The History and Science of the Modern Wind Turbine

Ty Whatley

University Physics II
Dr. John Stewart
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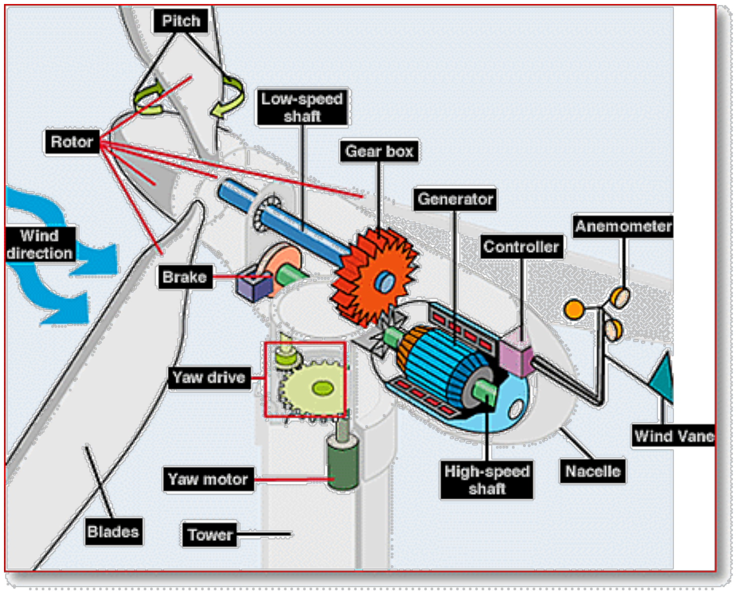
Windmill and wind turbines have been used for centuries by many different civilizations for many different uses. The first windmills of record sprang up in Persia around 500-900 A.D. These first windmills were used to draw up water and to power grindstones to mill grains into flour (Dodge 2006). The first windmills used a vertical axis system constructed of lightweight materials that created aerodynamic drag, which was connected to a shaft that was connected on the other end to the grindstone or pump mechanism and in return moved the grindstones or the water pump.

This technology was not completely revolutionary at the time. Humans had been using wind power for travel in sailboats since ancient times, but as far as efficiency goes, this development was a huge step forward. Before the emergence of windmills, humans had used man or animal power to run such machines in a slow process that was very difficult work. Since this early use of wind power, this technology continued to spread into Europe and around the world and ever since and has since been effectively used to achieve higher efficiency.

Wind energy is still being used to this day and making a strong push in the United States and around the globe as a very solid contender to be one of the frontrunners in the search for safe, clean, and efficient sources of alternative energy to replace fossil fuels. This goes to show that although wind energy is very low-tech and elementary, it is still just as relevant today as it has been for more than a thousand years previous.

Modern wind turbines are much more high tech than the primal forms of windmills and wind pumps yet contain the same basic purpose. The turbines today can generate massive amounts of electricity in a relatively short amount of time. The outer appearance is relatively simple with one very tall tower—the higher up the tower stands the more wind it is subject to— that contains a rotor and three blades that can reach as much 150 feet long. The rotor is connected to a shaft that is turned by the blades and rotor when the wind blows, but only at about eighteen revolutions per minute. In order to generate electricity the main shaft is connected to a series of gears that vamp the last shaft up about one thousand eight hundred revolutions per minute. This shaft spins within a generator and thus creates very large amounts of electricity and outputs a vast amount of energy. The blades of the turbine are similar to the wings of an airplane, in that they are curved so that pressure is higher on one side than it is on the other which causes them to move and spin due to Bernoulli's Principle. Each turbine also contains a wind vain that is connected to a computer that takes in the direction of the wind and adjusts the pitch of the blades and uses a yaw drive and yaw motor to rotate the entire rotor to the correct orientation in order for the blades to create the correct variance in pressure in order to spin.

This explanation and the diagram included below are referring to basic wind turbines and the basic physics and engineering that go into the making of general turbines and their generation of electricity. There are several different manufacturers of windmills and there are more and less complex versions of the wind turbine. They can range from General Electric Wind Energy's new 3.6 megawatt turbine that is one of the largest prototypes ever built all the way down to turbines that produce less than 200 kilowatts—rougly 0.05% or the GE mega turbine—that are used to power homes or water pumps such as rural wells.



http://www.eere.energy.gov/

Anemometer: Measures the wind speed and transmits wind speed data to the controller to be analyzed and moved to the correct orientation in respect to wind direction and speed.

Blades: Most turbines have either two or three blades. The blades turn due to lift explained by either Bernoulli's Principle or Newton's theory of lift. (Technically either is correct)

Brake: the brake stops the rotor in emergency situations, such as excess winds, and is applied by various methods.

Controller: The controller is the computer on-board the turbine that controls it's movement based on wind direction and also determines when the machine runs and doesn't run to save money and ensure that that machine is not damaged. The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

Gear box: what connects the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 rotations per minute to about 1000 to 1800 rotations per minute, the rotational speed required by most generators to produce electricity. The gearbox is a very expensive part of the turbine. Engineers are currently looking at ways of improving this mechanism or going to a drive that connects the low-speed shaft directly to the generator and producing a generator that can output energy at such low levels of mechanical energy.

Generator: Is generally a run-of-the-mill induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator after being spun by the gearbox connected to the low-speed shaft that is rotated by the blades.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: Contains the gearbox, low- and high-speed shafts, generator, controller, and brake.

Pitch: Blades are turned out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together form the rotor.

Tower: towers are made from either steel or concrete. The towers are generally very tall due to higher wind speeds at the higher altitudes. Taller turbines capture more wind and are generally more efficient.

Wind vane: Measures wind direction and communicates with the yaw drive to the correct orientation of the turbine with respect to the wind.

Yaw drive: The yaw drive is used to keep the rotor facing into the wind as the wind direction changes.

Yaw motor: Powers the yaw drive.

There is large variety of different types of turbines that started fairly simply and have continued to be improved and, to some degree, even reinvented. And to this day, technology is still being heavily researched and the best and most efficient turbines are sought after. The Gedser wind turbine ushered in the current era of electricity-producing wind turbines in 1957 when a turbine was produced that cranked out 200 kilowatts of power. In the early half of the 1970's similar turbines were produced using similar, but cheaper components—such as used car parts—but only generated around 20 kilowatts of power. In the time since then the wind turbine has been reinvented and generate much more power— upwards of 3 megawatts (3000 kilowatts) as compared to the previous 20 kilowatts—while using essentially the same design as the Gedser generator. The biggest design changes to the wind turbine during that time include varying pitch blades, a modification of the electric field, and switching from asynchronous generators to synchronous generators or asynchronous generators with wound rotors. The biggest electrical change to the turbine has been the shift to variable speed generating mechanisms that allow the wind turbine to produce more efficiently at various wind speeds.

The designs of wind turbines can vary greatly between models from the "conventional" turbine that was used in the 1980's and 1990's that was simply an upwind, stall-regulated, three-bladed asynchronous turbine that used an induction generator—a cage rotor—all the way up to the current model used some manufacturers today that are multipole wound synchronous generating system turbines that use a rectifier and frequency converter to convert the power to the grid and achieve variable speed capabilities without a gear box. And as the demand for these turbines goes up as a form of alternative energy, it is expected that the designs will become more and more complex to in order to output more and more amounts of power with the same amount of wind (Hanson 2001).

There is also much science, and particularly physics, as to why wind turbines are garnering more and more support as a highly viable source of alternative energy. One reason for all the support is simply because of how much energy can be created. Even small farms can generate enough energy using simple electromagnetic principles to power as many as nine thousand homes and larger farms can be sustainable for many, many more making this a very efficient source of energy. The key to this massive power output is the recent integration of the variable-speed and pitch-controlling turbines. It has been shown that because of these new technologies, electricity can be produced at any wind speed and any rpm and the only limiting factor is the upper limit rating of the converter and generator. The turbines are also able to produce significant amounts of electricity at very low wind speeds by maximizing the pitch angle to its optimal setting (Muljadi 1999). These key innovations to the wind turbine are what is making the wind turbine such a useful instrument in the production of electricity on both large and small scales from enormous wind farm productions to personal wind turbines to help ease the sting of the electric bill.

But some of the downsides to wind power are that it is not constant and that air is not very dense. According to research done at the electrical engineering department of the University of Ryukyus in Okinawa, Japan, one effective way to counter this is to build the turbines with rotors that act as inductors in the circuit to act as a power leveling device. This helps to smooth out the power output of the turbine during varying winds by storing energy during acceleration and restore power during deceleration. (Senjyu 2008)

The research of the optimization of the output of wind turbines is becoming a very widely researched field. The placement of the turbines in a wind farm is also being researched in China. The placement could affect the wake of the wind coming off the turbine and the ideal placement of these turbines could lead to great improvements in the output of electricity by the turbines. In the study, the wind turbines were placed in various alignments and were tested in different categories for efficiency to show that the placement of each turbine and the overall pattern did in fact alter the productivity and efficiency of the farm as a whole. (Feng 2009) Further research has been done showing the optimal number of turbines and the spacing between each turbine can help to boost the efficiency and total electricity output of a farm. To have the least deflection of wind and reduction of output and efficiency of downwind turbines, it is ideal to have the least amount of turbines in the most amount of space, assuming that you position them in a square alignment. This means that having a two by two arrangement over the same are as a ten by ten square will yield a higher efficiency per turbine. (Masters 2004)

Wind energy is also receiving backing because this method of generating electricity is completely clean, renewable, and wind is free. This appeals to many because current power producing methods can be harmful to the environment such as coal producing disturbing amounts of carbon dioxide (CO_2) and nuclear plants producing harmful radioactive byproduct. And the fact that wind is completely renewable and natural lures in even more. One of the largest problems with fossil fuels is the crippling dependence on foreign countries to supply the fuel.

Wind turbines can also make economical sense in ways other than simply reducing dependence on other forms of energy production. If a school or university set up a single or series of wind turbines to produce its own energy, said school will not only no longer have an electric bill, but any excess electricity produced can be sold to the city and pumped into the public grid, creating a source of revenue for the school. (Gevorkian 2007)

But like everything else, there are also downsides to the use of wind turbines. Some environmentalists are unhappy that due to their mechanics and engineering, the turbines make too much noise. There have also been many reports of birds flying into the blades and being killed that are disturbing to some. Others also complain that the large and bulky turbines are eyesores to the landscapes on which they are placed.

Another one of the more challenging problems with wind energy is finding places where wind farms are sustainable. Since the earth's atmosphere is made up of gas, it is an enormous fluid. Since fluids transfer heat very easily, wind is created when there is a significant difference in temperatures of the atmosphere. This generally occurs in remote places such as mountain ranges in the deserts and wide-open fields on the prairies and Great Plains. This is a problem for two main reasons; the first being that there are so few places to put them, and the second being that the few places that the turbines can be put are generally sparsely populated. Since electricity generally does not do well travelling long distances, transferring this electricity to more densely populated is a problem.

To deal with this problem, scientists are coming up with new places to construct these wind farms and the most viable new location is offshore. There is a very steady wind that comes off the ocean at almost all times and developers want to capitalize on this. The wind is also generally faster offshore than on land which aids the push to move farms to the ocean and the environmental impacts are less at sea than on land. All of these factors are compiling to have a significant push in Europe to begin building the wind farms at sea. (Fox 2007) Other solutions include placing them atop mountains in areas where there are more populated mountain communities to justify building them in areas such as Hawaii and various European countries.

Another setback for wind energy is the high cost of initial setup of the wind farms. A well-built wind turbine can be very costly due to all the research and development that went into the production of the turbine. All of the electrical parts of the machine that produce the electricity contribute greatly to the cost of the overall machine. High quality circuit materials, magnets, and wires are difficult to produce and are therefore expensive to buy. It is currently cheaper to set up traditional fossil fuel energy plants currently and these plants can also be set up just about anywhere and very close to cities making them tough competition for the budding wind power industry.

Yet another drawback of wind energy and wind turbines is that their full potential can never be completely ascertained. Some can get fairly close to converting one hundred percent of the kinetic energy of the wind to rotational energy of the blades to electrical energy from the generator, but overall the complete efficiency and utilization of the energy of the wind is not quite achievable yet. This is due in part to stints of "unavailability" during times of repair and maintenance. The time that the wind turbine is non-functional results in a decrease in overall yearly efficiency and output and causes the turbine to be less efficient. The lapse in efficiency is also caused by the frequent unavailability of the wind. There is never a wind that is active at all times and this too hurts the efficiency of the wind turbine. (Hau 2006)

Wind turbines and the concept of wind energy encorporate massive amounts of science and, in particular, physics to usher in a whole new era of possibilities and potential for a rapidly growing field of alternative energies that will eventually challenge and replace the current giants of the energy industry.

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