Wind Power Essay, Research Paper

The wind turbine, also called a windmill, is a means of harnessing the

kinetic energy of the wind and converting it into electrical energy. This

is accomplished by turning blades called aerofoils, which drive a shaft,

which drive a motor (turbine) and ar e connected to a generator. “It is

estimated that the total power capacity of winds surrounding the earth is

1 x 1011 Gigawatts” (Cheremisinoff 6). The total energy of the winds

fluctuates from year to year. Windmill expert Richard Hills said that the

wind really is a fickle source of power, with wind speeds to low or

inconsistent for the windmill to be of practical use. However, that

hasn’t stopped windmill engineers from trying. Today, there are many

kinds of windmills, some of which serve differen t functions. They are a

complex alternative energy source.

What to consider when building a windmill In choosing where to build a

windmill, there are many important factors to consider. First is the

location: 1) Available wind energy is usually higher near the seacoast or

coasts of very large lakes and offshore islands. 2) Available wind energy

is gene rally high in the central plains region of the U.S. because of the

wide expanses of level (low surface roughness) terrain. 3) Available wind

energy is generally low throughout the Southeastern U.S. except for

certain hills in the Appalachian and Blue Rid ge Mountains, the North

Carolina coast, and the Southern tip of Florida. This is because of the

influence of the “Bermuda high” pressure system, which is a factor

especially during the summer. Also important to consider is the wind

where you are going to build: 1) the mean wind speed (calculated my

cubing the averages and taking the mean of the cubes) and its seasonal

variations. 2) The probability distribution of wind speed and of extreme

wi nds. The mean wind speed must be high enough, and the distribution must

be so that all the data points are very similar. 3) The height variation

of wind speed and wind direction. Wind cannot be too high or too low in

relation to the ground or it is too

difficult to harness. 4) The gustiness of the wind field in both speed

and direction. Gusty winds greatly affect the power output of the

windmills and are usually harmful. 5) The wind direction distribution and

probability of sudden large shifts in di rection. The wind must be

unlikely to suddenly shift direction. It must blow in the same general

direction. 6) the seasonal density of the air, and variations of density

of the air with height. The denser the air, the worse it will be for

windmills. 7) Hazard conditions such as sandstorms, humidity, and

salt-spray, which are bad for windmills. The physics behind these will be

discussed later. 8) Trade winds in the subtropics, and the channeled

wind through mountain passes are especially beneficial to windmills. Once

a suitable location is found, the wind is analyzed extensively, and the

criteria is met, there are still more requisites. 1) The terrain upon

which the windmills are built must be relatively flat. The elevation

difference between the turbine site and the terrain is no larger than 60

meters over a 12-km radius. You may have seen windmills such as those in

California on little hills, but this is because the requirement is met.

The hill may be the only one around for miles. 2) All hills must have

small height to width ratios: h:l must be < 0.016. 3) The elevation

difference between the highest and lowest point must be 1/3 or less of the

height difference between the bottom of the rotor disk and the lowest

point in the terrain strip. The surface roughness of the terrain upon

which the windmill is to be built must be low. If it varies by more than

10%, this is no good. The terrain must be smooth, and consistently so. A

rough surface has more of a negative effect on the wind than a s mooth

surface. There is a value n, called, which is assigned to the terrain in

terms of its roughness. This value is used to calculate the height of the

windmill. For instance, over the sea, the index location, n is 0.14.

Over rough inland country, n is 0.34.

Turbines

Windmills are turbines. The two names can be used synonymously.

Turbines are a means of harnessing the a fluid’s power (the wind) by

converting the kinetic energy of the fluid (the wind) into mechanical

power (the rotating shaft) When the shaft of a w indmill is hooked up to a

generator, electrical energy can be formed. The generator can be used to

produce either DC or AC current. Generators that produce DC can be

connected to batteries, an inverter to produce AC, or to power DC loads.

Some generato rs are connected to heating coils. Generators that produce

AC can be hooked up to AC motors such as water pumps. Windmills are NOT

efficient. At the very most, a windmill can extract only 16/27ths of the

kinetic energy from the wind. This is called the Betz Limit and it can be

mathematically proven through calculus. Most of today’s windmills extract

about 30 perc ent of the wind’s energy. The American farm windmill can

only extract 10%. An important equation used to find the wind power

density, how much power is available per square meter is the equation P =

.5 pu?, where P is the wind power density in W/m2, p is the density of the

air, and u? is the cube of the wind velocity. An equation for the power

available is (kinetic energy flux) = .5 p V3 A, where p is the kinetic

energy density J/m?, V is the velocity of the wind, A is the cross

sectional area of the wind on the turbine.

The equation for determining the power of the shaft, (which is

less than the final power output, since gear trains and generators cause

power to be lost) is as follows: Cp = P((((((((

(0.5 p V ? ( D2)

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Where Cp is the power coefficient (Power of shaft), p is the air density,

D is the rotor diameter, V is the velocity of the wind and P is the net

power output.

Also Cp = P available

P turbine

The power available is a function of elevation. At ground level, 100% of

the power is available. At 100 feet, 97% is available. At 5000 feet, 86%

is available. Some turbines are shrouded like jet engines. The shroud is

a way to channel the wind. An equation for the power harnessed by a

shrouded wind turbine is: P(Pe) = ( QT ((p + (k) where P is the power,

Pe is the power extracted, ( is the turbine efficiency, QT is the

volumetric flow rate of air on the turbine, (V/A), ((p + (k) is the change

in pressure energy between the inlet and the exit of the wind turbine, and

k is the cane in kinetic energy of a unit volume of air that passes

through the machine.

Shrouds concentrate and diffuse the wind as it passes through a

horizontal access wind-turbine. They reduce the turbulence of the wind

and “direct it”. The advantages of shrouds, as told by Cheremisinoff (pg.

61 of Fundamentals of Wind Energy), are: a ) the axial velocity of the

turbine increases, meaning that smaller rotors can operate at higher

revolutions, b) the shroud can greatly reduce tip-losses, and c) the

aerofoils would not have to be rotated in a direction parallel to the wind

if the wind-di rection changed. The cut in speed is the lowest wind speed

below which no usable power can be produced by a wind turbine. This means

that the wind must be fast enough to move the aerofoils to drive the shaft

to create enough power, after much is lost, so that the end amo unt of

power is greater than zero. Rated power is the maximum power output of a

turbine, which is dependent on a number of factors, especially the

generator. In calculating the height of the windmill, it is important to

keep in mind that the windmill must be high enough to be above

obstructions. The wind velocity decreases as one approaches the surface.

That means that the higher you build, the better chance

there will be that the wind speed is higher, however, you must find the

perfect medium–there are often more variables as you increase in

altitude. In calculating how high a windmill should be the following

equation is used: V1/V2 = (H1/H2)n, Where V1 is the wind speed at the

highest point of the highest blade, V2 is the wind speed at the lowest

point of the lowest blade, H1 is the height of the highest point, and H2

is the height of the lowest point. n is the index location of the site, a

va lue that measures the roughness of the terrain.

The structures, aerofoils (see also vector diagrams, attached)

The support of the windmill is generally made out of steel. The

windshaft is the shaft which carries the windwheel or aerofoils. It is

turned as the aerofoils turn. It is made of steel or wood.

Aerofoils are the blades on a windmill. They can be made out of

any material. They were first made of wood or wood composites. Steel was

used after that. Aluminum is used in the Darrieus windmills because it is

much stronger. Unfortunately, Aluminum fatigues quicker. Some windmills

use fiberglass blades. New materials such as strong alloys are being used

in today’s windmills experimentally. It is important that the blades have

a large lift force and a small drag force. The lift force is the force

needed to bend the flow of the (fluid) air. It is the force perpendicular

to the stream of the air. The drag force is the force parallel to the

stream. The aerofoil must be able to develop a lift force at least 50

times greater than the drag. Torque acts on the aerofoil with a vector

from the center of rotation away. Other forces that act on the blades of

windmills are wind shears, wind gusts, which push on the aerofoils,

gravity, a pull towards the earth, and shifts in the direction of the

wind. Shifts in the direction of the wind are often accounted for by

having a

small blade, called a tailvane, on the backside of a windmill. The wind

blows on a flat side of the tail, which is oriented differently from the

aerofoils. Then, the aerofoils can be rotated to face into the wind. If

the wind is blowing in the directi on of this tail instead of the

direction of the aerofoils, the tail rotates a shaft, which rotates the

whole windmill in the proper direction so as to orient it towards the

wind. As Paul Gipe explained in his book Wind Energy comes of age, (page

27), Wind gusts can greatly affect a windmill. A turbulent gust is a gust

greater than two minutes with a certain mean wind speed. Gusts are

analyzed extensively, with magnitudes, one fo r the lull speed, which is

the wind speed of a negative gust amplitude, and the peak speed, which is

the wind speed for a positive gust amplitude. The gust amplitude is the

difference between the largest speed in the gust and the mean speed. The

gust du ration is the time from the beginning to the end of a gust. The

gust frequency is the number of positive gusts, which occur per unit time.

The gust formation time is the time it takes from the beginning of a gust

to the time it attains the peak gust spe ed. The gust decay time is the

time it takes for the gust the end after it reaches its highest amplitude.

There is quite a bit of terminology with aerofoils. The angle of the

surface to the fluid flow is the angle of attack, alpha. The angle of

attack must be just right. If it is too great, the lift will dramatically

decrease and the drag will increase, st alling the windmill. At rest,

(when the windmill is not in operation), the angle of attack is 85?. When

in motion, the angle of attack is anywhere from 2-10 degrees. Newer and

more advanced windmills have an angle of attack in the upper end of this

ran ge. The pitch angle, ? is the angle between the chord of the aerofoil

and its plane of rotation. The pitch angle can be adjusted. Solidity is

the ratio of the blade width (at widest point) to the distance between the

centers of the blades. A typical “pinwh eel American windmill” might have

a ratio of about 1:1, because the blades are very narrow and very close

together, whereas a new two-bladed aerofoil would have a ratio of about

0.03. There is a transfer of work between the wind stream and the moving

blade. In order for this transfer to be efficient, a typical blade is

usually 1/4 the width of its length. (If the blade is 10 feet long, it

will be 2.5 feet wide at its widest point). A erofoils come in many

shapes. Some blades are made a little wider than this ratio, because it

is easier to start such a windmill. However, blades like this aren’t as

efficient. No matter what the shape, “most have a blunt nose and a finely

tapering tab le” (Calvert). A flow must be able to follow the curved

surfaces of the aerofoil without being separated. The mass flow rate is

given by the equation: m = p Vb A, where p is the air density, Vb is the

air speed at the blades and A is the area. The number of blades on a

windmill varies. There are many different types of windmills. The

following equation helps figure out how fast the a certain-bladed windmill

will rotate in relation to windmills with different numbers of blades:

Speed of windmill = 1 / sq. root of number of blades The aerofoils of a

four bladed machine rotate 71% as fast as that of a 2 bladed machine. A

six bladed machine rotates at 58% and an 8 bladed machine rotates at 56%

as fast as a 2 bladed machine.

Electricity and Storage of Energy

As mentioned previously, the generators in a wind turbine can

convert the mechanical energy produced by the rotation of the shaft into

electrical energy, DC. From there, some windmills have synchronous

inverters, complex electronic devices which convert

the DC generated by the turbines into AC. This is an expensive option.

There is a loss of power as well through its processes. Others have

induction generators, which produce AC current without a synchronous

inverter and less power loss. The energy extracted from the wind and

converted into mechanical energy then electrical energy by the generator

must be stored, since it is not used generally used all at once. It is

important to keep a surplus of energy for usage when the wind is not bl

owing fast enough, despite the corrections that can be made in the pitch

of the aerofoil blades and when the windmill is out of service or the

demand is especially high.

Storing the wind’s energy effectively is the key to its long-term

use. Windmills used as water pumpers or air-compressors can pump excess

water, hydrogen or air into reserve tanks. Today, there are a number of

ways to store the wind’s energy. Windmills

are used to charge Electrolyte batteries. Lead-acid or Lead-cobalt car

batteries are commonly used as well. However, batteries may be expensive

and inefficient–they may lose 10-25% of the energy stored in them.

Nickel-Iron, Nickel-cadmium, and zinc-a ir cells are often used as well.

These tend to be more efficient. Some windmills are now using organic

electrolyte batteries such as CuCl2, Ni Cl2, and NiF2 batteries as well as

sodium-sulfur batteries, which operate at high temperature, are used.

Although uncommon and still in experimental phases, some energy is

stored not by being converted directly into electrical energy, but rather

by being stored as thermal or electromagnetic energy,

Sound Fluids are elastic. Pressure waves are constantly being created and

propagated by the aerofoils and the turbine as a whole (entire components

excepting the support). We can hear them in the sound given off. The

sound intensity is directly proportional with the speed of the windmill.

The frequency of the waves is directly proportional to the angular speed

of the blades on the rotor. The flutter you hear has aerodynamic and

elastic properties. The higher speed the aerofoils are, the louder the

sound a nd the louder the flutter they will make, as more pressure waves

are being created and propagated. The generators are noisy. They often

confuse birds and cause them to fly towards the turbine. Windmills can be

very noisy. A 300 kW turbine at 1 mile away has a dB level equal to a

traffic light 100 feet away (Gipe). Windmill sound levels are regulate d.

The sound level must be kept under 46 dB in a residential area. Wind

turbines can cause interference, disturbances with TV and radio reception

(ghost images on TVs), affect microwaves and disrupt satellite

communication. These problems are currently being resolved. Many have

already been fixed. There is also a .009

probability of a bird or insect being struck by the blades. Windmill

makers must use artificial sound or florescent paint or scents to scare

away flying creatures.

Brakes

Mechanical brakes are used to hold windmills at rest when they are

not needed, are not functioning, or are under repair. Greek windmills

used sticks or logs jammed into the ground to keep the windmill stopped,

but modern brakes are more sophisticated. Many windmills today use

airbrakes like those used in planes. Other windmills have rope brakes.

Ropes connected to the aerofoils are simply pulled and tethered to a post

to keep the aerofoils from turning. The torque on a rope brake can be

calculated b y the equation (M-m)(R2 + r)g.

The Types of Windmills

There are a number of types of windmills. They are divided into

Horizontal-Axis and Vertical-Axis types. Low speed horizontal-axis

windmills are used for water pumping and air compressing. American

windmills (of the Midwest) are an example. Earlier wi ndmills such as the

ones in England and Holland build a couple hundred years ago are another

example. The horizontal-axis was invented in Egypt and Greece in 300 BCE.

“It had 8 to 10 wooden beams rigged with sails, and a rotor which turned

perpendicular

to the wind direction” (Naar 5). This specific type of windmill became

popular in Portugal and Greece. In the 1200’s, the crusaders built and

developed the post-mill, which where used to mill grain. It was first used

to produce electricity in Denmark i n the late 1800’s and spread soon

after to the U.S. In America, windmills made the great plains. They were

used to pump water and irrigate crops. During World War I, farmers rigged

windmills to generate 1 kW of DC current. They mounted their devices o n

the tops of buildings and towers. On western farms and railroad stations,

the pumping windmill was 20-50 feet high with a 6-16 foot wheel diameter”

(45)]. With 10-mph wind speed, a 6 foot-diameter wheel, a 2-foot diameter

pump cylinder, a windmill-pump could lift 52 gallons per hour to a

height of 38 feet. A 12-foot in diameter wheel could lift 80 gallons per

hour to a height of 120 feet. (Naar, p. 46).

The growth of wind-electricity in America was greatly stunned in 1937 with

the Rural Electrification Act, which made low-cost electricity more

available. However, in the 1970’s, due to oil shortages, earlier

prototypes of high-speed horizontal-axis windm ills were developed.

High-speed horizontal-axis types are used for many purposes, come in many

sizes. These include the typical windmills on a California windmill farm

and other windmill farms, and any other wind turbines in which the shaft

turned by th e aerofoils is horizontal. High-speed horizontal types may

have 1, 2, 3, 4, or many aerofoils. Low-speed types such as European ones

have much larger aerofoils in relation to their height above the ground.

Low speed types such as American Midwest ones are usually a pinwheel, with

many small blades encircled with an outer frame like a wheel.

Vertical-axis windmills were first developed in the Persians in

1500 BCE to mill corn. Sails were mounted on a boom, which was attached

to a shaft that turned vertically. By 500 BCE, the technology had spread

to Northern Africa and Spain. Low-speed ve rtical-axis windmills are

popular in Finland. They are about 150 years old. They consist of a

55-gallon oil drum split in half. They are used to pump water and aerate

land. They are inefficient. High-speed vertical-axis windmills include

the Darrieus

models. These have long, thin, curved outer blades, which rotate at 3 to

4 times the wind speed. They have a low starting torque and a high

tip-speed ratio. They are inexpensive and are used for electricity

generation and irrigation. There are three types, the delta, chi, and

gamma models. All models are built on a tripod. The advantages to a

Darrieus-windmill are that it can deliver mechanical power at ground

level. The generator, gearbox, and turbine components are on the ground,

instead of at t he top of a tower as in horizontal-axis windmills. They

cost much less to construct, because there is less material, and the pitch

of the blades does not have to be adjusted. Another type of HSVAW’s are

the Madaras and Flettner types, revolving cylinder s which sit on a

tracked carriage. “The motion of a spinning cylinder causes the carriage

to move over a circular track and the carriage wheels to drive an electric

generator” (Justus). The Savonius model, which originated in Finland in

the 1920’s, is a n S-shaped blade, which rotates and turns a vertical

shaft. Today, these types of windmills are very popular with scientists

and their technology is being developed.

Windmills Today Many windmills are used today: some estimates say 150,000

(Cheremisinoff 31), in the Midwest. They are used to heat water,

refrigerate storage buildings or rooms, refrigerate produce, dry crops,

irrigate crops, heat buildings, and charge batteries for tr actors on

farms (33). Ever since the energy shortages of the 70’s, the growing

concern of pollution due to the burning of fossil fuels and the depletion

of natural resources, windmills have been greatly studied and developed.

Today, Sandia National Laboratories, Alcoa, GE, Boe ing, Grumman, UTC,

Westinghouse, and other scientists are researching and developing

Darrieuses and new types of windmills. Today, windmills are used to

operate sawmills and oil mills in Europe. They are used in mining to

extract minerals, to pump water , to generate electricity, and to charge

batteries. “Windmills have been used on buoys moored far out in the

ocean, the power being used for the collection and transmission of

oceanographic and weather data. They also work in deserted places as an

aid t o radio and telephone communications and they are used to work

navigation lights on isolated hazards” (Calvert 77).

My Windmill

I built a windmill of my own. The goal of the windmill was to get

as much electrical energy as possible. This immediately ruled out any

new-wave type windmill. Instead, I went to Home Depot and got a returned

ceiling fan. I took off the white box wit h the motor and switches and

left the spinning black box on. I mounted the blades on the black box. I

put this on a post and a support. Then I got a Maxon DC motor and, after

fashioning a clamp-like device to hold the motor on to the support, I put

a r ubber tire on the spinning shaft of the motor and adjusted it so that

this rubber tire would be rotated by the spinning black box upon which the

blades spun. Next, I attached two large wires to the motor. I then made

a circuit. This circuit was a littl e difficult to make. It had a place

for the wires from the motor, ran through resistors and a variable

resistor, and then an Ammeter and then the place where I was to plug in

the light. In parallel was a place for a battery and/or a voltmeter.

After a few minor adjustments, I was ready to test my product. At first,

when the circuit was completed, the current flow was very low. There were

a number of adjustments I had to make in order to make the windmill work

better. First, I moved the fan that was blowing air on the blades,

farther away. I added a seco nd fan and adjusted the angle of these two

so that they were blowing at the center of the windmill. I turned the

windmill around so that it faced away from the fans. I loosened the

screws that held the blades on. I inserted a piece of cardboard 1/3″ th

ick into this space. This was to adjust the pitch angle of the blades so

that they would “cut through” the air better. The adjustments I made were

excellent. They worked. When I connected everything, I began to notice

an immediate change in the Ammete r. I was seeing as much as 20 milliamps

and 6.1Volts. Before, there were 5 milliamps and 3.5 Volts. I began to

experiment more with the angles of the fans, distances, and stuff like

that. For my light source, I used a green light. It had an internal

resistance of 450 ohms. This bulb was 1/2 W. It lit up easily and was

bright. The Future

The Future will likely bring bigger and better things for the wind

turbine. Many new wind turbine models are being built. The wind turbine

holds much promise for energy production in the years to come.

BY DAN TORTORA

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