if the utility is down but the wind generator is still capable of DC power production which could be used in emergencies for resistive heating. A **synchronous generator** can be designed to provide its own signal but must first be disconnected from the utility line for safety reasons.

Some people may want to consider installing a remote wind system with no backup system. Here again, the reliability of power supply is an important question. Some users might be willing to put up with little or no electricity during occasional periods of low winds, making do with kerosene lamps and without radios or vacuum cleaners. Such a user would have to be ready for this, however. A heating system with an electronically controlled thermostat would be impractical if there were no backup available. Food stored in a refrigerator or freezer may spoil if the power goes off for long (an icebox might be substituted for a refrigerator). If your water supply depended upon an electric pump, you might have to install a large holding tank - and be able to keep the water in it from freezing without electricity. Is this worth it? The answer, again, may not be so much one of dollars and cents as on of the user's preferences.

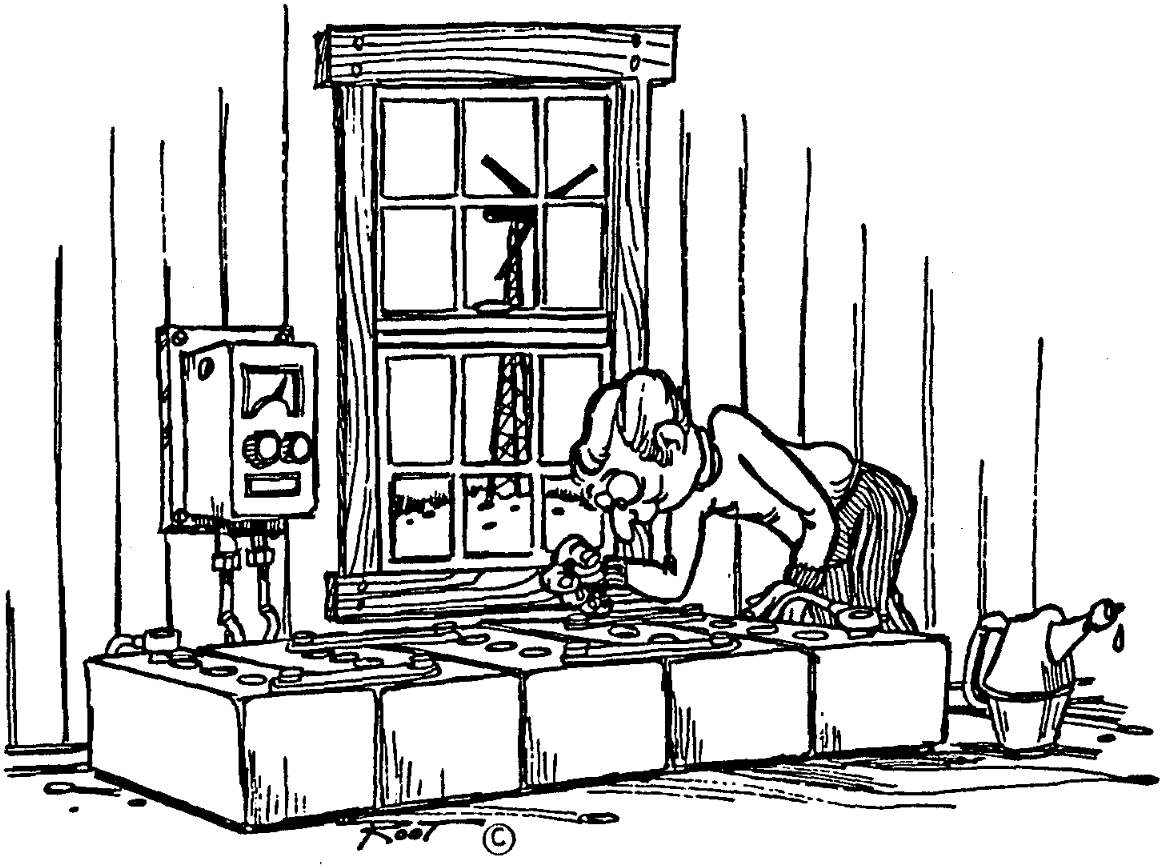
3:J:3 AESTHETICS

Some people simply like the idea of getting their electricity from the wind, and may be willing to pay a premium for it. They may like the fact that wind power is a clean, non-polluting source of power, or that it's a renewable energy source. They may like the fact that their use of wind power reduces dependence on oil in general and on OPEC supplies in particular (they may even consider it a more reliable energy source if they're araid of oil shortages). Others may simply prefer a wind system because they don't want to listen to the roar of diesel generators. Of course there are always those people wanting to be the first on the block with a new gadget.

A person with opinions such as these may choose to install a wind electric system even if it's not the least expensive alternative. It may cost more money, but who is to say that it's not worth it?

Another intangible value of a wind system - although perhaps not an aesthetic one - might be its use as an educational tool. A working system installed at a school could be a valuable aid in the teaching of physics, electronics, mechanics, and even economics. There is a value to this, to be sure, but just as with the other factors mentioned above, this value is not solely an economic one.

PART FOUR



WIND SYSTEM INSTALLATION AND MAINTENANCE

4:A Wind System Installation

The installation of a wind system requires abilities in several fields; structural work on foundations and towers, mechanical assembly of the **windgenerator** itself, and electricial wiring. This is not a good place for inexperienced people to experiment; the equipment is simply too expensive. This handbook makes no claim to be a detailed construction guide, and will not substitute for knowledge or experience, nor will it replace assembly procedures detailed by equipment manufacturers.

Wind system installation can, of course, be contracted out to professionals. Most **windgenerator** distributors can arrange these services. Most of the larger **windgenerator** manufacturers and distributors, in fact, will not guarantee their product unless they or their subcontractors install it themselves; others require that at least one of their representatives be present during installation. Warranty provisions such as this should be checked early in the planning process.

Many wind system owners will want to carry out at least part of the wind system installation themselves, particularly if theirs is a small system. Because of this, some of the more important points in this process are discussed here.

Before any construction begins, the requirements and procedures of the entire process should be understood. The installer should be sure that any required equipment will be available at the site (in one recent case, it was only after a medium-sized **windgenerator** was delivered to an Alaska Peninsula site that the installers learned that there was no crane within hundreds of miles to place it atop the tower). Similarly, the installer should make a complete inventory of system parts before taking them into the bush. If the installer is short the bolts to attach the **windgenerator** to the tower cap, he should know this before the **windgenerator** is 60 feet in the air and 300 miles from the nearest supplier. He should also check that the blades have been properly matched, by assembling them on the rotor hub and seeing if they will balance on the hub. All other equipment should also be tested as fully as possible before transporting it to a remote site.

4:A:1 FOUNDATIONS

Care should be taken to ensure a strong and stable foundation; the best tower and **windgenerator** in the world will be reduced to wreckage if placed on a poor foundation. Foundation designs will vary so much that only a few generalizations will be made here.

Compaction: Any fill or disturbed soil which is to support a load must be well compacted. This is virtually impossible with frozen soils. Soil settlement after construction is at best a serious problem; a tilted tower will result, which will cause unanticipated loads and vibrations which can destroy a wind system.

Concrete or piling placement: Concrete footings or pilings must be placed at sufficient depth; design specifications to prevent the jacking of foundations due to frost or their uplifting due to wind loads must be followed. Sufficient time must be given for the curing of concrete or the freezing of 'ad-freeze' piles in permafrost before loads are placed on them.

Anchor bolts: Anchor bolts or other devices to attach the tower to the foundation must be able to resist the stresses placed on them. Anchors must be firmly embedded in concrete or securely attached to piles.

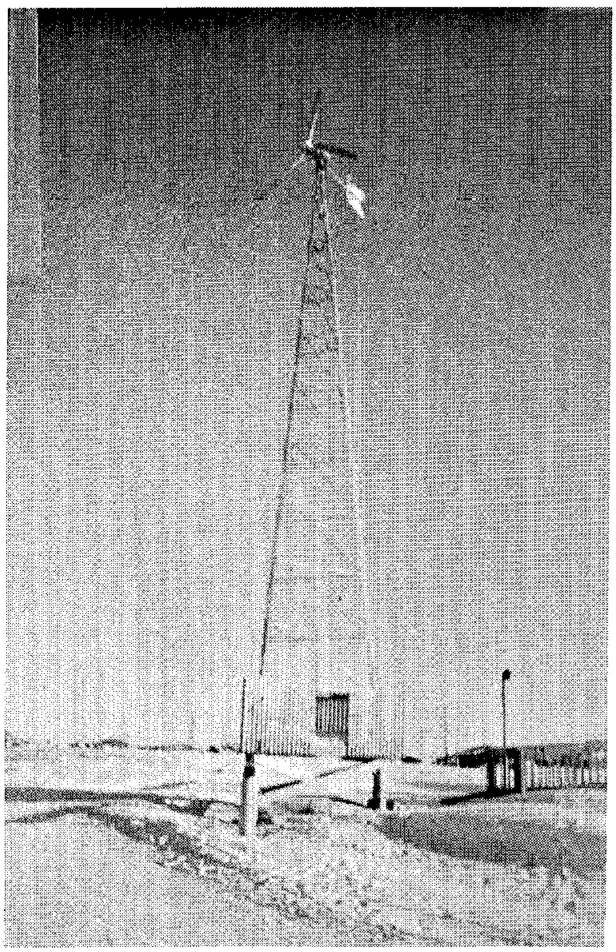


Fig.4-1: Wood piling foundation for self supporting tower in Kotzebue (Source: Newell)

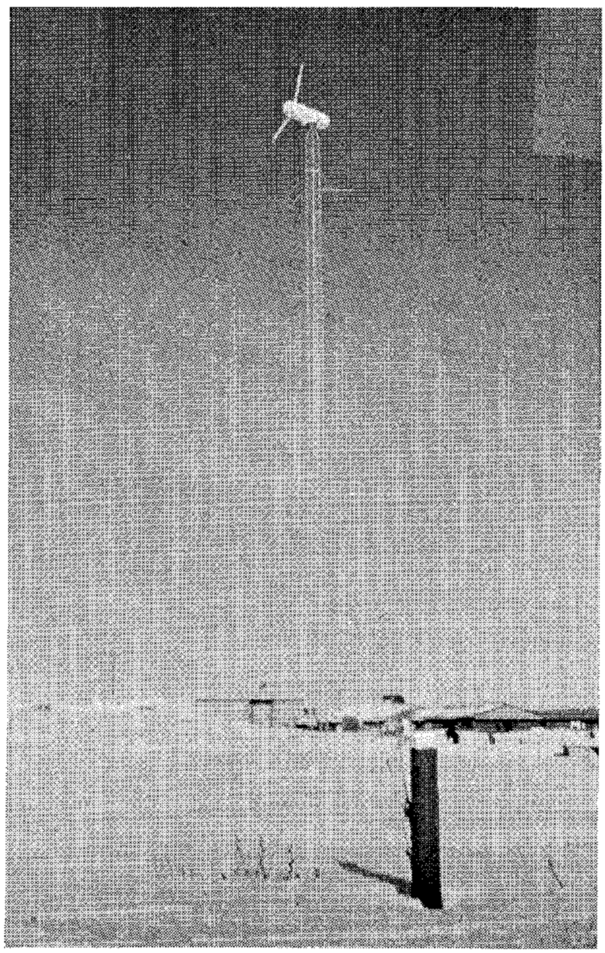


Fig.4-2: Steel piling anchor for guyed tower in Kotzebue (Source: Newell)

4:A:2 TOWERS

Towers should be installed as close to perfectly plumb as possible. All bolts should be securely tightened; all guy wires must be put under the proper tension. Once completed, all of these should be rechecked - vertical alignment, tightening of connections, and guy wire tension.

Attention to safety should be a primary concern with tower installation. No tower should be allowed to remain in an unstable state where it might fall over (e.g. without anchor bolts fastened or guy wires attached). Any time a person is working up on the tower, safety belts should be used, and hard hats worn by **everybody** down below.

Free standing towers are sometimes erected, piece by piece, from the ground up. Usually the first few sections - perhaps 10 or 20 feet - area assembled flat on the ground, then tilted up and checked for vertical alignment. The remaining sections are then bolted, one by one, atop this base. This method will work, but it is cumbersome and requires that a lot of work be done up on the tower. This is a slower and potentially more dangerous practice than assembly on the ground, but may be the only alternative in the bush area where no cranes are availble.

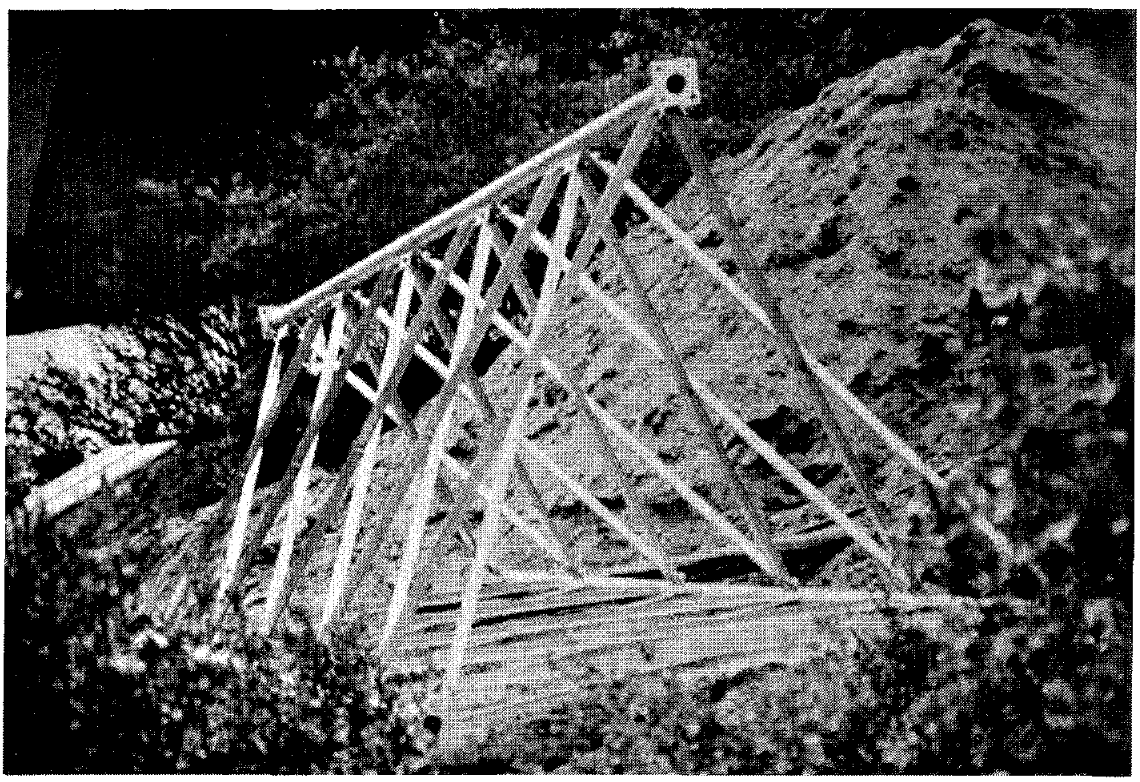


Fig.4-3: Self-support tower assembly (Source: 4 Winds of Alaska)

A more common method with free-standing towers, and one nearly always used with guyed towers, is to assemble the entire tower on the ground and raise it up as a unit, either with a crane or with a gin pole and winch. In some cases, some or all of the tower cap and **windgenerator** components is attached to the tower before raising it.

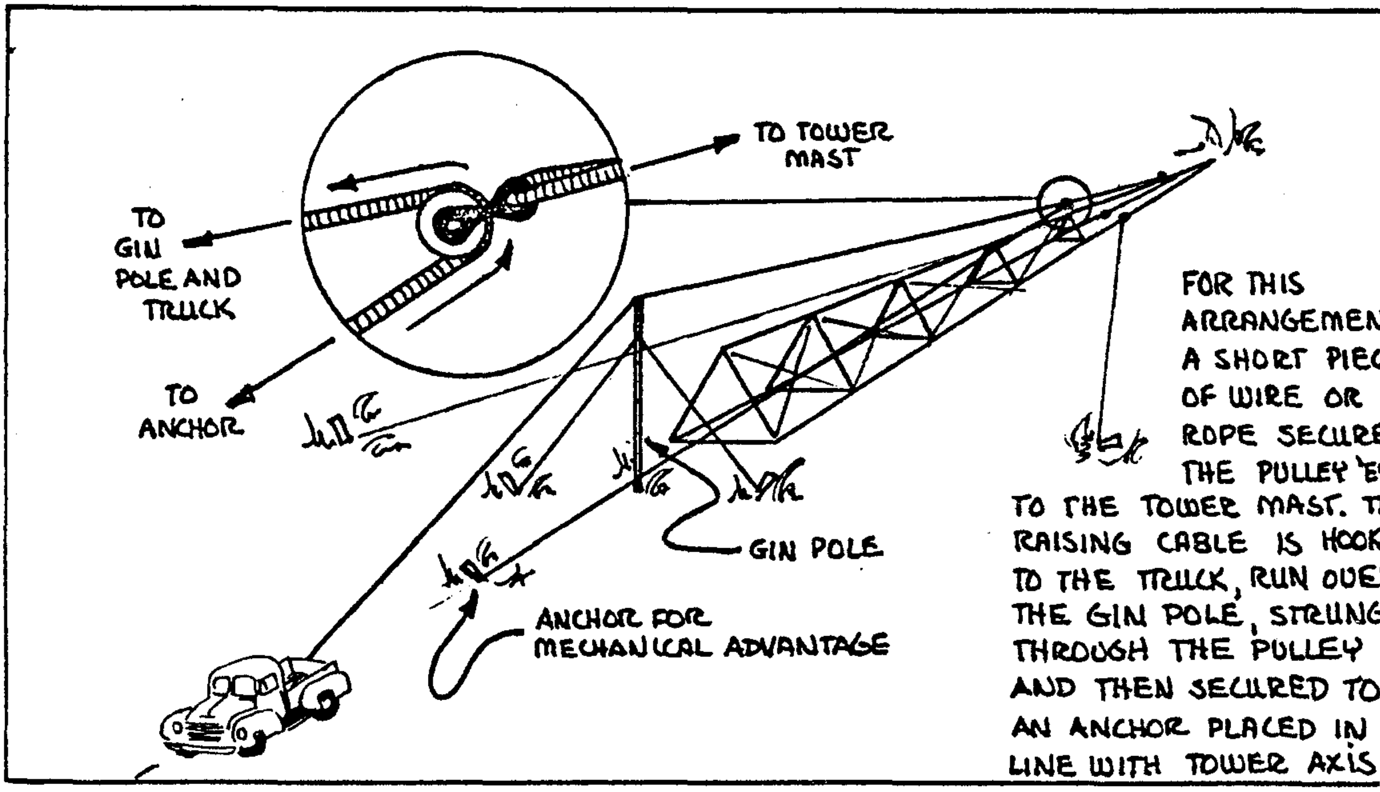


Fig.4-4: Gin pole method of tower erection (Source: Hackleman)

A pair of guys will be necessary on the gin pole to keep it from tipping over sideways during the operation. If the tower is a guyed pole, all of the guys should be attached to the tower before raising it. All of these tower guys should also be attached to their anchors, except for those on the gin pole side of the tower (these won't reach until the tower is raised). This will keep the tower from tipping over sideways during the tower raising, and will keep you from pulling the tower past vertical and over on top of yourself. Similar tower guys, of a temporary nature, are advisable even for free-standing towers; these can be removed once the tower is upright and bolted to its foundation.

The tower, during this erection procedure, will have bending stresses (due to its own weight being supported at each end, like a beam). It will also have axial (compressive) stresses due to the pull of the raising cable. This combination of bending and compressive stresses may cause buckling and collapse of the tower. These stresses can be reduced by using a larger gin pole and by leaving unnecessary weight (such as the **windgenerator**) off of the tower; both of these reduce the tension in the raising cable. If there is any doubt that the tower is capable of withstanding these stresses, a structural engineer or the tower manufacturer shoud be consulted.

Once in place, the tower should be adequately grounded for lightning protection.

4:A:3 WINDGENERATOR INSTALLATION

There are several methods of assembling the **windgenerator** and raising it on the tower; the manufacturer will specify the recommended procedure. In some cases (with small machines) the entire **windgenerator** can be assembled on the ground with the tower and raised with it. A related method is to raise the generator-gearbox-hub mechanism with the tower, and then hoist and attach the blades later.

More frequently, none of the **windgenerator** will be raised with the tower. Instead, the **windgenerator** is raised, in pieces or assembled, by a crane or by a temporary gin pole attached to the tower. Figure 4-5 & 4-6 illustrates this procedure.

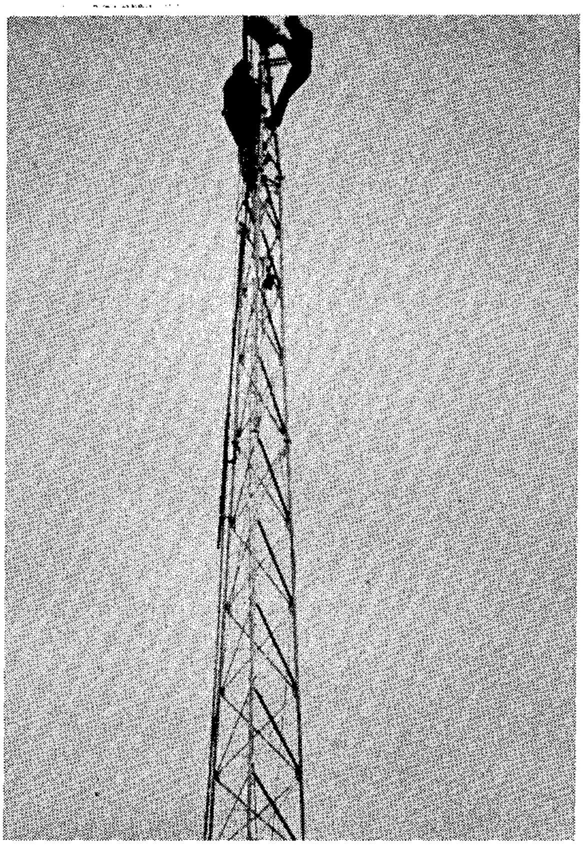


Fig. 4-5: Raising generator with gin pole.
(Source: 4 Winds of Alaska)

Fig. 4-6: Attaching generator to tower using gin pole.
(Source: 4 Winds of Alaska)

There will probably be several initial adjustments required for proper operation of the **windgenerator**; these will depend on the machine model. Among these will be adjusting the blades so that they lie in as nearly perfect a plane as possible. This reduces noise and vibration in the operating machine, and should be performed with care. Adjustment will probably also be required on springs, weights, cables, etc. to ensure that overspeed controls and manual and automatic brakes function properly. The angle of incidence of the blades may also need to be set. The **windgenerator** will need to be leveled on top of the tower; this is usually done with adjusting screws and locknuts.

Fig. 4-7: Installing blades on windgenerator. (Source: 4 Winds of Alaska)

There will also be a number of maintenance procedures which must be performed on installation (as well as periodically thereafter). These may include filling the gearbox with transmission oil, greasing fittings, and tightening of bolts to specified torque settings.

The operation of the **windgenerator** and the rotor should be checked, insofar as possible, upon installation. The rotor should be manually rotated to assure that it turns freely, and the machine should be pivoted in a complete circle to check that blades, brake mechanisms, etc. do not strike the tower in any position. Blade clearance of the tower should be sufficient to allow for the appreciable flexing of the blades in high winds; the manufacturer should specify this clearance. Except during these testing procedures, the wind generator should be left in a manually braked position until the complete system is installed and ready for testing.

4:A:4 CONTROLS AND WIRING

The nature of the control system and wiring will vary considerably between systems. As with the **windgenerator**, much of the installation procedure should be specified by the manufacturer, but unfortunately not always is. In addition, all applicable electrical codes should be observed, as well as standard practices for circuit breakers, wire gauges, etc. All system components should be adequately grounded, and care should be taken that the correct polarity is observed in all connections, especially with battery series-parallel combinations.

The wind system control panel (switchboard) should be mounted in an easily accessible spot. Batteries (if you have them) should also be accessible, so that their state of charge and electrolyte level can be checked. The battery storage area should be rechecked to make sure it has adequate ventilation and that no flames or sparks will be present (backup generators, for example, must be placed in another area). The use of hydro-caps is highly recommended.

There will probably be an anemometer and perhaps a wind vane as well to be mounted on the tower. These are generally mounted on a horizontal boom below the reach of the blades. This reduces the interference that the tower and the **windgenerator** blades have on the wind striking the instruments.

4:B Start Up

As with any machine, the wind electric system's operation should be carefully observed during its initial operation to make sure everything is working as it should. The **windgenerator** should be allowed to operate in relatively light winds for several hours, at least, before exposing it to high winds. If high winds come up during the initial test period, the machine can be braked and/or turned out of the wind, to only allow partial output and still have control of the unit if shut-down is necessary.

Some vibration in the operating machine is to be expected. The cause of any large vibrations, however, should be tracked down and corrected immediately, as they can cause metal fatigue, loosen bolts, and destroy bearings. The manual brake should be operated repeatedly to make sure its reliable; overspeed controls and automatic braking should also be observed to see if they cut in at the correct windspeed. If necessary, these should be adjusted, and the machine re-tested.

The operation of all electrical components should be checked. Of particular importance here are **windgenerator** output and voltage regulation. Check the current output of the **windgenerator** at various windspeeds to ensure conformity to manufacturers specifications. See that the voltage regulator is unloading the machine when the batteries are fully charged, or switching the current to a power dump if one is installed. A great deal of time can be spent at the job site during start-up because of fine tuning the machine. In most cases there will be inadequate wind to test the machine immediately, since installation usually is scheduled for calm days.

4:C Routine Maintenance

Wind-electric systems need little routine maintenance compared to diesel-electric systems; this is not to say that this maintenance is unimportant, however. Equipment manufacturers will usually specify the maintenance requirements, and this section only summarizes generalized procedures.

The wind turbine-generator itself requires less attention than some other system components. Many have bearings which require greasing occasionally (twice a year is a common recommendation). On some models sealed, service-free bearings are used, and this is not required. **Windgenerators** with gearboxes need to have gearbox transmission oil checked and/or changed from time to time. The recommended interval for this is often one or two years. In most of Alaska, however (and certainly at all sites north of the Alaska Range) gearbox oil should probably be changed twice a year, with a heavier oil used for the summer months and a lighter one used in winter. Some manufacturers claim that with the use of synthetic oils, gearbox oil needs to be changed only once every five years, regardless of weather. Even so, the oil level should be checked whenever one climbs the tower for other maintenance duties.

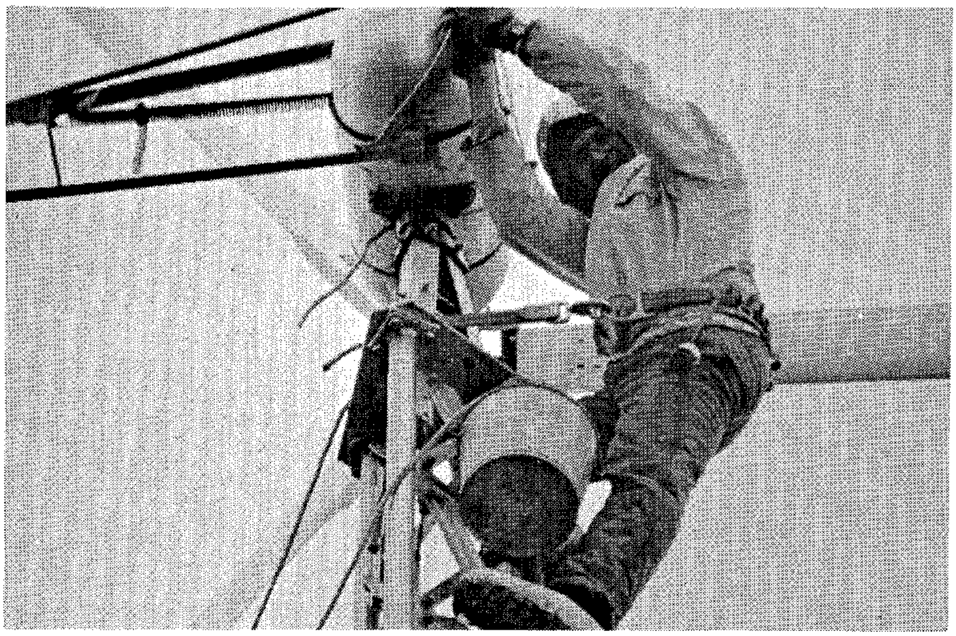


Fig. 4-8: One of the authors securely attached with a safety belt. (Source: Newell)

Another check to be made whenever the tower is climbed, and preferably at least twice a year, is to check bolts for tightness, particularly the connections of the blades to the hub and of the wind machine base to the tower cap. It is advisable to check these more frequently during the first year of operation, and any time that excessive vibrations develop for any reason. Wind machines have been lost when bolts worked loose and the entire machine was lifted off the tower by the wind.

Other than this, the only routine maintenance to be expected on the windgenerator will probably be to clean up the contacts on any slip rings (commutators) by buffing them with a piece of commutator paper and cleaning them with an alcohol base cleaner. This duty, under normal circumstances, is rarely needed. Of course, any time abnormal behavior is noticed - be it excessive vibration, abnormal output levels, or failure of overspeed controls or automatic brakes - the machine should be stopped and repairs made immediately.

Bolts on the tower itself should be checked for proper torque occasionally, although this is rarely a problem. More importantly, the tower should be checked to assure proper tension. This is particularly important if soil conditions are poor. Problems are most likely to occur during early winter, when frost heaving may happen, and at breakup, when thawing soils are in a weak state and may settle.

Batteries in a wind system require maintenance similar to that for automobile batteries, i.e. periodic checking of the electrolyte level and adding of distilled water, if necessary. Hydro caps, a device which catalyzes the oxygen and hydrogen back to water will minimize any water needed after the first month of operation. In addition, it is advisable to equalize the charge of the batteries periodically (perhaps every other month). This corrects imbalances in the charge level of different cells which can develop over time, a situation which leads to overuse of, and shorter life for, the more highly charged cells. This maintenance consists merely of applying a charging voltage for long enough that all cells are fully (and thus equally) charged. This can be done with a backup generator, with utility power and a battery charger, or with the wind generator itself during long windy periods.

4:D Common Types of Breakdowns

Perhaps the most common form of breakdown in wind systems is the loss of blades or the failure of bearings due to an imbalance in the blades. This emphasizes the importance of correct balancing and installation of blades in the first place. Icing can also cause harmful blade imbalance. During normal operation, icing does not seem to be a great problem, because the blades flex enough to shed ice. If a machine has been stopped for a time, however, and a heavy ice build-up occurs, it is advisable to clear the blades of ice before start-up.

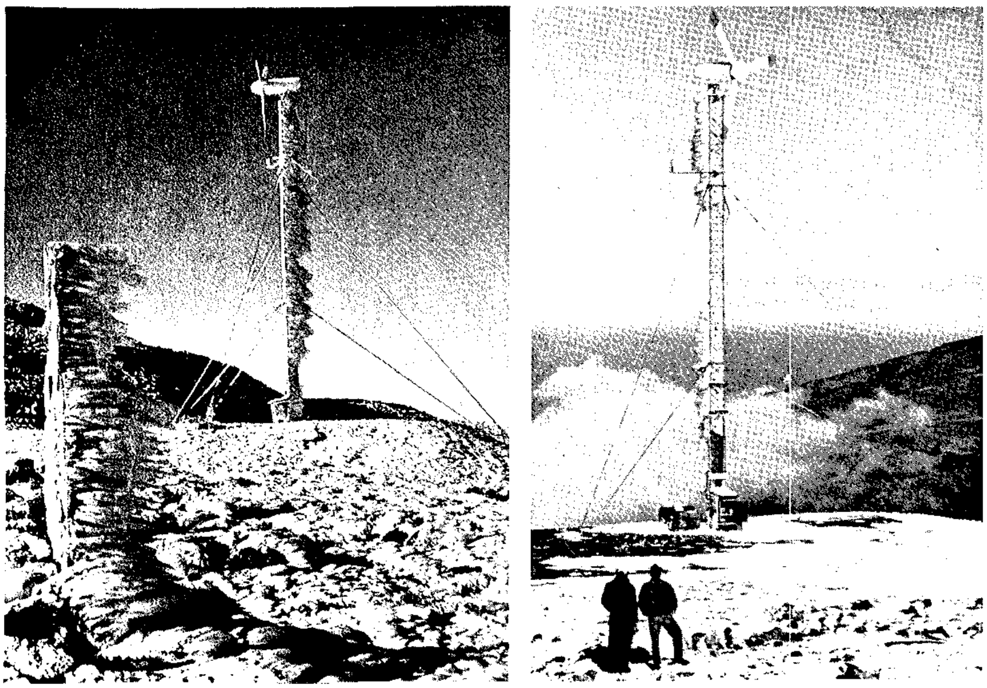


Fig. 4-9: Rime ice build-up on windgenerator and subsequent shedding. (Source: Enertech)

Another cause of lost blades is high gusts of wind, which can snap blades off at their roots. This problem will obviously be reduced by avoiding turbulent wind sites. Another means of protection is to avoid using blades made of materials subject to metal fatigue, and materials which become brittle in very cold temperatures. Brass and aluminum are better in this respect than steel; some of the fiber-reinforced plastics may perform well. Of all wind turbine blade materials, wood (usually Sitka spruce) has the longest record of success.

Overspeed controls and automatic brakes should protect the blades and bearings during periods of steady high winds. It is possible, however, that mechanical controls will ice up enough, or their lubricants to become sufficiently stiff at low temperatures, that they will not operate properly. **Windgenerators** with exposed springs, cables, etc. are obviously more vulnerable to these icing problems than others. Electronic overspeed controls and brakes can also fail, leading to overspeeding and loss of blades or bearings. On some models these controls are designed to be (fail-safe); this is a worthwhile feature to look for. On these models, the 'normal' position is to have the brake on; they are released only at operating wind speeds. In this way, should a failure occur, the wind generator will be braked, and not allowed to spin uncontrollably. Periodic checking of control operation, especially if a period of high winds is expected, will reduce the chances of machine damage due to these causes.

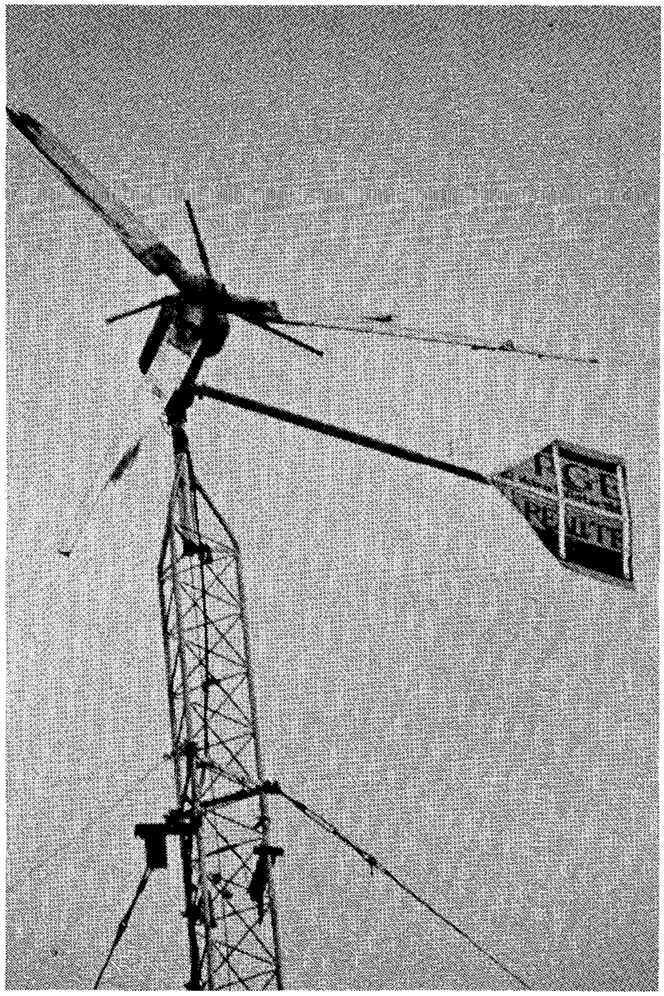


Fig. 4-10: Redwood blades (not Sitka spruce) on a foreign make machine (Source: Newell)

Bolts or guy wires which are allowed to come loose can also cause machine failures. **Windgenerators** have been known to come off the tower entirely when bolts came loose; blades have been thrown when connections to the rotor hub have worked loose. Loose guy wires, which allows excessive sway of the tower, can also be dangerous. With proper preventive maintenance, these accidents should not occur.

Moisture working its way through seals is a potential problem; the same is true of salt at a shore location. Salty air can also corrode some kinds of blades; some manufacturers sell special blades for use in oceanfront sites. Electronic equipment can also fail. Most equipment on modern machines is solid state, and problems will normally show up almost immediately, if at all.

The problem stems from vibrations encountered during transportation to the site, or poor quality control of the manufacturer.

There are two basic things that a potential wind electric system owner can do to minimize the potential for a wind system failure. The first of these is to minimize vibrations in the machines; this involves avoiding turbulent wind sites, using a strong tower on a stable foundation, and careful installation of blades, which can't be emphasized enough.

The other is to choose a reliable machine from a responsible distributor. In the wake of expanded interest in wind energy, some **windgenerator** models have been put on the market with little testing. This doesn't necessarily mean that these models shouldn't be used, if the machine has a good warranty and the distributor can be trusted to quickly repair or replace failed equipment. One manufacturer, informed of a brake failure on a relatively new model installed in Kotzebue, not only quickly repaired the Kotzebue machine, but also refitted every machine of that model which had been sold to avoid reoccurrence of the problem. Such service is good for both the buyers of wind machines and, in the long run, for the wind system manufacturing industry in general. On the other hand, there are companies selling wind machines who are located far from Alaska and/or on a weak financial base from whom service is not reliable.

Another key factor for a successful **windgenerator** operation here in the harsh Alaskan environment is a good preventative maintenance program set up and followed by the owner-operator.

4:E Skills Required

4:E:1 ARCTIC SURVIVAL AND SAFETY

Following is a list of skills needed to become a competent dealer/installer of wind systems. While not intended to be all inclusive it does give you and idea of what's involved and what services or skills you may need to hire out.

Because of Alaska's extreme cold, tremendous stresses are placed on stationary and rotating devices. **Windgenerators** are thus subject to their greatest problems during the winter months. The majority of all failures will occur at this time of year. Therefore the individual must have training in cold weather first-aid. This includes knowledge of how to prepare himself to work in the extreme cold both mentally and physically. The ability to recognize the symptoms that lead to frost bite, hypothermia, and dehydration are imperative.

Climbing a tower in winter can be especially dangerous when the steps are icy. Proper safety gear is imperative and knowledge of its use and function are very important.

In addition, hard hats and protective clothing and equipment are needed for working around towers and high voltages.

4:E:2 BLUE PRINT READING

A **windgenerator** installer, if it be the dealer or the owner installing the unit, must have the competence to evaluate blue prints from all the related components to make a complete system. Many times discrepancies appear on both the mechanical and electrical blue prints. Also many as-built electrical blue prints may or may not be submitted with the actual hardware. In the bush, installations require many on the spot decisions because the recommended materials were not furnished or are unavailable. Thus logistics require the individual to read and understand blueprints to make intelligent decisions in regards to his system.

4:E:3 ELECTRICIAN

This is one of the more important skills necessary of the dealer-installer. In large urban areas the dealer-installer may sub-contract the electrical portion when installing the larger utility-intertie units - but in the remote bush applications he may not have this alternative. Wiring circuitry starts from the wind-turbine to the control box - to the batteries - to the inverter then to the home circuit breaker panel. In many cases he will be required to inter-connect for stand-by purposes the existing diesel generator for back-up use. He will be required to understand electrical drawings, trouble shoot problems both in the home and **windgenerator** system using a volt/ohm meter.

A background in D.C. automotive electricity and home A.C. wiring is an excellent start.

4:E:4 HEAVY EQUIPMENT OPERATOR

The size of the **windgenerator** to be installed, the type of sub-soil and presence of perma-frost - dictates the amount of large equipment which will either be rented or sub-contracted to do a phase of the project. Examples are lift cranes, back hoes, piling drivers and trench diggers. These are not skills required of the owner to maintain or operate his **windgenerator**, yet are essential to a good installation.

4:E:5 MASONRY

Below the Arctic Circle concrete foundations are possible to install. Again logistics play a big factor to the amount of excavating equipment available on the site, or that which can be brought in. Many of the foundations in the out reach areas may be excavated manually and the concrete mixed in any large available container. The knowledges relating to cement to aggregate rations, footing framing, transit operation, concrete finishing, and concrete estimating are essential.

4:E:6 MECHANIC/MACHINIST

These areas span a breadth of skills required to install and operate a **windgenerator**. The most rudimentary is the use of a grease gun and tightening bolts. However, a knowledge of fasteners, fittings, lubes and lubricants for the Arctic are important to the owner and installer alike. Additionally the dealer/installer should be skilled in: tapping and threading; gear ratios; bearings and seals; governor principles for speed regulation; torque and speed concepts; and properties of metals and their limitations.

4:E:7 WELDING

Due to manufacturer quality control errors, freight damages, freight losses, fatigue and stress problems in metal and because of the logistical cost to return items to the manufacturer welding skills are essential. The dealer-installer should have the ability to use an ox-acetylene torch and stick welding of ferrous metal. An understanding of galvanized iron, its preparation for welding and then after welding - cold galvanizing principles are equally important for tower installation. If the owner/operator is going to fix any damaged **windgenerator** or tower parts he should be adept at welding skills.

APPENDIX A

WIND ENERGY CONVERSION SYSTEMS

IN ALASKA BY REGION

WIND ENERGY CONVERSION SYSTEMS IN ALASKA BY REGION*

Legend

△ Installed and operating (year installed)

◭ Installed but not yet operational (year installed)

▲ Presently not in use (year installed)

☐ System planned and/or purchased (year-to-be installed)

NORTHERN (ARTIC) REGION

(1) ◭ Barrow, 2.2kw Enertech, Utility Intertie (1980)

(2) ◭ Barrow, 1.8kw Enertech, Utility Intertie (1980)

(3) ☐ Point Lay, 4kw Enertech, Utility Intertie (1981)

NORTHWESTERN REGION

(4) △ Ambler, 3kw Jacobs, Battery Charger (1979)

(5) △ Council, 1kw Aeropower, Battery Charger (1978)

(6) △ Elim, 2 kw Aeropower, Battery Charger (1980)

(7) ◭ Gambell, Four-4kw Independent Energy Systems, Utility Intertie/Dc water heating (1979)

(8) ☐ Gambell, 2kw Battery Charger (1981)

(9) △ Kobuk, 200 watt Wincharger, Battery Charger (1980)

(10) △ Kotzebue, 2kw Dunlite, Utility Intertie (1979)

(11) △ Kotzebue, 2.2kw Enertech, Utility Intertie (1980)

(12) ☐ Nome, 2kw Aeropower, Battery Charger (1981)

(13) ☐ Nome, 2kw Aeropower, Battery Charger (1981)

(14) ▲ Nome, 1kw Whirlwind, Battery Charger (1978)

(15) ▲ Nome, 500 watt Wincharger, Battery Charger (1940's)

(16) ☐ Nome, 1.5kw Aeropower, Utility Intertie (1981)

(17) △ Selawik, 2.2kw Enertech, Utility Intertie (1980)

(18) ☐ Unalakleet, Two 10-20kw, Utility Intertie (1981)

SOUTHCENTRAL REGION

(30) △ Anchorage, 18kw Jacobs, Battery Charger (1979)

(31) □ Homer, 18kw Stormmaster, Utility Intertie (1981)

(32) ▲ Homer, 11kw Locally Built, Utility Intertie (1980)

(33) △ Homer, 500 watt Paris-Dunn, Battery Charger (1978)

(34) □ Homer, 3kw Jacobs, Battery Charger (1981)

(35) △ Kasilof, 1kw Sencenbaugh, Battery Charger (1978)

(36) □ Mat-Su Valley, 2kw Aeropower, Battery Charger (1981)

(37) △ Palmer, 2kw Aeropower, Battery Charger (1979)

(38) △ Palmer, 1.5kw Aeropower, Utility Intertie (1980)

(39) □ Palmer, 10kw Jacobs, Utility Intertie (1981)

(40) □ Palmer, 4kw Enertech, Utility Intertie (1981)

(41) △ Portage, 24 watt Aerowatt, Battery Charge (1977)

(42) △ Seward, 200 watt Winco, Battery Charger (1980)

WESTERN REGION

(19) □ Alakanuk, Northern Technologies Grant (1981)

(20) △ Bethel, 2kw Dunlite, Battery Charger (1979)

(21) □ Bethel, 2.2kw Enertech, Utility Intertie (1981)

(22) □ Chevak, 2.2kw Enertech, Utility Intertie (1981)

(23) □ Hooper Bay, 8kw Jacobs, Intertie (1981)

(24) ▲ Kako, 1kw Wincharger, Battery Charger (1939)

(25) □ Kwigillingok, Battery Charger (1981-82)

(26) □ Pilot Station, 10kw Battery Charger (1981)

(27) □ Platinum, unknown (1981-82)

(28) △ Sheldon Point, 2kw Aeropower, Battery Charger (1981)

(29) □ Sheldon Point, Seven 2kw Aeropower's, Battery Charger (1981)

SOUTHWESTERN REGION

(43) □ Atognak Island, 2kw Aeropower, Battery Charger (1981)

(44) □ Chignik, 2kw Aeropower, Battery Charger (1981)

(45) □ Dillingham, 10kw Jacobs, Utility INtertie (1981)

(46) ◭ Dillingham, 4kw Aerowatt, Battery Charger (1975)

(47) △ Dillingham, 200 watt Wincharger, Battery Charger (1960's)

(48) △ False Pass, 2kw Dunlite, Battery Charger (1977)

(49) ◭ Fox Bay, 1.8kw Jacobs, Battery Charger (1978)

(50) △ Illiamna, 4kw Dakota, Battery Charger (1979)

(51) ◭ Illiamna, 4kw Dakota, Battery Charger (1979)

(52) △ King Salmon, 300 watt Aerowatt, Battery Charger (1975)

(53) △ King Salmon, 2.2kw Enertech, Utility Intertie (1979)

(54) △ Kodiak, 2kw Aeropower, Battery Charger (1980)

(55) □ Kodiak, 1kw Aeropower, Battery Charger (1981)

(56) □ Kodiak, 10kw Jacobs, Utility Intertie (1981)

(57) △ Lake Clark, 3kw Jacobs, Battery Charger (1977)

(58) □ Lake Clark, 4kw Dakota, Battery Charger (1981)

(59) ◭ Nikolski, 2kw Aeropower, DC motor, lights & heat (1980)

(60) △ Naknek, 2.2kw Enertech, Utility Intertie (1980)

(61) □ Naknek, 3kw Battery Charger (1981)

(62) ▲ Nelson Lagoon, 20kw Gramman, Utility Intertie (1977)

(63) □ Nelson Lagoon, 15kw Gramman, Utility Intertie (1981)

(64) ◭ Newhallen, 8kw Stormmaster, Battery Charger (1980)

(65) △ Port Alsworth, 2kw Jacobs, Battery Charger (1978)

(66) □ Port Heiden, 2kw Aeropower, Battery Charger (1981)

(67) ◭ Togiak, 2kw Aeropower, Battery Charger (1980)

(68) □ Unalaska, Three 4kw Battery Chargers (1981)

(69) △ Unalaska, 200 watt Wincharger, Battery Charger (1977)

SOUTHEASTERN REGION

(70) △ Haines, 2.2kw Enertech, Utility Intertie (1980)

(71) △ Haines, 10kw Electro, Battery Charger (1979)

(72) △ Ketchikan, 1.8kw Jacobs, Battery Charger (1976)
4kw Dakota, Battery Charger (1979)

(73) □ Skagway, Utility Intertie (1981)

INTERIOR REGION

(74) △ Cantrell, 4kw Dakota Wind & Sun, Battery Charger (1979)

(75) □ Clear, 7kw Battery Charger (1981-1982)

(76) ▲ Delta Junction, 6kw Electro, Utility Intertie (1977)

(77) △ Gakona, 1kw Aeropower, Battery Charger (1978)

(78) △ Livengood, 200 watt Winco, Battery Charger (1979)

(79) □ Slana, 3kw Dakota, Battery Charger (1981)

(80) □ Shaw Creek, 3-5kw Battery Chargers (1981-82)

(81) △ Sherman, 200 watt Winco, Battery Charger (1979)

(82) △ Tok Cut-off, 200 watt Winco, Battery Charger (1980)

* An incomplete compilation done by Wind Systems Engineering in March of 1981.

APPENDIX B

ENERGY LOAD CALCULATIONS

Source: State Division of Energy and Power Development

ENERGY LOAD CALCULATION

✓	Appliance and Typical wattage	Average Use	Average Monthly Kilowatt-Hour Use		Your Average Cost per Kilowatt-Hour		Estimated Monthly Cost
___	baby food warmer 165 watts	3 times per day	3 kwh	x	________	=	________
___	blanket 150 watts	every night	19 kwh	x	________	=	________
___	blender 385 watts	6 times per week	1 kwh	x	________	=	________
___	broiler (portable) 1140 watts	twice a week	7 kwh	x	________	=	________
___	can opener 100 watts	3 uses per day	03 kwh	x	________	=	________
___	carving knife 95 watts	twice a week	1 kwh	x	________	=	________
___	clock 2.5 watts	every day	2 kwh	x	________	=	________
___	clothes dryer 4900 watts	6 loads per week	83 kwh	x	________	=	________
___ ___	clothes washer (automatic) 512 watts	6 loads per week	9 kwh	x	________	=	________

___	coffee maker 600 watts	once a day	5 kwh	x	______	=	______
___	corn popper 575 watts	2 uses per week	1 kwh	x	______	=	______
___	curling iron 40 watts	once a day	.3 kwh	x	______	=	______
___	deep fat fryer* 1200 watts	3 times a month	2 kwh	x	______	=	______
___	dishwasher 1200 watts	25 loads per month	30 kwh	x	______	=	______
___	disposer 445 watts	every day	3 kwh	x	______	=	______
___	electric heating**						
___	egg cooker 550 watts	5 times per week	1 kwh	x	______	=	______
	Fans						
___	window 200 watts	2 hours every day	14 kwh	x	______	=	______
___	furnace or central air 270 watts	7 hours every day	59 kwh	x	______	=	______
___	floor polisher 305 watts	4 hours per month	1 kwh	x	______	=	______
___	fondue/chafing dish* 800 watts	once a month	.4 kwh	x	______	=	______
	Freezers (15 cu. ft.)						
___	manual defrost 341 watts	every day	100 kwh	x	______	=	______
___	frost-free 440 watts	every day	147 kwh	x	______	=	______
___	fry pan* 1200 watts	15 uses	9 kwh	x	______	=	______
___	griddle* 1200 watts	twice a week	4 kwh	x	______	=	______
	Hair dryers						
___	soft bonnet 400 watts	twice a week	2 kwh	x	______	=	______
___	hard bonnet 900 watts	twice a week	4 kwh	x	______	=	______
___	hand held 600 watts	5 times per week	.2 kwh	x	______	=	______
___	hair setter/curler 350 watts	3 times per week	1 kwh	x	______	=	______
___	heating pad* 60 watts	5 times per month	.3 kwh	x	______	=	______
___	humidifier 177 watts	every day	14 kwh	x	______	=	______
___	ice cream freezer 130 watts	once per month	.1 kwh	x	______	=	______
___	ice crusher 100 watts	twice a week	.04 kwh	x	______	=	______
___	iron* 1100 watts	2 hours per week	5 kwh	x	______	=	______
___	juicer 90 watts	once a day	.05 kwh	x	______	=	______
___	knife sharpener 40 watts	once a week	.01 kwh	x	______	=	______
___	lighting		108 kwh	x	______	=	______
___	make-up mirror 20 watts	once a day	.1 kwh	x	______	=	______
___	microwave oven 1450 watts	20 minutes per day	16 kwh	x	______	=	______

	Mixers						
	hand 80 watts	3 times	.1 kwh	x		=	
	stand 150 watts	twice a week	.2 kwh	x		=	
	radio 25 watts	2 hours every day	2 kwh	x		=	
	range 12,200 watts	for a family of 3	100 kwh	x		=	
	self-cleaning process*	twice a month	9 kwh	x		=	
	roaster* 1425 watts	once a month	5 kwh	x		=	
	refrigerator (12 cu. ft.)						
	manual defrost 241 watts	every day	61 kwh	x		=	
	frost-free 321 watts	every day	101 kwh	x		=	
	refrigerator/freezer (14 cu. ft.)						
	manual defrost 326 watts	every day	95 kwh	x		=	
	frost-free 615 watts	every day	152 kwh	x		=	
	sewing machine 75 watts	4 hours per week	1 kwh	x		=	
	shaver 15 watts	once a day	05 kwh	x		=	
	shaving cream dispenser 60 watts	every day	.03 kwh	x		=	
	slow cooker 200 watts	twice a month	3 kwh	x		=	
	stereo/hi-fi 109 watts	2 hours per day	9 kwh	x		=	
	sun lamp 290 watts	10 minutes	1 kwh	x		=	
	Televisions						
	black & white tube type 160 watts	6 hours every day	29 kwh	x		=	
	black & white solid state 55 watts	6 hours every day	10 kwh	x		=	
	color, tube-type 300 watts	6 hours every day	55 kwh	x		=	
	color, solid state 200 watts	6 hours every day	37 kwh	x		=	
	toaster 1400 watts	twice a day	4 kwh	x		=	
	toothbrush 1.1 watts	every day	1 kwh	x		=	
	trash compacter 400 watts	1/2 hour every day	4 kwh	x		=	
	vacuum cleaner 650	10 minutes every day	4 kwh	x		=	
	waffle iron* 1200 watts	once a week	2 kwh	x		=	
	warming tray 140 watts	twice per month	1 kwh	x		=	
	Water heaters						
	general use	350 gallons per person for a family of 4	350 kwh	x		=	
	for clothes washer	6 loads per week	108 kwh	x		=	

____	water pump 1000 watts	1/2 hour every day	15 kwh	x ________	=__________
____	workshop and hobby equipment	________________	__________	x=__________	

* Thermostatically controlled. Cost based on appliance estimated "On" time.

* Electric heating costs vary with each home. Many items affect an accurate estimate: size of home, type of system, amount of nsulation, number of doors, windows, etc. KWH usage in northern Alaska would be higher. Usage in southern portions of laska would be lower.

APPENDIX C

GLOSSARY OF TERMS

A glossary of terms and a discussion of wind technology basics are included to help the reader evaluate the machines.

Terms which are used to describe systems that extract energy from the wind can, if not properly defined, adversely influence communications both within the wind energy industry and between the wind energy industry and the public.

Two acronyms are in widespread use within the field of wind energy utilization. These are Wind Energy Conversion Systems (WECS) and Wind Turbine Generators (WTGs).

The terms used in this guide to describe wind systems have been divided into three categories. The **Physical Characteristics** describe the type of system, rotor size, materials, and weights. The **Operational Characteristics** describe the WECS' operating range, type of generator or alternator, and control system. The **Performance Characteristics** describe the maximum and rated power, and power production vs. wind speed.

What follows is a list of the terms that have been used in assessing the wind energy conversion systems, together with their definitions and a brief dicussion of their significance.

PHYSICAL CHARACTERISTICS

Generic Description:

Definition

This describes the general type of system including type of extracter, such as propeller, Savonious, Darrieus, multi-rotor, contra-rotating rotor, diffuser augumented, vortex augmented, tip-vane augmented, or concentrator. Axis of rotation (horizontal or vertical) is also given.

Significance

Each type of WECS has individual operating characteristics which are dependent on its design. Each type has limitations on efficiency, speed of rotation, and type of applications to which it is best suited.

Capture Area:

Definition

The capture area is defined as πR^2, where R is the maximum blade radius for a WECS whose frontal silhouette is a circle. This would be the height times the width for a wind turbine whose frontal silhouette is a rectangle.

Significance

The capture area is one of the major limit factors in determining the amount of power t will be produced by a WECS. Other fact include wind speed, generator capacity, a structural characteristics. A WECS can extr energy only from wind it is exposed to, both terms of area and speed. It should be noted t various designs augment this effective captu area through the use of concentrators, diffuse or multiple sets of propellers. This term may ha to be further defined as more radical concepts energy extraction are developed, but captu area will remain one of the major limiting fact to wind energy extraction.

Rotor Diameter:

Definition

The effective rotor diameter of a propeller-ty wind turbine is determined by measuring from t center of rotation to the tip of a blade a multiplying by two.

Significance

This is a derivative of capture area, and is a te commonly used in describing a horizontal a WECS which uses propeller-type blades.

Blade Quantity:

Definition

Total number of rotor blades, of each type, whi are used on a wind machine to extract ener from the wind.

Significance

The number of blades relates to the solidity o given design. (Solidity is defined as the ratio blade surface area to total swept area.) A WE with a high solidity ratio, near 100%, generally h a lower rotational speed than a low solidity ro of the same diameter.

Blade Materials:

Definition

The blade materials include the skin or surfa the core or body of the blade, and the spar structural element. This will vary with the type blade construction.

Significance

The importance of blade materials will vary w type of climate and application for which WECS is intended. Materials descriptions can used to determine blade life, durability, a maintenance requirements.

aw Control:

Definition

Yaw control is the means by which the orientation of a horizontal axis WECS is controlled in response to changes in wind direction. A WECS may be free to yaw, damped in yaw, or motor driven in yaw.

Significance

For horizontal axis WECS, the rate of yaw adjustment is important to their performance. The wind is constantly changing in direction even though it may be from a predominant direction. This will affect power production, but more importantly, it will affect the loads experienced by the rotor due to gyroscopic forces. It should be noted that some horizontal axis and vertical axis WTG's do not need yaw control.

enerator/Alternator:

Definition-Description

The description of the generator of alternator includes the type of power generator (AC or DC), continuous rated capacity in volts and amps., and a brief description of the source of the field excitation.

Significance

For a WECS that is used to generate electricity, its generator determines the performance and suitability for a particular application. If the model number is known, performance curves (power vs. rpm, torque vs. rpm, and efficiency vs. rpm) can be obtained from the manufacturer. The nominal and rated voltage and amperage will limit both the power that can be extracted and the types of applications for which a given wind system is suited.

ltage Regulation:

Definition

Voltage regulation is the method, either by electrical, mechanical, or electronic means, that is used to maintain the system output voltage within desired limits.

Significance

There are a number of applicants, battery charging for example, which require voltage control within fairly narrow limits. Other applications, such as line-commutated inverters or resistance heaters do not necessarily require voltage control.

chanical Power Transmission:

Definition/Description

With some WECS a speed changer is needed to match rotor rpm with the rpm requirements of the generator or other device. Its speed ratio and type is specified. Common types include gear, belt, and hydraulic. Other methods of mechanical power transmission are indicated where appropriate.

Significance

The power transmission affects system life, overall efficiency, and maintenance. Again, specific types of power transmission offer unique characteristics that may make it best suited for a given application.

PERFORMANCE CHARACTERISTICS

Rated Power @ Wind Speed:

Definition

This term is the rated power which the wind machine produces and the lowest wind speed at which it occurs. Measured at the output terminals of the generator or the slip rings, this excludes internal power requirements, e.g., the field excitation power.

Significance

This term is useful in assessing the energy production of a given WECS at a specific site. In general, the lower the rated wind speed, the larger the energy production for an equal rated power.

Maximum Power @ Wind Speed:

Definition

The maximum power a WECS will produce and the wind speed at which it occurs.

Significance

Some WECS have the capability to produce greater amounts of power than the rated value defined above. In some cases these peaks can be maintained for only short periods of time, but in others they can be maintained indefinitely.

Power Curves:

Definition

These are graphs of WECS performance, with watts or kilowatts (or other system output) plotted against wind speed. An indication is given if they are produced by calculation or by testing. If calculated, the assumed rotor efficiency (Cp) is given.

Significance

These curves are important in that they include all of the subsystem inefficiencies, that is, rotor performance, mechanical power transmission, and generator losses. These curves give a broadly stated indication of how a WECS would perform at a given site. Although the power in the wind increases with the cube of the velocity, generally

System Weight:

Definition

The weight includes all the components of the wind energy conversion system. This includes everything above the top of the tower, and in some cases, components that are part of the tower.

Significance

This weight will have to be raised to the top of the tower and represents a portion of the static load the tower will experience. In addition, the lower limit of the cost of machinery can be estimated on a price per pound of material basis.

Rotor Weight:

Definition

The rotor is defined as being the blades (or extractor) and the hub to which it is attached.

Significance

The weight of the rotor induces additional structural loads on the tower arising from gyroscopic and centrifugal forces. In many cases, the rotor may be hoisted to the top of the tower separately from the rest of the wind machine.

OPERATIONAL CHARACTERISTICS

Cut-In Wind Speed:

Definition

The cut-in wind speed is that speed at which the wind machine begins to produce useable output. (This is not the start-up wind speed, which is the speed required to begin rotation of the blades.)

Significance

In determining the amount of energy a WECS will produce at a specific site, cut-in speed must be known. All winds below that speed are not used in determining energy production.

Cut-Out Wind Speed:

Definition

This is the wind speed at which the WECS is no longer expected to generate power. It is often referred to as the shut-down wind speed. Method of shut-down is also indicated, i.e. automatic or manual, tail folding, full blade feather, mechanical brake or other.

Significance

The cut-out wind speed is important because it indicates the wind speed above which no power will be produced by the WECS. Winds above that speed would not be used in determining energy production. Some WECS have automatic means to shut themselves off whenever winds exceed pre-set value. Other designs rely on manu intervention in order to avoid operation i dangerously high winds.

Survival Wind Speed:

Definition

This is the maximum wind speed which th WECS is designed to withstand withou sustaining structural failure, not necessaril under load. Appropriate safety factors may b stated.

Significance

The importance of knowing the survival win speed is apparent. This number should b compared with the maximum winds that ar expected at a given site over the anticipate service life of the WECS. It might be noted that i most cases the system is shutdown and no producing power when exposed to the surviva wind speed.

RPM @ Rated Output

Definition

The number of complete rotations per minut made by the rotor when the WECS is producin its rated output.

Significance

This operating rpm is significance primarily i component matching i.e. in selecting the rotor drive-train, generator, and other components.

Maximum RPM @ Wind Speed

Definition

The maximum rpm expected from the rotor an the wind speed at which it occurs.

Significance

This maximum rpm has a direct effect on systen loads. Furthermore, it provides as indication o the operating range of the rotor speed controls

Overspeed Control:

Definition

Methods used to prevent excessive rotationa speeds. Common methods used include: blad feathering, blade stall, mechanical brake, dra brake, lift spoilers, and turning the rotor edgewis to the wind. Operation of overspeed controls ma be automatic and/or manual.

Significance

The overspeed control is, in most cases, also th control that is used to protest the WECS fro sustaining structural damage which might resu from an ungoverned condition.

the actual performance follows a second order curve. The cut-in, rated and shut-down wind speeds are also indicated on these curves.

ude:

Definition

The total vertical distance from sea level to the center of the rotor's swept area.

Significance

Power available from the wind is proportional to air density. A WECS whose performance is rated at sea level would provide about 13.8% less output at 5000 feet of altitude in otherwise identical operating conditions.

ng Procedures:

Definition

If the output data were obtained through actual tests, an indication of how the tests were conducted is given. This includes a description of the type and location of wind measuring devices, methods of data collection, and the method of reducing the raw data. Typically the raw data is spread over a range. At a nominal wind speed, a number of power levels could be recorded depending on the rate of wind speed or direction change. The type of load, i.e., batteries, fixed resistance, or variable resistance, is also specified together with other instrumentation used for the test procedure.

Significance

While power curve for a given WECS may be the most instructive, it is, at the same time, the most difficult to obtain. The nature of the wind, the testing methods, and the load all have an impact on wind system performance. In general, a WECS will perform best in a smooth wind flow such as in wind tunnel or "truck" testing (during which the WECS is mounted on a vehicle driven at the desired wind speed). In actual operation, when the wind is constantly changing in direction and speed, performance can be on the order of 25% less than under ideal conditions. The load also plays an important role because at any given level of power production, there will be an optimum load or power requirement that maximizes the efficiency of the generator.

Maximum Axial Thrust

Definition

The sum of the horizontal forces on the blades.

Significance

Axial thrust is a horizontal force the tower must withstand. This figure can be used to assess tower structural requirements when combined with the gravity load and the air drag on the tower and WECS.

Miscellaneous:

Operation Experience

Length of operation of a wind system that is in or being planned for production and is offered for sale.

Manufacturer's Comments

These describe any design features of a wind system which the manufacturer feels are unique or are of special value to the user.

Warranty

The expressed warranties a manufacturer offers with his system, including type of coverage and duration.

Recommended Maintenance

The manufacturer's recommended schedule of maintenance is specified.

Owner's Manual

An indication is given if an owner's manual is available with or without the purchase of a wind system, along with the cost of the manual.

TAXONOMY

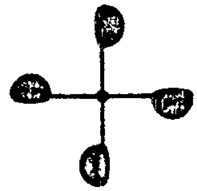
VERTICAL AXIS

PRIMARILY DRAG-TYPE

Savonius

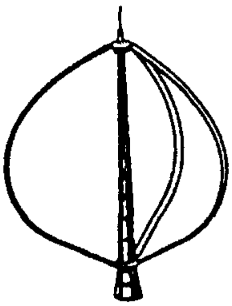
Multi-Bladed Savonius

Plates

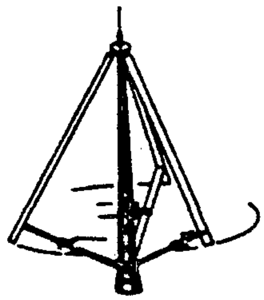


Cupped

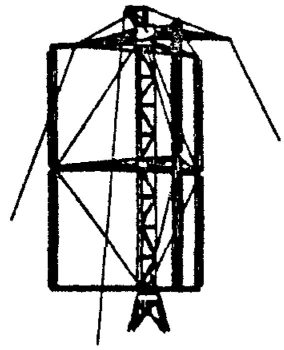
PRIMARILY LIFT-TYPE



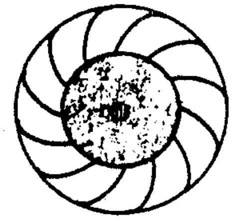
Ø- Darrieus



Δ - Darrieus

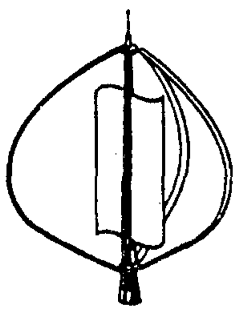


Giromill



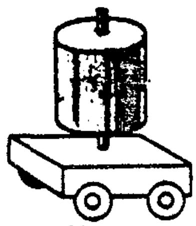
Turbine

COMBINATIONS

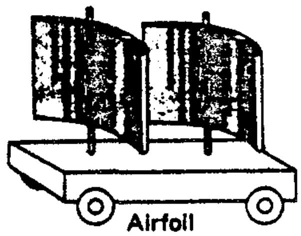


Savonius/Ø - Darrieus

Split Savonius

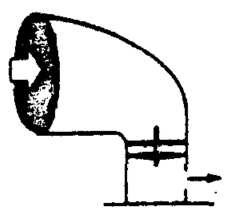


Magnus

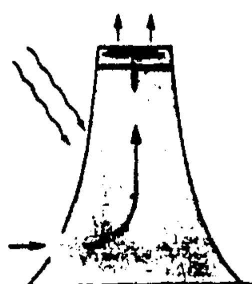


Airfoil

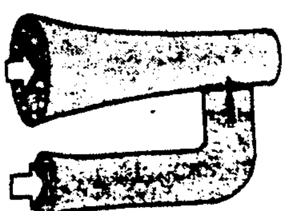
OTHERS



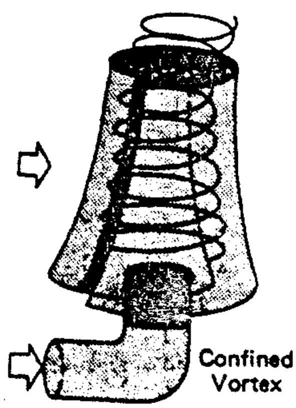
Deflector



Sunlight



Venturi

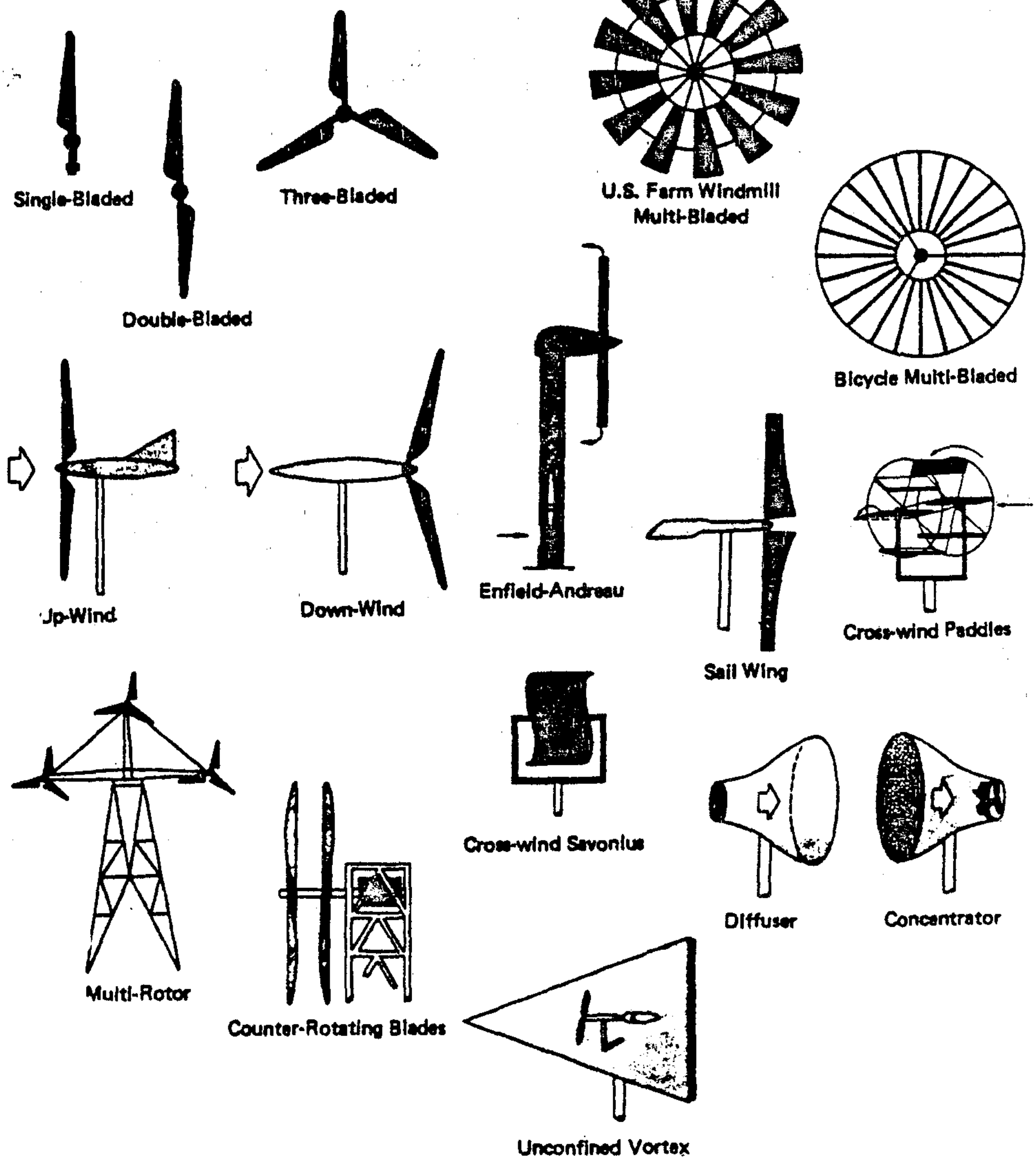


Confined Vortex

Our thanks to Mr. Frank Eldridge for permission to reprint these pages from his Wind Machines

TAXONOMY

HORIZONTAL AXIS



APPENDIX D

CONVERSION TABLES

Units Conversion

Length

Feet = Meters x 3.28
Meters = Feet x 0.305

Miles = Kilometers x 0.621
Kilometers = Miles x 1.609

Miles = Nautical miles x 1.15
Nautical Miles = Miles x 0.869

Kilometers = Nautical miles x 1.852

Speed

Miles per hour (mph) = Meters per second x 2.24
Meters per second = mph x 0.447

mph = Knots x 1.15
Knots = mph x 0.869

Knots = Meters per second x 1.94
Meters per second = Knots x 0.514

Kilometers per hour = Meters per second x 3.6

Area

Square feet = Square meters x 10.76
Square meters = Square feet x 0.093

Power

Horsepower = Watts x 0.00134
Watts = Horsepower x 746

Horsepower = Kilowatts x 1.34
Kilowatts = Horsepower x 0.746

Kilowatts = Watts x 1000

Conversion Table

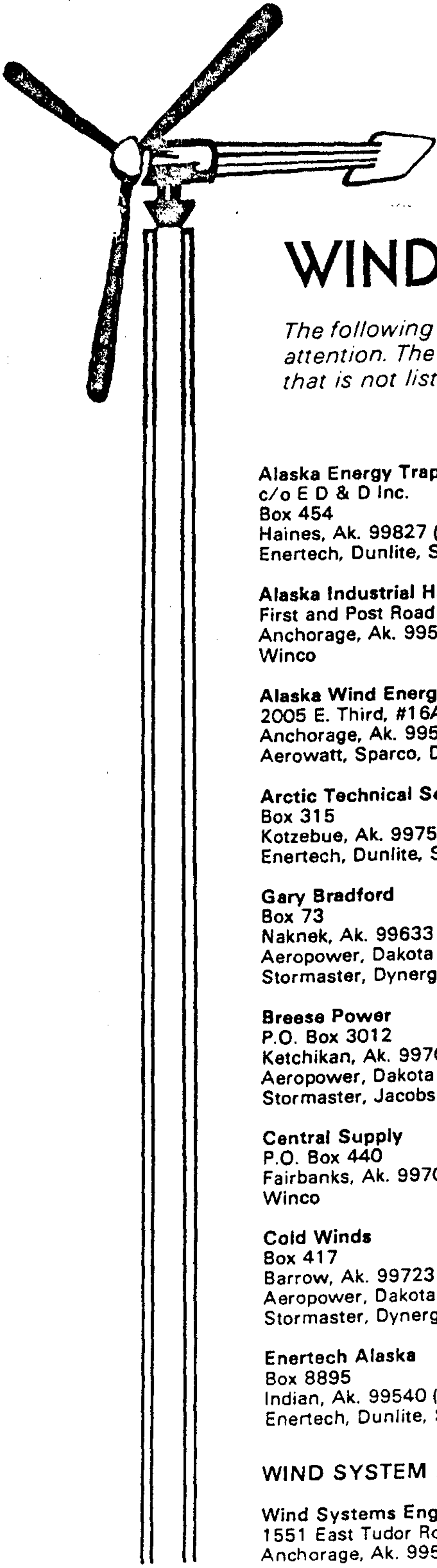
Miles per Hour	Knots	Meters per Second	Feet per Second	Kilometers per Hour	Feet per Minute
1	0.9	0.4	1.5	1.6	88
2	1.7	0.9	2.9	3.2	176
3	2.6	1.3	4.4	4.8	264
4	3.5	1.8	5.9	6.4	352
5	4.3	2.2	7.3	8.0	440
6	5.2	2.7	8.8	9.7	528
7	6.1	3.1	10.3	11.3	616
8	6.9	3.6	11.7	12.9	704
9	7.8	4.0	13.2	14.5	792
10	8.7	4.5	14.7	16.1	880
11	9.6	4.9	16.1	17.7	968
12	10.4	5.4	17.6	19.3	1056
13	11.3	5.8	19.1	20.9	1144
14	12.2	6.3	20.5	22.5	1232
15	13.0	6.7	22.0	24.1	1320
16	13.9	7.2	23.5	25.7	1408
17	14.8	7.6	24.9	27.4	1496
18	15.6	8.0	26.4	29.0	1584
19	16.5	8.5	27.9	30.6	1672
20	17.4	8.9	29.3	32.2	1760
21	18.2	9.4	30.8	33.8	1848
22	19.1	9.8	32.3	35.4	1936
23	20.0	10.3	33.7	37.0	2024
24	20.8	10.7	35.2	38.6	2112
25	21.7	11.2	36.7	40.2	2200
26	22.6	11.6	38.1	41.8	2288
27	23.4	12.1	39.6	43.5	2376
28	24.3	12.5	41.1	45.1	2464
29	25.2	13.0	42.5	46.7	2552
30	26.1	13.4	44.0	48.3	2640
31	26.9	13.9	45.5	49.9	2728
32	27.8	14.3	46.9	51.5	2816
33	28.7	14.8	48.4	53.1	2904
34	29.5	15.2	49.9	54.7	2992
35	30.4	15.6	51.3	56.3	3080
36	31.3	16.1	52.8	57.9	3168
37	32.1	16.5	54.3	59.5	3256
38	33.0	17.0	55.7	61.2	3344
39	33.9	17.4	57.2	62.8	3432
40	34.7	17.9	58.7	64.4	3520
41	35.6	18.3	60.1	66.0	3608
42	36.5	18.8	61.6	67.6	3696
43	37.3	19.2	63.1	69.2	3784
44	38.2	19.7	64.5	70.8	3872
45	39.1	20.1	66.0	72.4	3960
46	39.9	20.6	67.5	74.0	4048
47	40.8	21.0	68.9	75.6	4136
48	41.7	21.5	70.4	77.2	4224
49	42.6	21.9	71.9	78.9	4312
50	43.4	22.4	73.3	80.5	4400
51	44.3	22.8	74.8	82.1	4488
52	45.2	23.2	76.3	83.7	4576
53	46.0	23.7	77.7	85.3	4664
54	46.9	24.1	79.2	86.9	4752
55	47.8	24.6	80.7	88.5	4840
56	48.6	25.0	82.1	90.1	4928
57	49.5	25.5	83.6	91.7	5016
58	50.4	25.9	85.1	93.3	5104
59	51.2	26.4	86.5	95.0	5192
60	52.1	26.8	88.0	96.6	5280
61	53.0	27.3	89.5	98.2	5368
62	53.8	27.7	90.0	99.8	5456
63	54.7	28.2	92.4	101.4	5544
64	55.6	28.6	93.9	103.0	5632
65	56.4	29.1	95.3	104.6	5720
66	57.3	29.5	96.8	106.2	5808
67	58.2	30.0	98.3	107.8	5896
68	59.1	30.4	99.7	109.4	5984
69	59.9	30.8	101.2	111.0	6072
70	60.8	31.3	102.7	112.7	6160
71	61.7	31.7	104.1	114.3	6248
72	62.5	32.2	105.6	115.9	6336
73	63.4	32.6	107.1	117.5	6424
74	64.3	33.1	108.5	119.1	6512
75	65.1	33.5	110.0	120.7	6600
76	66.0	34.0	111.5	122.3	6688
77	66.9	34.4	112.9	123.9	6776
78	67.7	34.9	114.4	125.5	6864
79	68.6	35.3	115.9	127.1	6952
80	69.5	35.8	117.3	128.7	7040
81	70.3	36.2	118.8	130.4	7128
82	71.2	36.7	120.3	132.0	7216
83	72.1	37.1	121.7	133.6	7304
84	72.9	37.6	123.2	135.2	7392
85	73.8	38.0	124.7	136.8	7480
86	74.7	38.4	126.1	138.4	7568
87	75.5	38.9	127.6	140.0	7656
88	76.4	39.3	129.1	141.6	7744
89	77.3	39.8	130.5	143.2	7832
90	78.2	40.2	132.0	144.8	7920
91	79.0	40.7	133.5	146.5	8008
92	79.9	41.1	134.9	148.1	8096
93	80.8	41.6	136.4	149.7	8184
94	81.6	42.0	137.9	151.3	8272
95	82.5	42.5	139.3	152.9	8360
96	83.4	42.9	140.8	154.5	8448
97	84.2	43.4	142.3	156.1	8536
98	85.1	43.8	143.7	157.7	8624
99	86.0	44.3	145.2	159.3	8712
100	86.8	44.7	146.7	160.9	8800

taken from Smithsonian Meteorological Tables

Wind Speed Units:
1 mile per hour = 0.868391 knot
= 1.46667 ft./sec.
= 0.44704 m/sec.
= 1.609344 km/hr.
= 88 ft./min.
= 0.34754° lat/day

APPENDIX E

BIBLIOGRAPHY



Source:
Appropriate Energections
Alaska Division of Energy
338 Denali Street, Suite 110
Anchorage, Alaska 99501

WIND DISTRIBUTORS IN ALASK/

The following is a listing of wind related distributors that have been brought to o attention. The listings are only for informational purposes. If you are aware of a fi that is not listed please contact **Energections.**

WIND SYSTEMS

Alaska Energy Trappers
c/o E D & D Inc.
Box 454
Haines, Ak. 99827 (766-2337)
Enertech, Dunlite, Sencenbaugh

Alaska Industrial Hardware
First and Post Road
Anchorage, Ak. 99501 (272-1441)
Winco

Alaska Wind Energy
2005 E. Third, #16A
Anchorage, Ak. 99501 (278-3825)
Aerowatt, Sparco, Dunlite, Sencenbaugh

Arctic Technical Services
Box 315
Kotzebue, Ak. 99752 (442-3247)
Enertech, Dunlite, Sencenbaugh

Gary Bradford
Box 73
Naknek, Ak. 99633 (268-4242)
Aeropower, Dakota Wind & Sun,
Stormaster, Dynergy, Jacobs

Breese Power
P.O. Box 3012
Ketchikan, Ak. 99701 (225-2866)
Aeropower, Dakota Wind & Sun,
Stormaster, Jacobs

Central Supply
P.O. Box 440
Fairbanks, Ak. 99701 (452-2195)
Winco

Cold Winds
Box 417
Barrow, Ak. 99723 (852-7700)
Aeropower, Dakota Wind and Sun,
Stormaster, Dynergy, Jacobs

Enertech Alaska
Box 8895
Indian, Ak. 99540 (277-1911)
Enertech, Dunlite, Sencenbaugh

4-Winds of Alaska
5100 Vi Street
Anchorage, Ak. 99507 (344-1650)
Aeropower, Dakota Wind & Sun, Dynerg
Jacobs, Stormaster, Jacobs

Fabricreations
Iliamna, Ak. 99606 (338-1624)
Aeropower, Dakota Wind & Sun,
Stormaster, Dynergy, Jacobs

Jim Huff
Box 21
Naknek, Ak. 99637
Enertech, Dunlite, Sencenbaugh

Kodiak Winds
Box 92
Kodiak, Ak. 99615 (486-4366)
Aeropower, Dakota Wind & Sun,
Stormaster, Dynergy, Jacobs

Kramer Electric
3002 East Tudor Road
Anchorage, Ak. 99504 (272-4816)
Winco

S & S Electric
P.O. Box 10-317
Anchorage, Ak. 99507 (344-0022)
Grumman

Temp-Trol
Box 154
Unalaska, Ak. 99685 (581-1204)
Aeropower, Dakota Wind & Sun,
Stormaster, Dynergy, Jacobs

Wind Point Enterprises
Box 911
Homer, Ak. 99603 (235-8838)
Aeropower, Dakota Wind & Sun,
Stormaster, Dynergy, Jacobs

WIND SYSTEM DESIGN

Wind Systems Engineering, Inc.
1551 East Tudor Road
Anchorage, Ak. 99507 (274-2627)

WIND SYSTEM INSTALLATION

Fabricreations
5100 Vi Street
Anchorage, Ak. 99507 (344-1650)

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BOOKS

Energy from the Wind, 1977
CER-74-75 BLB-RNM-44

Burke, B.L. and Merony, R.N.

Engineering Sciences Branch Library
Engineering Research Center
Colorado State University
Foothills Campus
Ft. Collins, CO. 80523
(cost/copy $12.95)

A comprehensive, annotated bibliography of general and technical wind energy references, articles, and publications. Best suited for general research work. Updates will be available on a regular basis.

Energy Primer, 1978

Merrill, R. and Gage, T.

Delta Books
New York

The Wind section, pp. 120-149, contains extensive reviews of available books and reports.

Wind Energy: A Bibliography with Abstracts and Keywords

Van Steyn, R.

Library Administration
University of Technology
P.O. Box 573
Eindhoven, Netherlands

Wind Energy Information Directory
October, 1979.

SERI Report No. 061-000-00350-9

Superintendents of Documents
U.S. Government Printing Office
Washington D.C. 20402

Wind Energy Information Sources

Document Distribution Service
Solar Energy Research Institute (SERI)
Golden, Colorado 80401

Wind Energy Resource Atlas: Volume 10-Alaska

Battelle Pacific Northwest Laboratories

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.
Spring field, VA. 22161

Wind Energy Utilization:
a Bibliography, April 1975

Technology Applications Center Report
No. TAC-W-75-700

Publications and Documents
University of New Mexico
Albequerque, NM. 87131

A complete bibliograpghy covering the period 1944-1974.

EQUIPMENT DIRECTORIES

A Guide to Commercially Availble Wind Machines

Rocky Flats Report
No. RFP-2836/3533/78/3

National Technical Information Service

Contains detailed descriptions of 66 *wind machines under* 100 *KW available in the United States and Canada; includes illustrations and power curves, plus directory of manufacturers and dealers*

Energy Primer, 1978
(updated and revised edition)

Merrill, R. and Gage, T.

Delta Books
New York

The wind section, pp. 120-148, *contains evaluctions, dealers and distributors of small scale wind machines and related components.*

Harnessing the Wind for Home Energy, 1978

McGuigan, D.

Garden Way Publishing Co.
Charlotte, Vermont

Contains descriptions and costs of wind machines and other equipment available in 1978.

Also: The American Wind Energy Association publishes a brochure that contains, among other things, a list of commercially available wind machines and their U.S. distributors.

Write: AWEA
1609 Connecticut Ave., N.W.
Washington DC 20009
or call (202) 667-9137

BOOKS

Battery Service Manual
8th Edition, 1978

Battery Council Internationsl
111 East Wacber Drive
Chicago, Ill. 60601

A good manual on care and feeding of all types of batteries.

The Generation of Electricity by Wind Power, 1955

Golding, E.W.

Available from:

Halsted Press
A devision of John Wiley & Sons, Inc.
605 Third Avenue
New York, N.Y. 10016
(cost/copy $19.95)

A classic wind energy publication originally written in 1955 by one of the pioneers in the wind energy field. The book provides a comprehensive review of wind characteristics, the design and operation of wind machines and the economics of wind energy systems in different applications. The revised 1976 edition of the book includes an additional chapter on recent developments in the wind energy field by R.I. Horres, a former colleague of the late Mr. Golding.

The Homebuilt, Wind-generated Electricity Handbook, 1975

Hackleman, M.

Earthmind
Maripose, California
(cost/copy $8.00)

Includes wind machine restoration, towers,installation, the control box, auxiliary electricity-generating equipment and wind machine design note.

Power from the Wind,1948

Putman, P.C.
Available fromm:

Von Nostrand Reinhold Co.
450 West 33rd Street
New York, NY 10001

An excellent historical account of the Smith-Putnam wind turbine project of 1934-1935. *This Smith-Putnam wind turbine was the largest wind generator built to date, (its blades spanned* 175 *feet) and fed* 1200 *KW of power into the grid network of Central Vermont utilities whenever the wind exceeded* 17 *mph.*

A Siting Handbook for
Small Wind Energy Conversion Systems

Wegley, H.L., etal

Battelle Pacific Northwest Laboratories
Report NO. PNL-2521

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA. 22161

Windbooks
P.O. Box 14
Rockville Centre NY. 11571
(516) 678-1230

***The** reference on siting! Every Perspective windsystem owner should read this book. Explains hows and whys of wind detailed methodology for site analysis and enviornmental factors.*

Wind-Catchers, 1976

Torrey, V.

Stephen Green Press
Brattleboro, VT 05301
(cost/copy $12.95)

A general historical overview of the use of wind energy systems from the first early water-pumpers (900 AD) through the various present-day applictions. An excellent series of photos accompany the text.

Wind Machines, 1975
Stock # 038-000-00272-4

Eldridge, F.

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

One of the best introductory references on wind energy. A review of the history, viability, taxonomy, and potential of wind machines for energy needs. Includes photos and graphics of various wind energy ststems.

Wind Power for Farms, Homes and Small Industry

Nielsen Engineering and Research, Inc.

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

The publication is designed to provide information to enable farmer, home-owners, and other prospective machine buyers to evaluate their energy needs and access the value and utility of wind systems in meeting those needs.

Wind Power and Other Energy Options, 1978

Inglis, D.R.

University of Michigan Press
Ann Arbor, Michigan

An excellent objective evaluation of wind generators in our energy future when compared to other solar, geophysical, and nuclear options. Written as a textbook, it gives one the broad picture and puts these notions in perspective.

The Wind Power Book, 1981

Park, J.

Cheshire Books
514 Bryant St.
Palo Alto, CA. 94301
(cost/copy $11.95)

A good up-to-date handbook on putting together a wind system whether you want to build your own or buy factory built components.

Windmills and Watermills, 1975

Reynolds, John

Praeger Publishers, Inc.
111 4th Ave. New York, NY. 10003

Historical development of windmills with detailed drawings and explanations of the mechanics of operation of mills.

Wind and Windspinners, 1974

Hackleman, M.

Peace Press
Culver City, California
also
Earthwind
Boyer Road
Mariposa, California 95338

A popular how-to book on Savonius rotor design and construction, but its advocacy of their use for electrical generation is somewhat impractical.

PERIODICALS

Alternative Sources of Energy
Milaca, Minnesota 56353

Canadian Renewable Energy News
P.O. Box 4869,
Station E, Ottawa, Ontario
K1S 5B4, Canada

RAIN: Journal of Appropriate Technology
2270 N.W. Irving,
Portland, Oregon 97210

Solar Age, published by Solarvision, Inc.
Church Hill,
Harrisville, New Hampshire 03450

Wind Energy Report
P.O. Box 14,
Rockville Center, New York 11571.

Wind Engineering
Published by Multi-Science
Publishing Company, Ltd,
The Old Mill, Dorset Place,
London E15 10J, United Kingdom

Windletter
Newsletter of the American
Wind Energy Association,
1609 Connecticut Avenue,
N.W., Washington, DC 20009

Wind Power Digest
115 East Lexington
Elkhart, Indiana 46516

Wind Technology Journal
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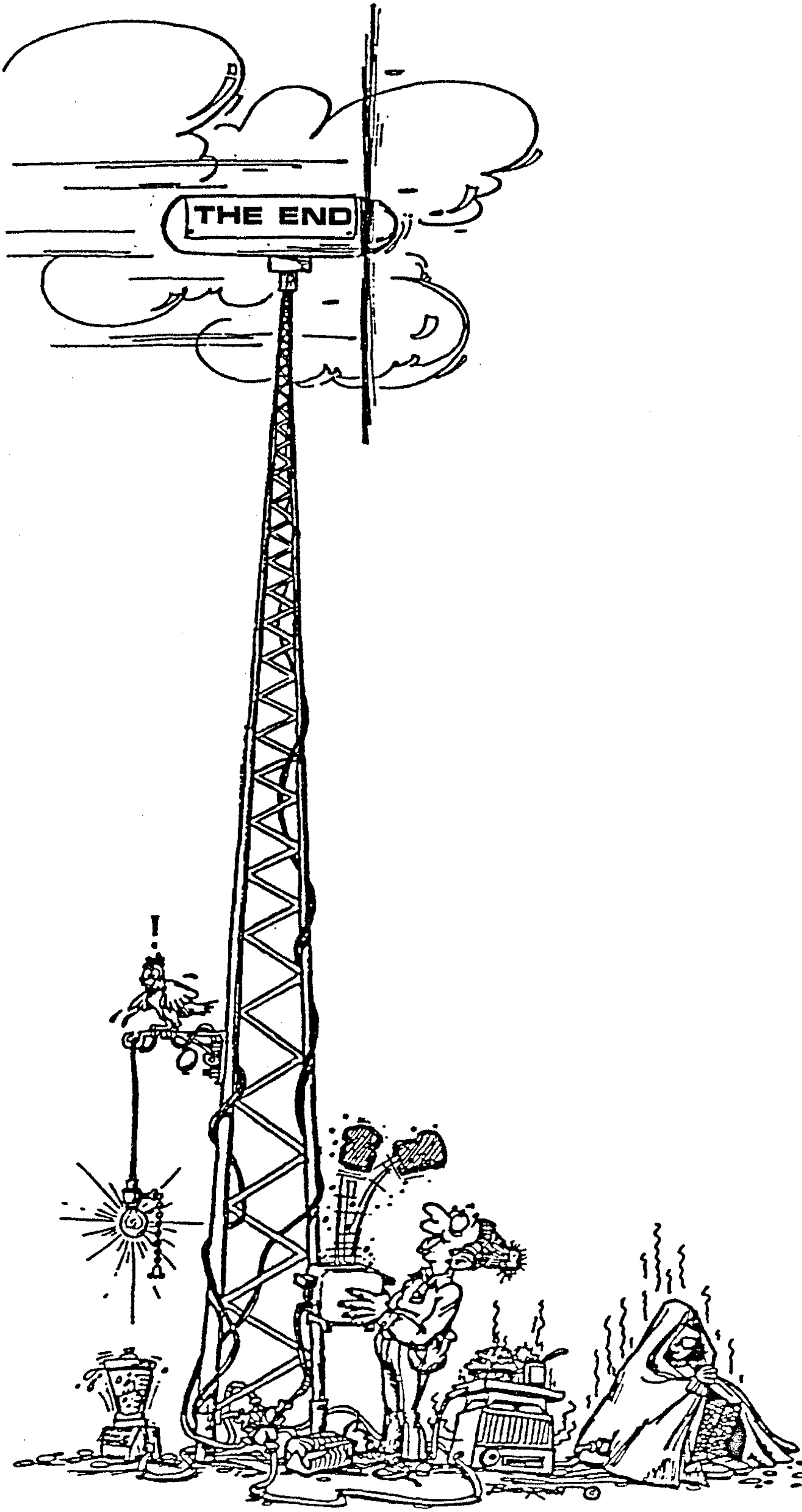
Wind Energy Association,
1609 Connecticut Avenue, N.W.,
Washington, DC 20009.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