Wind Power

(History, Theory, Technology)

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October 29, 2001

Xcel Energy℠

I plan to provide some background information today:

The history, theory and technology of wind power.

The benefits and costs of wind power lie on a balance;

On the one hand wind is clean and replenishable,

on the other hand wind is intermittent and dilute.

Wind power has the promise of reducing the need for the burning of fossil fuels, tempered with the knowledge that because of the variability of the wind resource, wind power cannot be relied on to be there when you turn on the switch.

In order to provide customers with the reliability they expect and demand, other more reliable sources have to exist to back up any wind generation and be ready to pick up the slack during the times when the wind is not blowing.

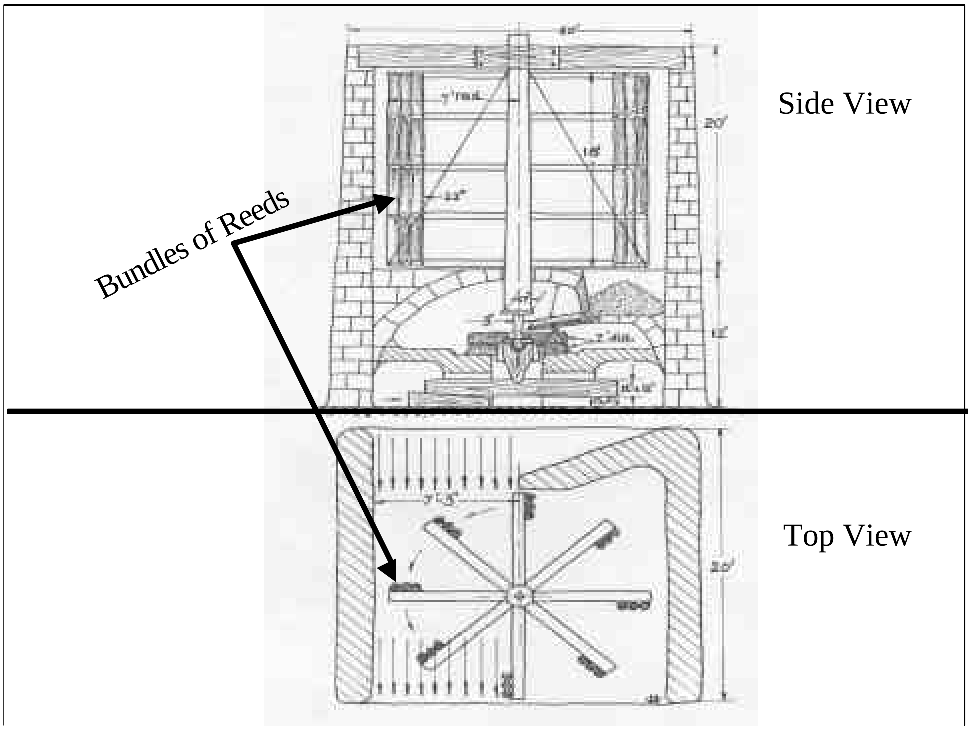
This fact increases the capital costs needed to integrate wind energy conversion machines.

History - Egyptians

The use of wind power by humans has a long history.

Wind power was probably first harnessed by the Egyptians for sailing.

The Nile river flows almost due north while the prevailing wind in the region blows due south. This coincidence allowed for the first sailing ships and helped to establish trade along the river that led to the worlds first great civilization.



History - Persian Grain Grinding

Although the Chinese were likely using wind to grind grain several thousand years ago, the Persians are credited with the first large scale development of wind machines for grinding grain.

This drawing shows a side view and a top view of a vertical axis machine using bundles of reeds for blades.

A wall protected half of the wind machine leaving the remaining half exposed toward the wind.

History - Mediterranean

Later horizontal axis machines spread throughout the Mediterranean area.

There are unique micro wind effects where water meets land. During the day the sun heats the land and the warmed air near the surface rises. As this air rises, cool air over the water rushes in to replace the partial vacuum. At night the reverse process occurs.

The benefit is that the wind direction in these areas is always toward the shoreline. Therefore simple machines with wooden booms and small jib sail clothes pointing in a fixed direction - toward the water - work quite nicely.

History - Europeans

The idea of wind mills was brought to Europe by returning Crusaders in the 12th Century.

This is a famous painting by Rembrandt from 1650 entitled “The Mill.” It depicts the technology that was prevalent in Europe at that time.

Because the wind direction in Europe was more variable than along the Mediterranean, the machine had to be able to be turned into the wind. The boom structure on the back side of this machine allowed humans or aided by oxen to turn the entire wind house into the wind.

The Dutch are credited with leading the way with technological innovations during this period. Machines like this were used extensively for draining the lowlands of the Rhine delta.

History - Cap Mill

This slide depicts one of the significant technological innovations that occurred by the 18th Century.

That is, rather than turn the entire wind house, why not move the turning mechanism up one story and just turn the cap of the wind tower.

This likely allowed for larger wind machines and led to the automation of the task of turning the machine into the wind.

While a few wind machines like this were constructed in North America, the plentiful flowing rivers allowed enough hydropower to limit the use of wind power in early America.

History - U.S. World Columbian Exposition

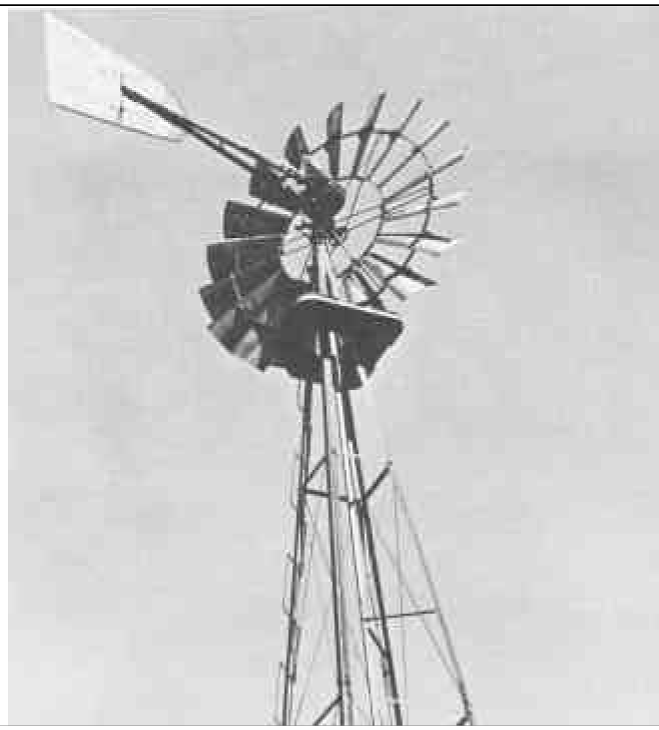
By the time of the World Columbian Exposition in Chicago in 1893 there were over 80 windmill manufacturers in the U.S.

By 1930 there were over 6 million of these type of machines in operation.

History - U.S. Water Pumping for transportation

As the United States expanded across the continent, railroads needed water at periodic locations between rivers.

Wind power provided that need.



History - U.S. Water Pumping on the Plains

Later wind machines were adapted for agricultural purposes on the Great Plains.

This is the kind of wind mill that was in operation when I was a kid. I got my first interest in wind power by climbing a windmill just like this.

History - Early Wind Electricity - Jacobs Wind Machine

During World War I American troops experienced and enjoyed electric lights in Europe.

This combined with the introduction of radio drove a market need to charge batteries for home radios.

In order to fill this market void, a number of tinkerers worked to develop a workable battery charger.

One successful inventer and devloper was the Jacobs Wind Charger.

History - Early Wind Electricity - Wincharger

Similar success was enjoyed by the Dyna Technologies of Sioux City, Iowa.

Their Wincharger became a popular model throughout the upper Midwest.

Both the Jacobs and the Wincharger machines were simple in their designs.

Both were mounted on 10 foot towers, and used wooden blades similar to airplane propellers of the time.

The blade diameters were 6 feet in length.

The generators were 12 Volt DC machines used to charge a bank of batteries normally located in a shed or in the basement.

History - Grandpa’s Knob, Vermont

No discussion of wind power history would be complete without noting the effort funded by Vanover Bush and designed by Palmer Putnam.

This large scale wind generator project began in 1934.

Putnam designed this behemoth with two 175 foot long blades, each 11 feet wide.

History - Grandpa’s Knob, Vermont Generating Machine

The tower stood 110 feet high and the electrical output could reach upwards of 1,250 kiloWatts of power.

The machine was completed in August of 1941 just before WWII.

It operated intermittently between numerous maintenance outages and within the constraints of wartime shortages until March of 1945 when one of the blades broke free and was launched into the next county.

History - U.S. ERDA Offering 1976

Following the Arab oil embargo in 1973 the US Government began an effort to stimulate alternative energy production technologies.

This slide shows one of the 4 machines that were tested around the country.

A nationwide bidding process for siting was undertaken.

Although SD entered a bid, the sites selected were Plum Brook, Ohio, Clayton, New Mexico, Culebra Island, Puerto Rico, and Block Island, Rhode Island.

These were 200 kW synchronous generating machines. The blades were 200 feet in diameter and the hub stood at 140 feet high. The important features to note are the 2 blade design and the synchronous generator required the blades to be finely and constantly controlled to maintain a constant rotational speed. (these were problems)

History - Tax Credits & Power Electronics

In the 1980s two things came together to launch the present era of wind energy conversion.

First, power electronics became available and the need for maintaining rotating blades at a synchronous speed was eliminated.

Secondly, federal tax credits became available.

These two factors together have driven the developments over the past 20 years.

This slide is from the Altamont pass east of San Francisco. There are about 7,000 wind machines in this area. Two other areas in California also are home to similar sized wind farms: Palm Springs and the Teuachi pass.

History - NSP’s Holland Project

This is a photograph of Xcel Energy’s first wind power effort.

These 3 wind machines were located on the Buffalo Ridge near Holland, Minnesota. The project was begun in 1986 and ran for about 10 years.

Each machine produced 65 kW of electrical power.

There were 2 generators in each nacelle. One was larger than the other.

Xcel Energy has now decommissioned these units.

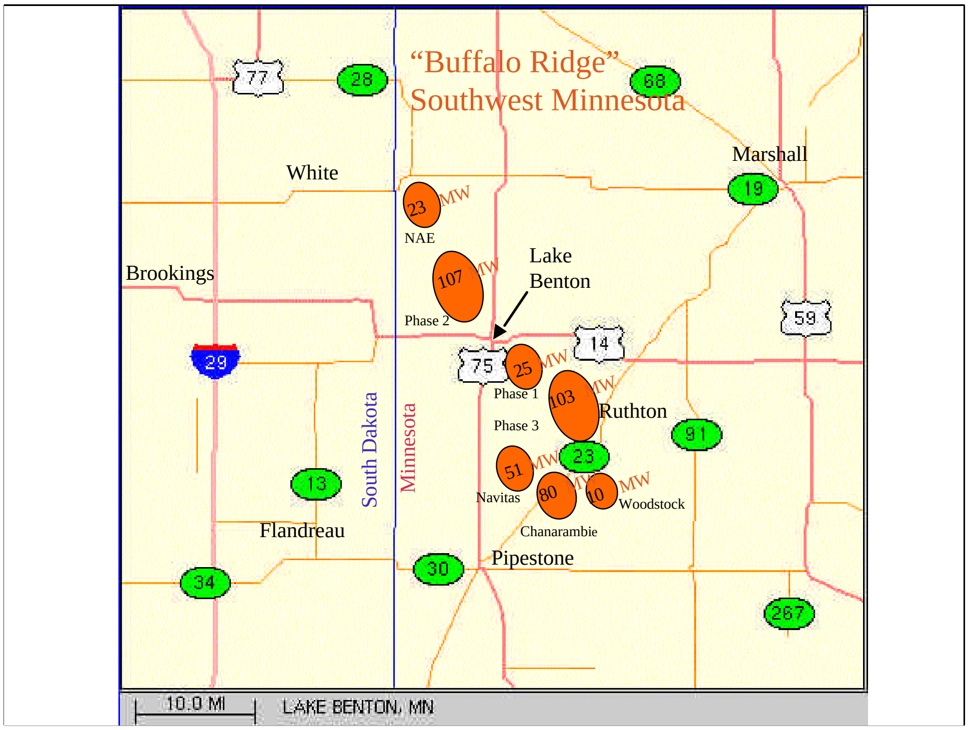
History - Xcel Energy’s Kennetech Project

The supplier to Xcel Energy’s first 25 MegaWatt project near Lake Benton was Kennetech.

They were located in Livermore, California near the Altamont Pass.

Kennetech has since gone bankrupt and this project is now owned by a group called the Wind Power Partners and is operated by Louisville Gas & Electric. This wind project is located just south and east of Lake Benton, Minnesota.

Xcel Energy purchases the power output from the 73 - 360 kW machines like this one at Lake Benton.



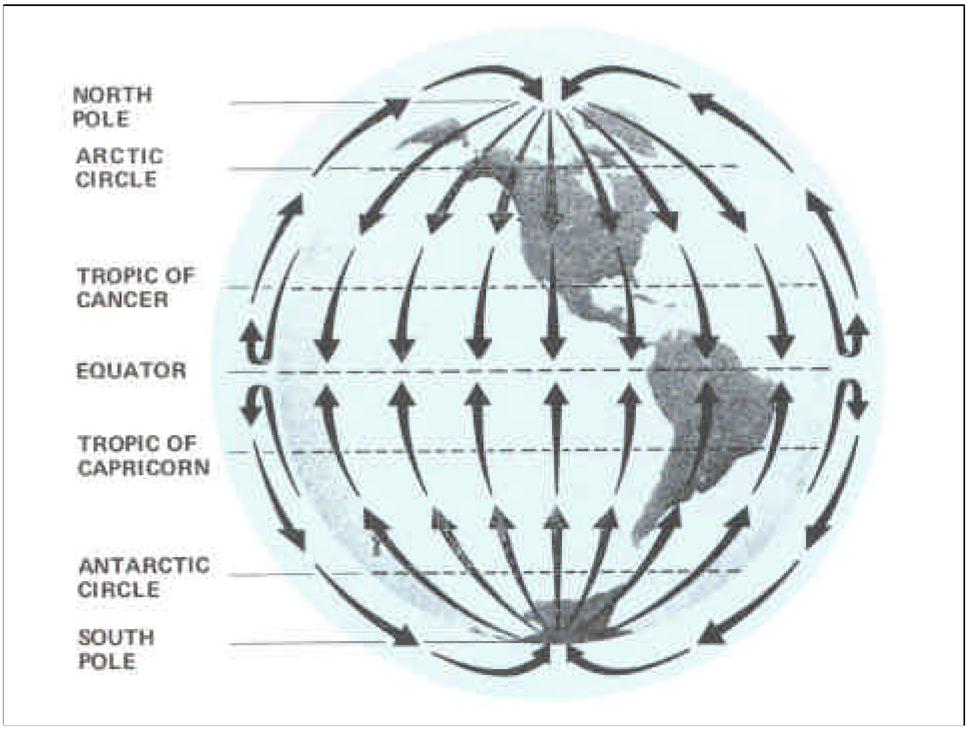
History - Buffalo Ridge, Minnesota

A subsidiary of Enron originally called Zond and now called Enron Wind constructed 281 wind machines in two phases. The first phase of 143 machines represent 107 MW of wind capacity and was completed northwest of Lake Benton, Minnesota in 1998. The second phase of 138 machines represents 103 MW of wind capacity and was completed near Ruthton, Minnesota in 1999.

A fourth phase of wind bids let included Northern Alternative Energies of Minneapolis. This project consisted of 33 machines producing 23 MW at two locations - Lakota Ridge and Shaokatan Hills both north of Lake Benton, Minnesota and north of the Zond Phase II project. Another project let consisted of 17 machines producing about 10 MW near Woodstock, MN. Another 50 or so machines representing 33 MW produced by a number of small companies are scattered throughout Minnesota.

Earlier this year bids were awarded to Navitas for 50 MW and to the Chanarambie Power Partners for 80 MW both to be constructed near Chanarambie, MN.

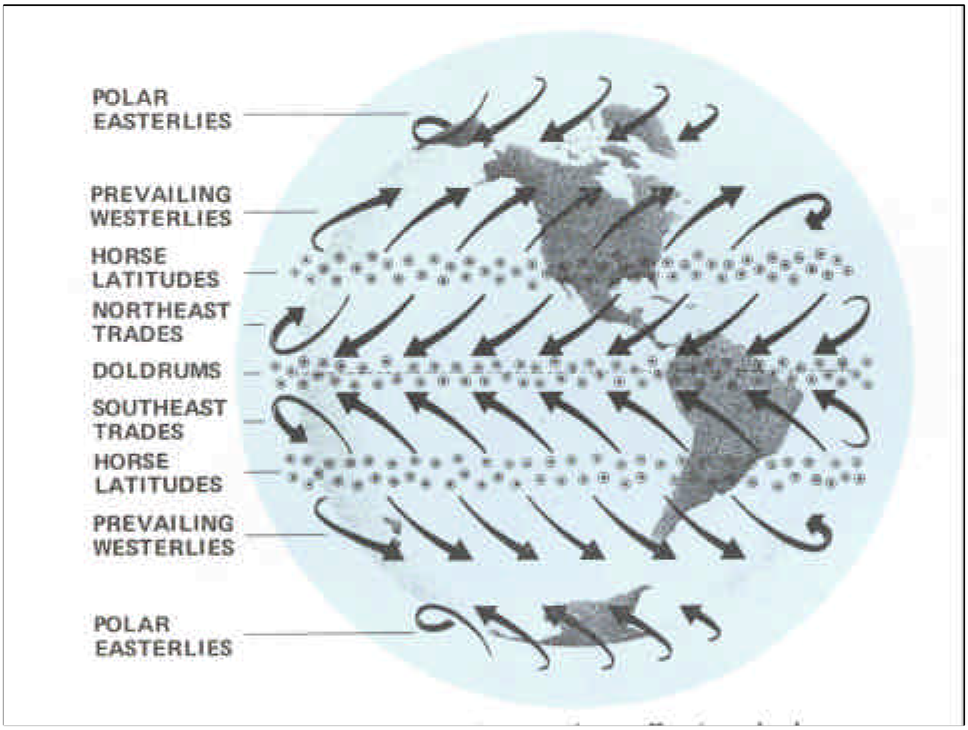
These projects will complete Xcel's 425 MW wind commitment to the MN Legislature.



Theory - Wind without rotation of the earth

Wind is caused by the unequal heating of the Earth's surface and is greatly affected by the rotation of the Earth.

Without any rotation, greater heating of the Earth's surface near the equator than at the poles would cause a general circulation of surface air from the poles to the equator with a return loop in the upper atmosphere.

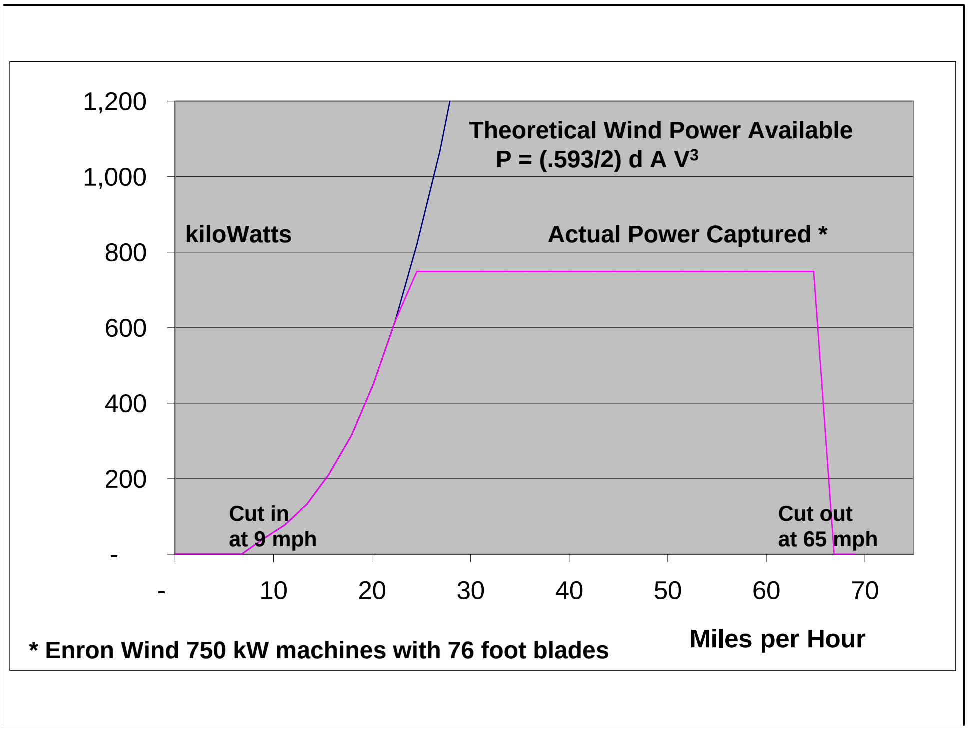


Theory - Wind accounting for rotation of the earth.

The west to east rotation of the Earth deforms the north to south ground flow of air. (This is called the Coriolis effect)

The Earth's surface velocity is about 1,000 miles per hour at the equator.

As the Earth turns toward the east the layer of air nearest the ground essentially "slips" over the land deforming the equatorial to polar returning air path and causing the swirling air flows as shown in this drawing.



Theory - Power in the wind

The power in the wind can be predicted with an algorithm. That is, power equals one-half the density of air multiplied by the swept area of the rotor and the cube of the wind velocity and constrained by the "Betz" theoretical limit.

Taking the wind power components one at a time:

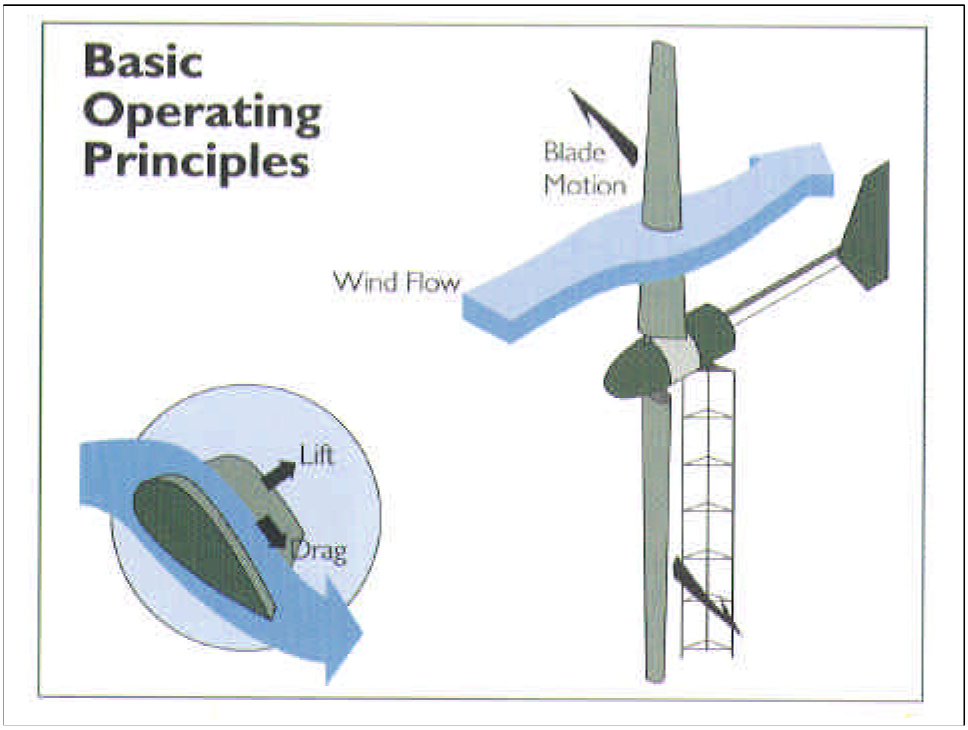
" Any wind machine has to allow air molecules to "slip" past the blades or they would pile up in front of the wind machine. This "Betz" limit has been determined empirically to be 59.3%.

" The density of the air can be as low as 1.0 gram per liter on a hot dry day in South Dakota to as high as 1.5 grams per liter on a cold wet day along the coast of the Netherlands. Density is a function of temperature, pressure and moisture content.

" The area swept by the rotor is determined by the design of the wind machine. That is, the square of the length of the blade radius (in Meters) times pi.

" **Most importantly, the power in the wind is directly proportional to the cube of the velocity of the wind (in Meters/Second).**

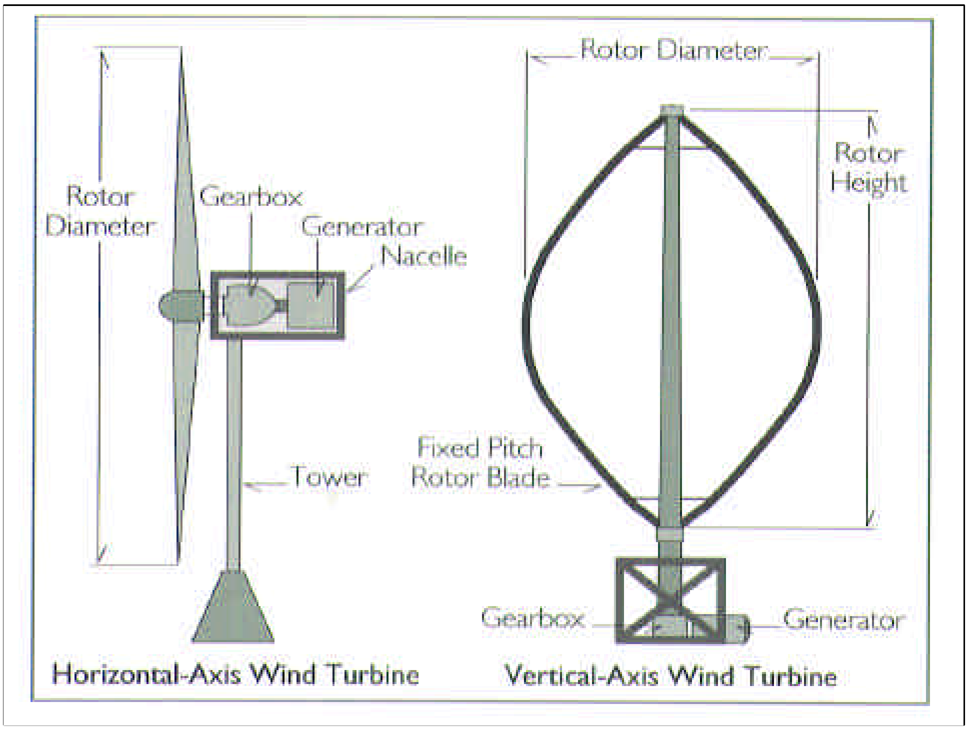
The actual power captured is limited by the size of the generator installed in the nacelle and the efficiency of the gearbox, mechanical systems, generator and electrical systems.



Wind Power Theory - Wing Lift and Drag

These diagrams depict the commonality between wind energy conversion and aeronautics.

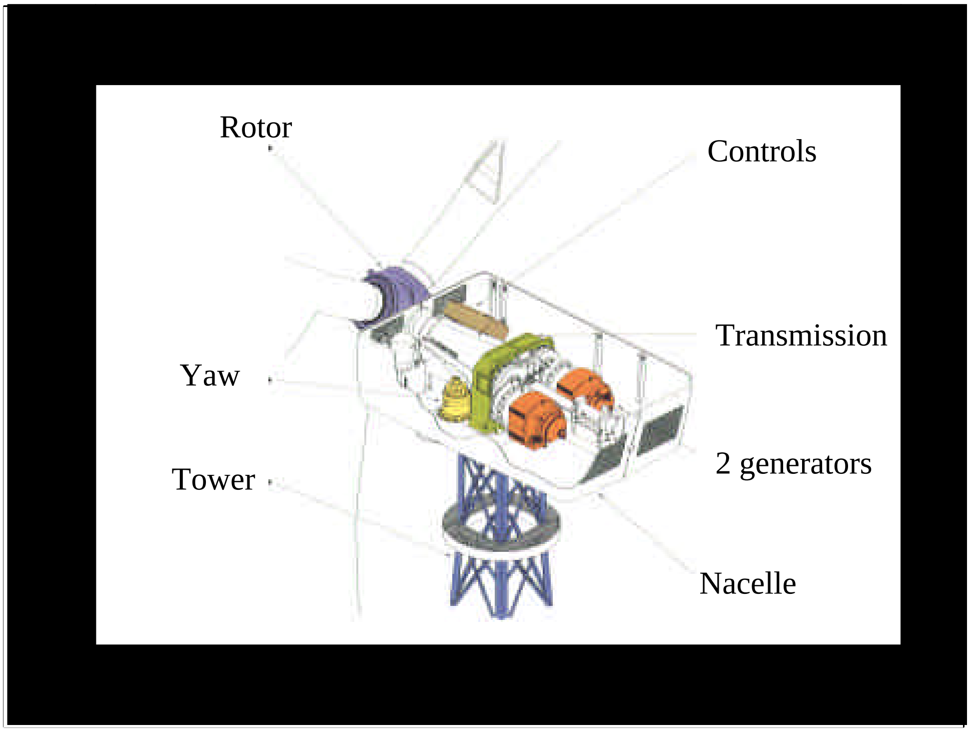
A rotating wind machine blade is much like a propeller on an airplane and follows the same principles of lift constrained by drag that an aircraft wing is affected by.



Technology - Taxonomy

The diagram on the right depicts a wind energy conversion technology commonly called an “egg beater,” but more properly termed a “Phi Darrius” rotor. It employs a vertical axis rotor and places the generator and gearbox in a more conveniently accessible ground location. This technology is pretty much out of favor in the wind power community

The diagram on the left depicts a more typical horizontal axis wind machine. The industry has pretty much settled on horizontal axis, upwind rotor, 3 blades, and variable speed as the standard. (at least for the time being.)



Technology - Nacelle

This drawing depicts the machinery inside the nacelle. (Kennetech Machine) In this case the rotating shaft connects to a gearbox that speeds up the rotational velocity and splits it driving two identical variable speed generators.

The concept of variable speed is important. Until power electronics came into being, wind machines necessarily had to produce direct current (DC) electricity or the machine had to be able to alter the pitch of the rotating blades to maintain a constant rotational velocity in order to drive a synchronous generator that would produce electricity matched to the 60 Hz power system.

Power electronics allows the application of a variable speed generator. The variable frequency electricity flows down the tower in power cables to the converter box where it is converted to DC and immediately inverted to a constant 60Hz sine wave by the power electronics system correctly matching the connected power system frequency.

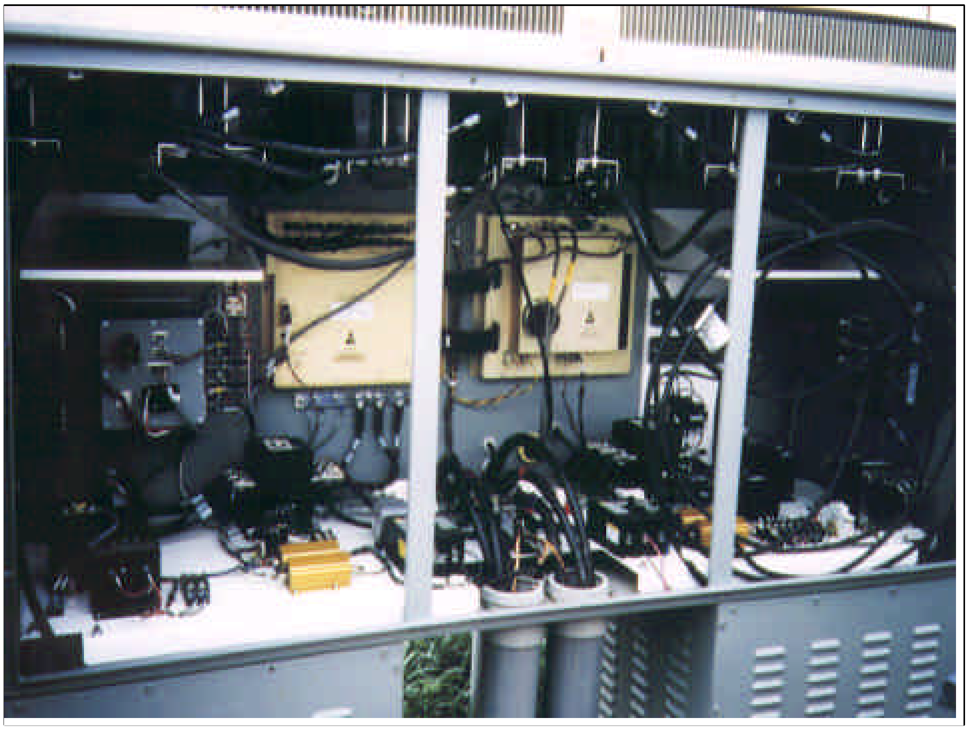
Additional mechanisms in the nacelle provide for yaw control, turning the wind machine into the wind.

Technology - Transformer and Power Conditioning

Each machine has its own transformer and power electronic conditioning box.

The variable speed generators in the Nacelles produce electricity of varying frequency. That alternating current electricity is converted to direct current in this box and then immediately inverted to a constant 60 Hertz alternating current that appropriately matches the frequency of the interconnected power system. The voltage is also stepped up to the collection system voltage and transmitted to the substation for further transformation.

A 34.5 KV distribution collection system connects these boxes to the Buffalo Ridge substation.



Technology - Power Electronics

Inside the cabinet, the power electronics package converts the variable frequency power of the generator to direct current (DC) and then inverts the DC to a constant frequency power as needed by the power system and as expected by the customers of the utility.

The total harmonic distortion (THD) of the quality of the output power is specified to be less than 1%.

Technology - Concrete Foundation

This slide shows the construction of a typical tower foundation. The foundation is comprised of steel rebar reinforced concrete slab 37 feet by 37 feet by 3 feet thick about 10 feet below the ground. This slab is connected to the upper slab with a cylinder of reinforced concrete. The upper slab is 15.5 feet by 15.5 feet by 6 feet thick.

This totals to over 400 Tons of concrete including 4 tons of steel reinforcing rebar.

Technology - Tower Construction

The Zond towers are 168 feet tall and each weighs about 63 Tons.

Each blade is 76 feet in length and each blade weighs about 2.8 Tons.

The nacelle, generator, gearing and equipment add another 32 Tons for a total above ground weight of about 100 Tons.

Xcel Energy Project

This photo depicts a number of wind machines on the Buffalo Ridge in Minnesota.

Conclusion

Wind is clean and replenishable, but intermittent and dilute. That is, there are few environmental impacts from generating electricity with wind. The wind blows frequently, but not all the time. (In fact the wind blows strong enough to make electricity about 1/4 of the time) In order to capture a significant amount of wind energy, we would have to construct many many wind machines all across the countryside.

The bottom line is that you cannot rely on wind power to be there when you walk to the wall and turn on the switch. Because of this fact, we also have to construct an equal amount of conventional fired generation to backup the wind machines in order to be able to provide electricity whenever the wind is not blowing.