Vertical-Axis Windmill Design and Implementation

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Abstract

The world's need for energy is consistently growing, and so is the demand for fossil fuels. At our current rate of consumption, we will not be able to sustain the future demand for fossil fuels, and the associated negative environmental effects of carbon emissions will continue to harm the planet. To keep up with the growing demand for energy and lessen the dependence of fossil fuels, we need to move towards more sustainable solutions with alternative energy technology. The alternative energy market has been decentralizing (i.e., many production sources are spread out across a large area) rather than maintaining one central production location. A decentralized alternative energy market allows each individual in a community to sustain themselves and the network if a node goes down. The concept of this project, which features a vertical-axis windmill, is to move forward with the design of individual sustainability. The vertical-axis windmill presented is cost effective, small, and can sustain a load. The vertical-axis windmill will be comprised of three parts: propellers, a gearbox, and a generator. Each part has a separate function. The propellers turn wind energy into mechanical energy, the gearbox increases rotational speed, and the generator converts mechanical energy to electrical energy.

I. Introduction

Wind energy has exhibited the most rapid growth of all renewable energy because it is a free and natural energy source [1]. We need a windmill in order to collect wind and use it for making energy [2]-[11]. A windmill converts the wind's kinetic energy into electrical energy by using a generator. There are essentially two types of windmills: the horizontal-axis windmill and the vertical-axis windmill. The former device rotates in the horizontal plane and the latter device rotates in the vertical plane. The vertical-axis windmill has a simpler design than its counterpart in that it does not require a yaw control mechanism, but designing and implementing one still has its challenges.

In this paper, we explain the vertical-axis windmill design concept, show measurement results of our design through voltage vs. rpm, current vs. rpm and efficiency vs. rpm plots, and present concluding remarks based on our project experience.

II. Vertical-Axis Windmill Design Concept

Most of the parts can be found online through websites such as eBay or Amazon. However, most of them can also be cheaply outsourced by going to used car lots instead. Since we desired a cost effective and clean energy source, we used recycled or repurposed parts to create our windmill.

First, we had to determine what kind of wind patterns to expect throughout the year in our area to decide on the style of our windmill. We decided to build a vertical-axis windmill because horizontal-axis windmills face only one direction and thereby receive wind from one direction, whereas vertical-axis windmills can receive wind from any direction. This makes the vertical-axis windmill more cost effective than the horizontal-axis windmill.

Furthermore, another advantage of the vertical-axis windmill is the amount of space that the vertical-axis windmill takes up compared to the horizontal-axis windmill. The horizontal-axis windmill utilizes a large propeller and has substantial height. A vertical-axis windmill does not need to be as tall or wide to receive as much air as a horizontal-axis windmill because it does not require as much air to start and maintain a steady speed.

We next had to determine what kind of motor, generator, or alternator to use in our windmill. We ended up choosing a power steering motor (i.e., 2003 Cobalt engine) since it was the most cost effective (i.e., obtained for free). This motor produces about 12V at 1800 rpm. Since we needed to create 13V to feed power back into a car battery that powers the motor, we used a pulley or gearing system to reach higher revolutions for the required voltage. The drive shaft of the motor is ¾ of an inch, so the gear needed to be roughly 25 inches wide to create 13V. The windmill needed to spin at 60 rpm to create this power output.

The blades were made out of PVC pipes cut up into pieces, which allowed the blades to catch the wind from any direction and rotate easily. Each PVC pipe is about 6" in diameter and cut into 2 sections. Although the blades are capable of catching wind from any direction, the blades were placed at a slight angle to rotate counter clockwise to optimally catch wind, since wind typically comes from the southeast during most of the year in Northern Indiana.

The battery powering the windmill is a regular rechargeable car battery that can be easily removed for mobile charging. The battery can be charged via a wall outlet, which can charge small electronics such as cell phones, mp3 players, and even laptops. Depending on the wind speed obtained, the motor should create about 200W of power and convert it to roughly 8A of current that is outputted to the wall outlet. Most car batteries charge with about 3-5A of current at roughly 12-13V.

The most difficult and troublesome part was figuring out the best solution for the breaking system. Our main solution includes electronic regenerative breaking to put a heavier load on the motor to make it stop or slow its rotations. In order to create breaking system circuitry that will not overheat and melt the motor, the circuit includes a combination of resistors, power transistor, voltage dividers, and Zener diodes.

III. Implementation

A. Propeller Design

The propeller converts the wind energy to rotational energy. Propellers are critical because they need to be as lightweight and as strong as possible. A propeller needs to be light so it can convert as much of the wind energy that hits it to mechanical energy. At the same time, it needs to be strong enough to prevent buckling under its own weight or the force of the wind. To achieve a good strength to weight ratio, PVC piping was used for the propeller blades. The blades were cut in half in order to create a "C" shape that is ideal for catching the wind. In total, 5 blades were used and positioned seventy-two degrees apart so that the wind can be caught at any angle. The propeller design is shown in Figure 1.

Figure 1. Propeller design

B. Gearbox

The gearbox converts the propeller's rotational energy to different speeds. The gearbox is essential because the generators need to be at certain speeds to produce power as efficiently as possible. After some research, it was found that most small windmills do not utilize a gear box and have the axis of rotation mounted directly to the generator. This is because the gearbox introduces losses in the system by decreasing efficiency through friction losses and increasing the torque needed to start and keep the windmill running. Regardless, for the sake of the experiment, the gearbox was used in hopes that a balance could be found to maximize efficiency. For the experiment, 3 different gear ratios were used: 1:1, 5:1, 15:1. Figure 2 depicts the gearbox. The schematic diagram of the gearbox is shown in Figure 3.

Figure 2. Gearbox

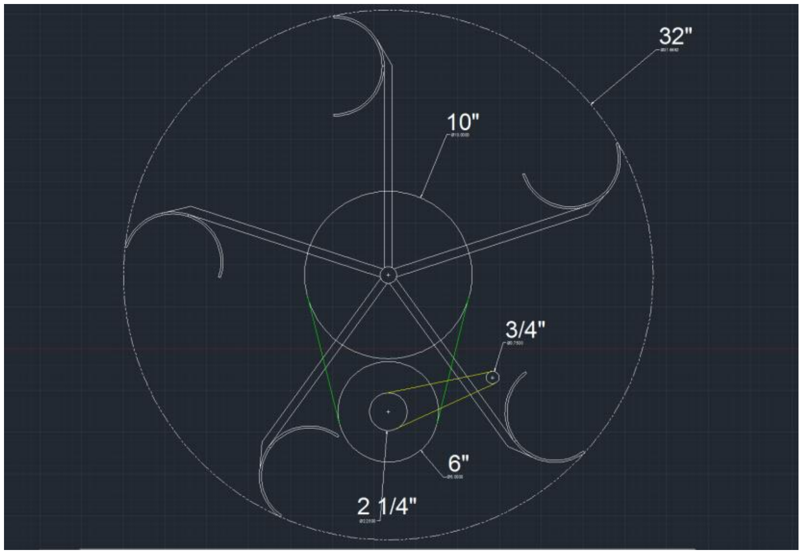

Figure 3. Schematic diagram of the gearbox

C. Generator

The generator converts mechanical power to electrical power. It is frequently used in daily life, from providing the power that comes from wall outlets to recharging a car battery. Generators require three characteristics in order to be functional: movement, magnetism, and wire. The movement is provided by the propellers, the magnetism is provided by either magnets or a field coil, and the generator is wire wrapped around the armature which provides the wire with an induced current. During this experiment, two types of generators were used: a permanent magnet motor and a car alternator. Their power generation at different speeds were measured to determine the most efficient generator for the windmill. Figure 4a and Figure 4b show a permanent magnet motor and a car alternator, respectively.

Figure 4a. Permanent magnet motor

Figure 4b. Car alternator

IV. Measurement Results

In this section, we compared the measurement results for motor and alternator. Table 1 shows the data for real life as a reference. Under the same rpm condition, the measured voltage and current for alternator and motor are shown in Table 2 and Table 3, respectively. As a result, we obtained about 7.52% efficiency rate in case of motor.

Table 1. Data for real life

RPM	Voltage (V)	Current (A)	Power (W)
70	245.2	2.1	514.92
115	244.9	2.1	514.29
190	245.2	2.1	514.92
300	240.8	2.1	505.68
460	244.8	2	489.6
755	244.5	2	489
1255	244	2	488
2000	243	2	486

Table 2. Data for alternator

RPM	Voltage (V)	Current (A)	Power (W)	Efficiency (%)
70	0.09	0.003	2.7E-4	5.24E-5
115	0.1	0.005	5.0E-4	9.72E-5
190	0.2	0.008	1.6E-3	3.1E-4
300	0.3	0.010	3.0E-3	5.93E-4
460	0.4	0.012	4.8E-3	9.8E-4
755	0.6	0.015	9.0E-3	1.84E-3
1255	0.74	0.019	1.406E-2	2.88E-3
2000	6.5	0.035	22.75E-2	4.6E-2

Table 3. Data for motor

RPM	Voltage (V)	Current (A)	Power (W)	Efficiency (%)
70	0.3	0.5	0.15	0.03
115	0.38	0.5	0.19	0.04
190	0.7	0.9	0.63	0.12
300	1.25	1.2	1.5	0.30
460	2.1	1.5	3.15	0.64
755	3.6	2.0	7.2	1.47
1255	6.4	2.8	17.92	3.67
2000	10.15	3.6	36.54	7.52

Figure 5, 6, and 7 show the comparison of voltage vs. rpm, current vs. rpm, and efficiency vs. rpm for motor and alternator, respectively.

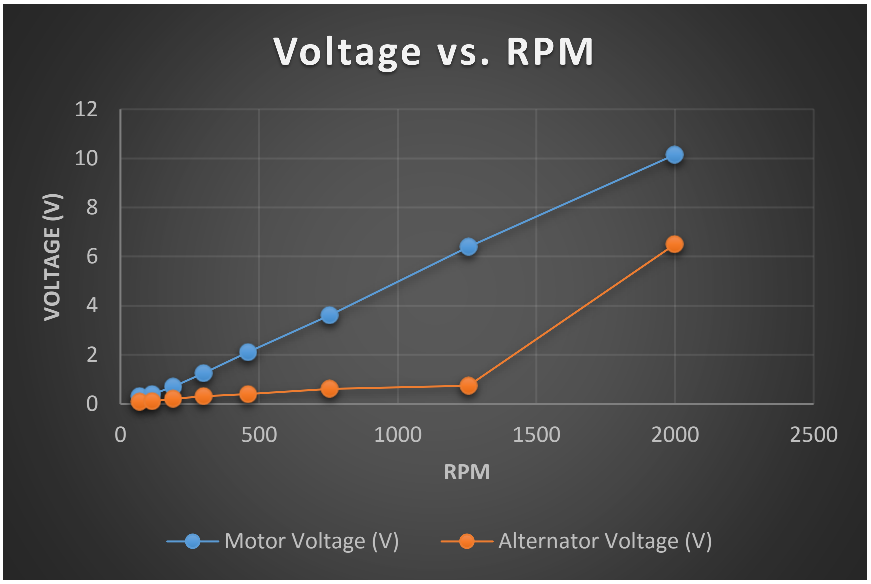

Figure 5. Comparison of voltage vs. rpm

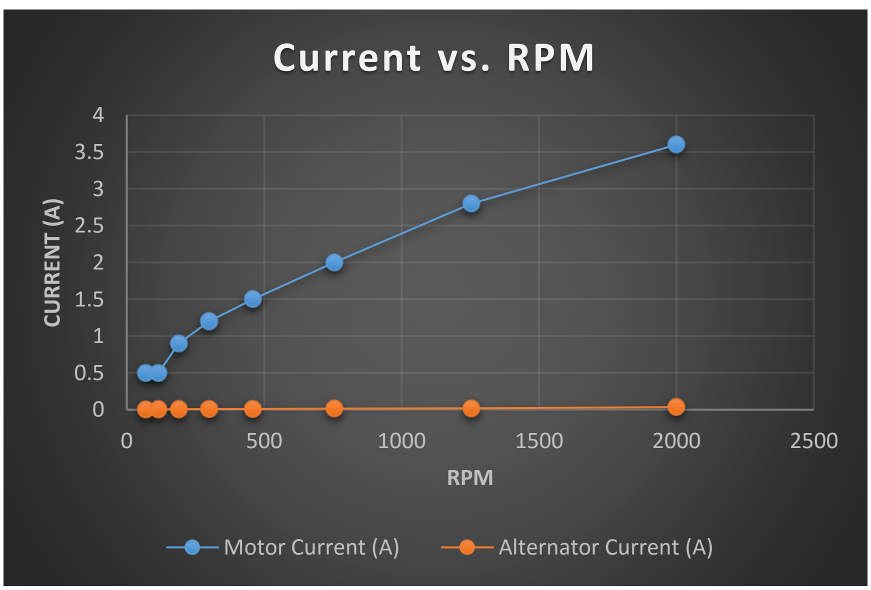

Figure 6. Comparison of current vs. rpm

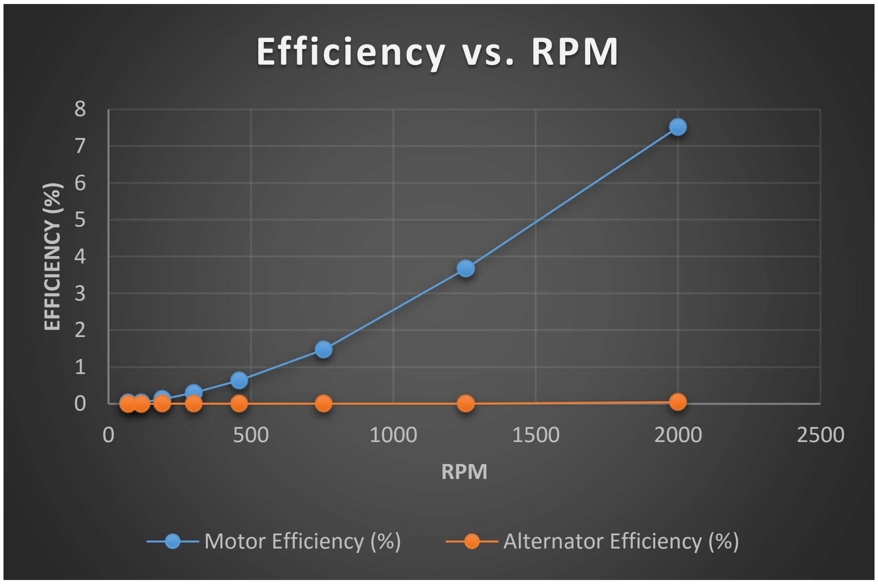

Figure 7. Comparison of efficiency vs. rpm

V. Lessons Obtained from Projects

As with any design project, there were different hurdles and roadblocks along the way. The biggest hurdle with this project was the timing. It was not expected to take as long as it did which forced the project to go in a different direction than was originally planned.

The first dilemma in this experiment was comprehending the mechanical concepts behind windmill creation. Our team had to take unconventional approaches in order to learn more about the mechanical design processes. Building the propellers was difficult because it had to be fabricated from scratch, and the measurements taken were not as precise as they needed to be. This made the design difficult because every part had to be hand fit. This method was not modular, so if one piece broke, another had to be custom made. The initial design had several design flaws with the largest being the gearbox. At the time, it was unknown as to what amount of torque was needed at a higher gear ratio. After researching the topic more, it was discovered that most small-scale wind turbines are direct drive. This changed the design to a 1:1 ratio.

Second, it was discovered that the propellers were located too far from the axis of rotation. This resulted in an increase in the moment of inertia and a decrease of angular velocity in the blades.

Finally, the motor and alternator used in this experiment were either too inefficient, or they could not generate the power needed at lower speeds. In hindsight, a generator should have been custom made with many windings and a smaller gauge wire than what was used in this experiment.

VI. Conclusion

For our senior design project, we decided to do a windmill project. At first, we thought this would be a very basic project that would teach us about the natural resources that are not being utilized enough in the United States. Since two of our group members already work within the solar industry, we decided to go with a wind power-based experiment to provide us with a challenge instead. It gave us a better holistic mechanical understanding because of how much mechanical knowledge was required just to create the physical windmill. After the windmill was built, the electronics compilation was easy enough with our only big obstacle being the selection of our power generator and creating the pulley set up. We decided to add both a data logger, for real life data, and calculated data in order to compare the two data sets. Although our project did not produce as much power as we had initially intended, it could produce a decent amount of power given the efficiency rating being calculated at 7.52%. Overall, the project taught us about motor selection, power production, efficiency ratings, mechanical design, problem solving, and other skills. This project was also aligned with STEM education goal due to necessity of hand-on skill when we completed the windmill design.

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