“Think Global, Act Local” Project

Kidwind Project: Mini Vertical Axis Wind Turbine

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ABSTRACT

In order to educate the UVA and Charlottesville-Albemarle communities on the viability of wind energy, our team constructed and tested several wind turbine designs, including both horizontal and vertical axis turbines. Our hypothesis was that the design which would perform the best would be the vertical axis turbine. This model will be used in conjunction with other materials to educate the community on wind turbines, specifically small-scale vertical axis turbines, as a feasible option for improving sustainable energy practices in the area.

INTRODUCTION

Project Definition

Our "Think Global, Act Local" project addresses the promotion of renewable energy and conservation within UVA and the surrounding area of Charlottesville. Specifically, our group was looking to create awareness and educate the UVA community about the benefits of wind as an alternative energy by creating our very own wind turbine.

The two designs we built used a KidWind generator that we purchased online. Kidwind is a for-profit company which has been the leader of clean energy education for nearly a decade. The company runs workshops for educators, provides supplies to students and curriculums for instructors, and hosts Kidwind Challenges for high school students.

The remaining components of our wind turbine we have chosen to be as sustainable and energy-efficient as possible. For example we used recycled wood from the wood shop in Campbell Hall at the University of Virginia, reused a Barnes and Noble plastic shopping bag and old notebook subject dividers. At the core of our mission, we attempted to design a turbine that is as energy-efficient and affordable as possible for a renewable energy generator of this size; with further time, more money, and greater expertise, the pioneering engineers of sustainability can use our designs and research as a foundation for further and more refined development.

Horizontal-Axis Style Turbine

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. A servo motor is a rotary actuator that allows for precise control of angular position and is usually used in robotics or machinery and automated manufacturing. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

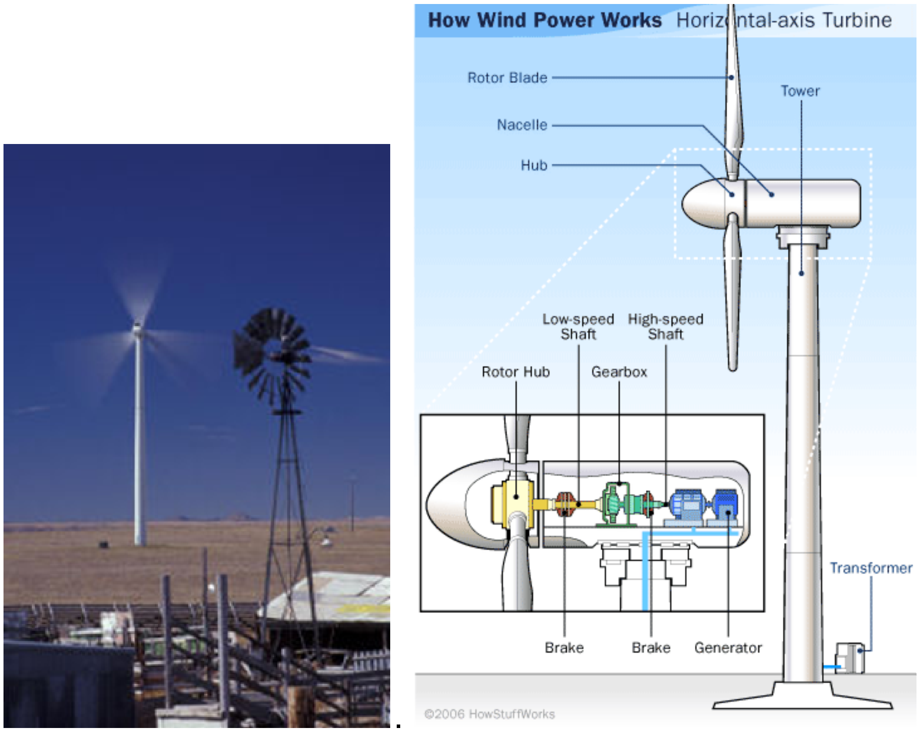

Figure 1. Horizontal axis wind turbines. Photo courtesy of Kidwind. Diagram courtesy of How Stuff Works.

Because a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

Downwind machines have been built, despite the problem of turbulence (mast wake), because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the blades may bend, which reduces their swept area and thus their wind resistance. Since cyclical (or repetitive) turbulence may lead to fatigue failures, most HAWTs are of the upwind design

Turbines used in wind farms for commercial production of electric power are usually three-bladed and pointed into the wind by computer-controlled motors. These have high tip speeds of over 320 km/h (200 mph), high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from 20 to 40 meters (66 to 130 ft) or more. The tubular steel towers range from 60 to 90 meters (200 to 300 ft) tall - wind speeds are greater at higher elevations. The blades rotate at 10 to 22 revolutions per minute. At 22 rotations per minute the tip speed exceeds 90 meters per second (300 ft/s). A gearbox is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but variable-speed turbines, which use a solid-state power converter to interface to the transmission system, can collect more energy. All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind, which ceases their rotation, supplemented by brakes.

Disadvantages to the horizontal wind turbine style include that most require winds over 10 miles per hour. Once the wind is strong enough, these turbines actually become less efficient at producing power in winds over 90 mph. These turbines cannot withstand extreme weather conditions, such as heavy snow, frost and freezing rain or winds over 110 mph. Additionally, the cost of building, maintaining and repairing these tall structures can be expensive. The gearboxes and excessive yawing due to design (the turbine must always face the wind) reduce the lifespan of horizontal axis wind turbines. Other concerns include noise pollution (as these structures can be quite loud) and their lack of visual appeal to the general public.

Vertical-Axis Style Turbine

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360-degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype.


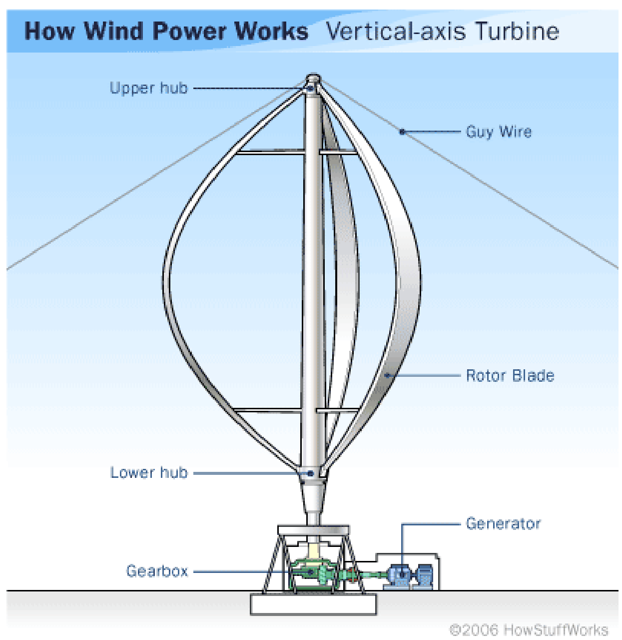

Figure 2. A vertical axis wind turbine. Photo courtesy of Kidwind. Diagram courtesy of How Stuff Works.

With a vertical axis, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, therefore improving accessibility for maintenance.. When a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. It should be borne in mind that wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

PLANNING

This project is not to create a large-scale wind turbine to power high-powered electronics, but it is a small-scale study model for students and residents of the county to learn from and become more aware of the possibilities of wind turbines in this area. For our study, we constructed both the horizontal- and vertical-axis turbines. The efficiency of each different design was compared in experiments that mimicked (to the best of our abilities and resources) the conditions of Albemarle County.

We bought the MINI Wind Turbine kit from KidWind in order to use some of the included materials in our designs and construction. Specifically, we used the triple-bladed plastic assembly, the generator, the wires, and the voltmeter from the kit. The blade from this kit was only used in one of our three proposed designs, however the generator and wires were used in all three designs to convert the generated energy to the cell phone we attempted to charge. The voltmeter was used to measure the energy produced. In addition to these purchased parts, we manufactured two different styles of blades ourselves. Also, we designed and constructed the proposed electricity converter ourselves.

Figure 3: Battery Power Source and USB Charger for Turbine

In our experiments, we tested different materials and designs and how these affected the amount of power produced by the wind turbine. We compared S-curve blades of felt in a vertical design against S-curve blades of plastic, against the purchased, pre-manufactured plastic triple-blade of the horizontal design. We individually tested each of these three designs on the generator and measured its voltage-efficiency. We used a small fan to blow wind onto each type of wind turbine and each blade in order to be able to more easily control the wind and have a constant wind flow.

Our hypothesis was that the S-curve blades of plastic in the vertical design would produce the most electrical power. We believed that the vertical-axis design would be more efficient than the horizontal-axis design because it easier adapts to constantly-changing wind directions. Furthermore, of the two proposed vertical-axis designs we believed that the blades made from plastic would be more efficient than those made from felt because plastic sports greater wind-resistance, thus spinning the dowel faster and generating more power.

DESIGN

We constructed three different wind turbines, each to test a different efficiency factor; two of these three we have designed completely from scratch. For our first model, we constructed a conventional, horizontal-axis wind turbine using the plastic blades included in the KidWind Mini Turbine Kit that we purchased. These three, angled blades rotate counter-clockwise and perpendicular to the ground, and adapt to changing wind-directions with the vane attached to the rear of the generator.

The other two designs are of the vertical-axis type. Due to the fact that the generator was designed by the original manufacturers to be parallel to the ground, we created a base that holds the generator sideways. This base is made out of wood so that it is strong enough to keep the vertical blades upright in the wind (Figure 4). In both of our vertical-axis designs, a wooden dowel no more than 2 inches in diameter and 9 inches in height stands straight up from the generator.

Figure 4: Wooden Base

Figure 5: Cutting the dowel

Attached to the dowel are four 'wings' set in a cross pattern at both the top and bottom of the dowel. These wings, also composed of wooden rods, are approximately 5-inch frames for our vertical blades (Figure 6). These blades, because of their S-curves, spin counter-clockwise and parallel to the ground. Each of the four blades on both designs have about 40 square inches of surface area.

Figure 6: Drilling the "wings"

In the first of our vertical-axis designs, the four blades are made of thin, moderately flexible plastic (Figure 7). In the second, the blades consisted of a more permeable, felt-like material. Both designs will shape the blades into an S-curve, therefore causing the wind to invariably push our blades in one consistent, desired direction (counter-clockwise).

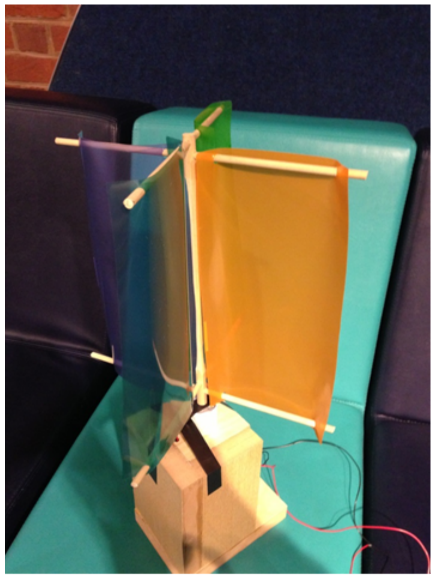

Figure 7: Plastic Blades (not shaped in S-curve)

CHALLENGES

We faced several problems early-on with our project. First off, we did not expect that a turbine of this size could generate enough electricity to charge a cell phone. The reason being that, when wind turns turbine blades, it turns the turbine's wheels, which turns the turbine's belts, which in turn turns a generator. Inside the generator, a coil of copper spins between a couple of magnets. This creates an electrical field that is made into DC current. The DC current passes through multiple rectifiers that convert the DC current into AC. AC is the type of current a typical household outlet uses. Then, the AC current runs to either your home or a power plant for distribution across several neighborhoods or in our case into your cell phone. In order to charge a cell phone, we were going to need to create a mini power converter that would take in the DC current and convert it into useable AC current. This is a significant challenge because the mini wind turbines that we are creating struggle to produce energy comparable to the speeds of conventional methods, such as power outlets. With a larger turbine, this challenge could have been addressed, but we as a group decided not to spend hundreds of thousands of dollars to construct a large wind turbine somewhere in Charlottesville. Nevertheless, we do want to build a mini turbine that might actually interest observers, so we have created a USB charging hub that attaches to the turbine. The charging hub's power is supplemented by several AAA batteries. Neither the batteries nor the turbine would be capable of charging a smartphone on their own, but together they are able to do so. This actually serves as a valuable metaphor for educating the community on how turbines can be integrated into existing power grids as supplemental power sources.

Later in our design process, we encountered another significant challenge. That is, after completing the design of our vertical-axis blade-frame in AutoCAD, we found out that the cost to 3D-print it would exceed $300. This was too expensive for us to pursue because we had no funding besides what our group wanted to pay out-of-pocket. So even though the 3D-printing avenue turned out to be a dead-end, we backtracked a step and continued on in a different direction. That is, we decided to keep the same design but instead construct it from different, cheaper materials. This called for slight modifications in our planning and a delay in our construction, but nothing so severe that completely halted our progress.

CONCLUSION

The purpose of our "Think Global, Act Local" project was to create awareness of wind turbines as a viable renewable energy source. We hope that after this demonstration on Sustainability Day, people within the UVA and greater Charlottesville community will have a better sense of how wind turbines work and the different design options that are available. Furthermore, from our experimentations with different blade materials and blade designs, we have concluded that it is possible to use recycled materials for parts that work. However, we found that material choice and the dimensions of the material are very significant for a successful design because the weight of the turbine is negatively correlated with the efficiency of the turbine. We believed that our demonstration would prove that the S-curve blades of plastic in the vertical design would produce the most electrical power and be the most energy efficient, because it easily adapts to wind variability,however we found that at a scale this small, vertical axis turbines are less efficient because of the weight put on the low-speed shaft. Though, if we decided to continue this process and further improve our design by using better/lighter material, making the turbine fan a smaller size, and designing a fan that can catch the wind better (i.e. helical design), our future research could discredit this finding.

We are very grateful that we were able to consult the Virginia Center for Wind Energy as well as Remy Martin Pangle at JMU, on any questions or concerns that we had throughout the process. During the course of this project, we have reached several challenges, and we realize that obstacles are nearly unavoidable when it comes to the design process. Despite these challenges, we feel that our final demonstration serves as a foundation for further development of wind turbine models, and we can only hope that our ideas will influence future sustainable designs that will be used in the greater Charlottesville area and possibly beyond.

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