



A STUDY OF WIND TURBINE DESIGNS

JULY 25, 2001

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## INTRODUCTION

Making electricity from fossil fuels causes more air pollution than any other industry. Wind energy is much cleaner than non-renewable energy, and wind turbines take up less space in comparison to the mining and drilling for fossil fuels. The burning of fossil fuels such as oil and coal can cause global warming. “With today’s technology, wind energy could provide 20% of America’s electricity with turbines installed on less than 1% of the land area. And within that area, less than 5% of the land would be occupied by wind equipment; the remaining 95% could continue to be used for farming and ranching” (Green Mountain Energy Company 2001).

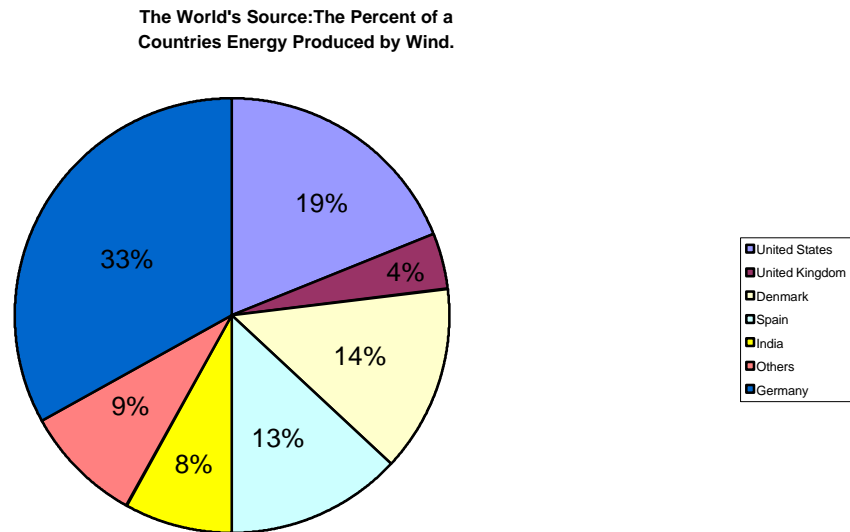
Windmills have been used for the past 1,000 years. Grain grinding was the first documented windmill application. The original windmills were developed to automate the tasks of grain grinding and water-pumping (Dodge 2001). Since 1875, windmills have been used for small scale purposes, but when the Industrial Revolution occurred, towns started to grow and windmills became less and less efficient to use. The first use of a large wind turbine to generate electricity was a system built in Cleveland, Ohio in 1888 by Charles F. Brush (Krohn, 2001).

The earliest known wind turbine design is the vertical axis system developed in Persia about 500-900 A.D. During World War II, the Danish engineering company F.L. Smidth built a number of two- and three-bladed wind turbines. All of these machines generated direct current (DC), which is the flow of electricity in a straight line (Dodge 2001). In the 1950’s, Johannes Juul developed the world’s first alternating current (AC) wind turbine, in which the flow of electricity is alternating, at Vester Egesburg, Denmark (Krohn 2001).

The teams went to the Green Mountain Wind Farm to check out wind turbines in action. The turbines located there produced a maximum of 10,400 kilowatts. The turbines power approximately 2,500 homes per year in Pennsylvania and New Jersey. There were eight turbines

with three ninety-foot long blades. Each complete wind turbine stands 200 feet high and weighs approximately five tons.

The purpose of this study is to find out which wind turbine design will produce the most voltage. The different variables tested included the blade angle, hub height, length of the blades, and the number of blades. Each of these variables is very important to determine the most successful design for the wind turbine. The hypothesis is that the forty-degree angle, the fifteen-foot height, the two-foot long blades, and the eight bladed wind turbine will produce the most voltage.



## METHODS

For the site selection, Dan's Rock, a rocky overlook on the top of Dan's mountain was chosen. The elevation of the site where the study was done was 2,898 feet, and it was chosen because it was one of the highest points in the area. It was important to choose a high area because the wind speeds are higher at the top of a hill or mountain than at its base, and obtaining higher wind speeds is important for significant voltage output. The site was visited before the

testing actually began and was quickly selected because the winds there were relatively higher than at the bottom of the mountain. Another reason that the site was selected was that it was above most of the trees and any other large objects that could block the wind or cause turbulence, allowing turbines to access the best wind flow possible. Moreover, another reason why the site was picked is that it was very easily accessible by car, which meant that the equipment and tools could be hauled safely and quickly to the site without any complications.

The turbines were built with blades that were different lengths (See Figure 1). The lengths were one-foot, two-feet, and three-feet long. The blades were attached to one-foot metal bolts by silicone caulk. These blades were then screwed into a metal hub, which was attached to a DC motor. The hub could hold a maximum of eight blades. The motor was then attached to a wooden mounting block by a sheet of metal and screws (See Figure 2). The whole arrangement was then attached to a metal pole by a mounting bracket on the bottom of the mounting block. The poles that were used were five and six-feet long. The group attached the poles to create six feet, eleven feet, and fifteen-feet poles. Then the wind turbine was lifted into the air and anchored down by rope and lots of duct tape.

During July 9 to July 12th, the testing was conducted from approximately 10:00 A.M. to 3:30 P.M. On the first day, there was no testing due to the lack of wind. The number of blades and angles of blades were tested on the second day. There were five teams, and each team tested a different number of blades, which included two, three, four, six, and eight blades. During a five-minute trial, the teams collected the voltage and wind speed at ten second intervals. After the five-minute interval, the teams retested the blades twice more.

For the angles, each team had to test two different angles from 0 to 90 every 10 degrees. The group set their blades to the first angle and tested it three times. Then the groups set their

blades to the second angle and tested it three times. Each time, the angles were tested in five-minute trials with ten second intervals.

On the third day, the lengths of the blades were tested. There were two groups who tested the one-foot blades, and one group for the two-foot blades. Each group tested three times. This repetition was to ensure that there was enough data for each one of the blade lengths.

On the fourth day, the researchers tested the height of the hub, at 6feet, 11feet, and 15feet. By this time, there were only three groups testing, allowing each group to evaluate one specific height. Each group tested their height three times for the five-minute trials.

Graphs were created to show the comparison between the wind speed and voltage produced for each of the variables. A linear trend line was used to show the comparison between each of the variables. Another graph was made for each variable in order to compare the design that had the most voltage production for all trials.

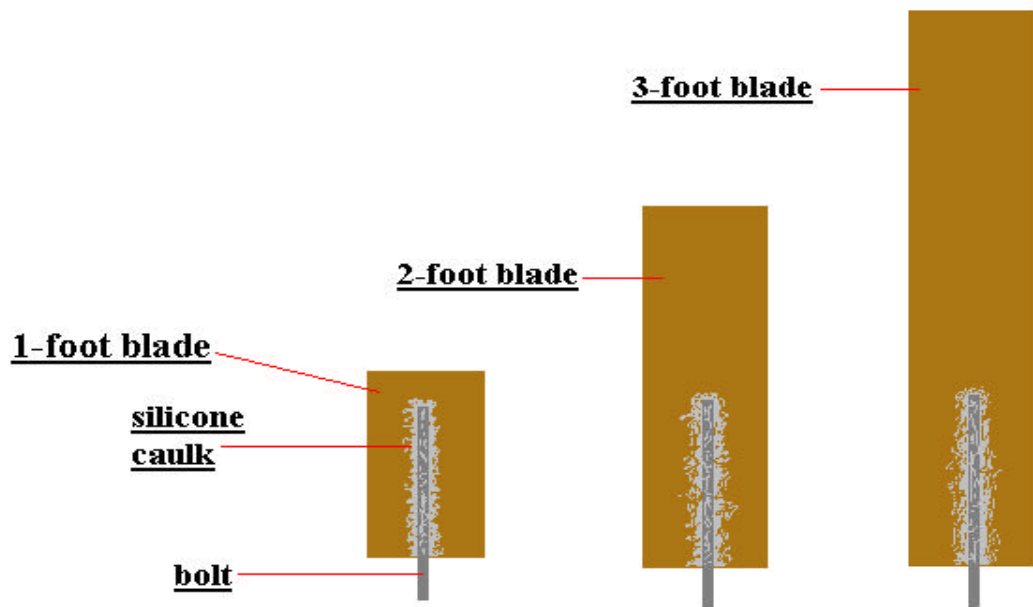


Fig.1. – This figure shows the different blade sizes.

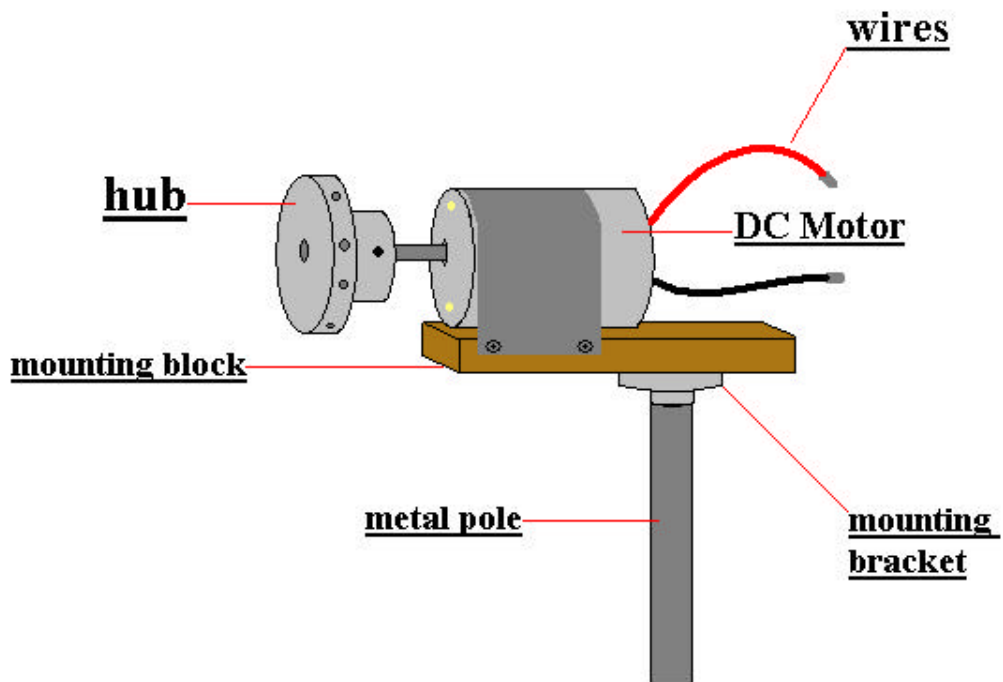


Fig. 2. – This figure shows the different parts of a wind turbine.

## RESULTS

The graphs show that four blades produce the most consistently high voltage. These findings were found on all of the three trials (See figures 3, 4, and 5). The variables that were constant were the blade angle at forty-five degrees, blade length at two feet, and the wind turbines height at eleven feet.

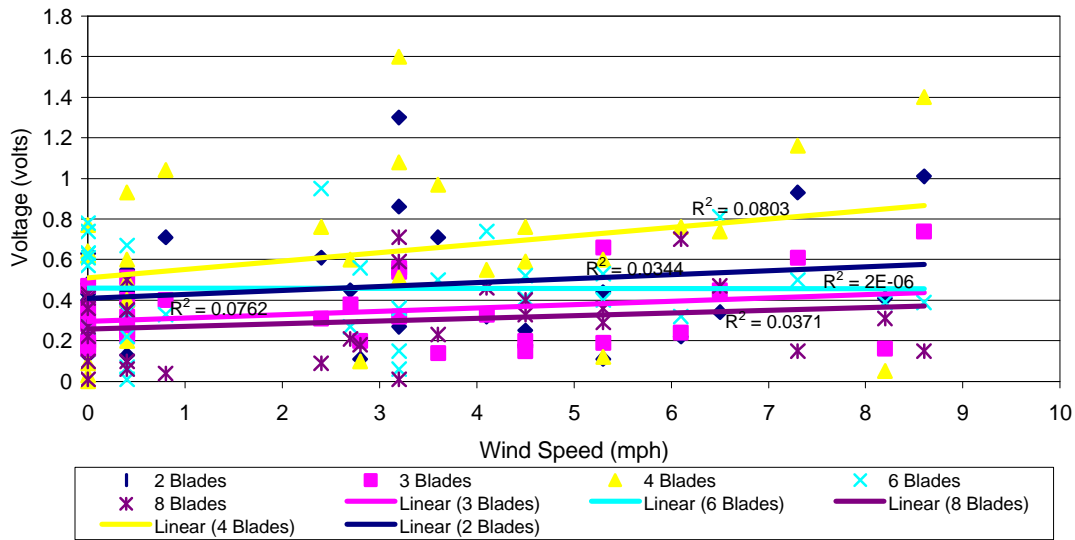


Fig. 3. - This graph shows voltage vs. wind speed for the varying number of blades (trial 1).

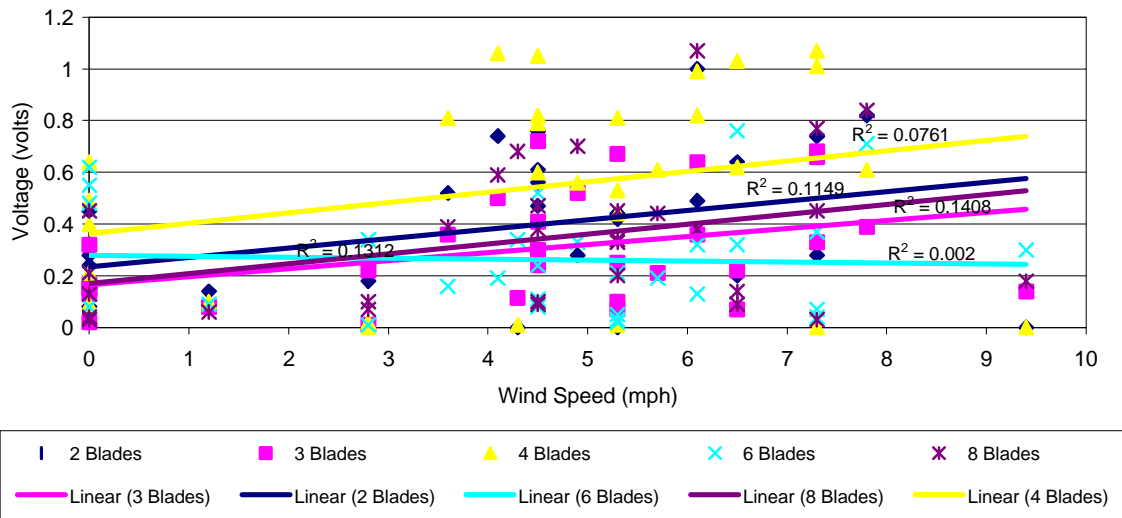


Fig. 4. - This graph shows the voltage vs. wind speed for the varying number of blades (trial 2).

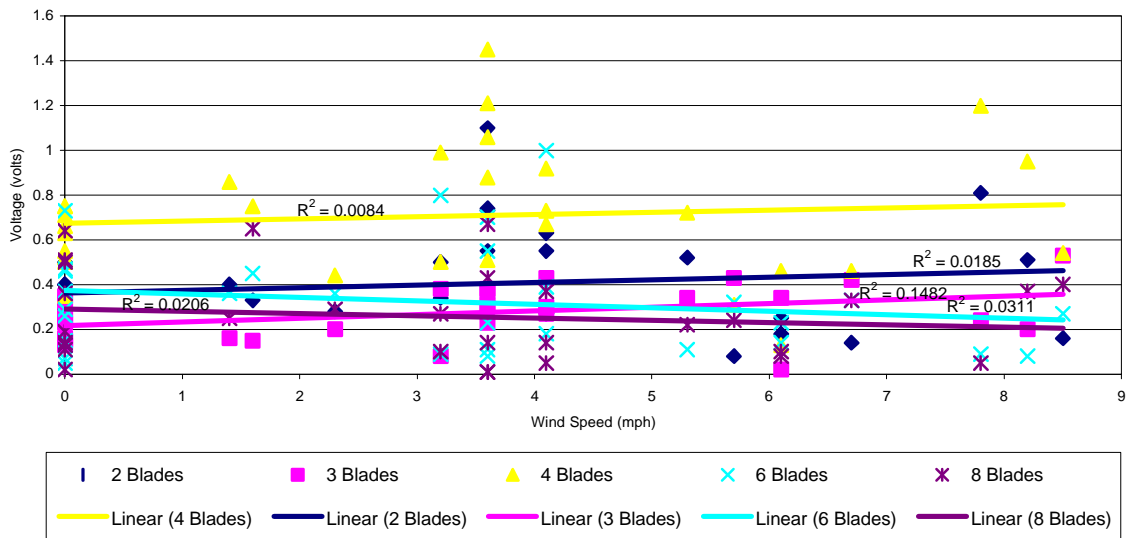


Fig.5. - This graph shows the voltage vs. wind speed for the varying number of blades (trial 3).

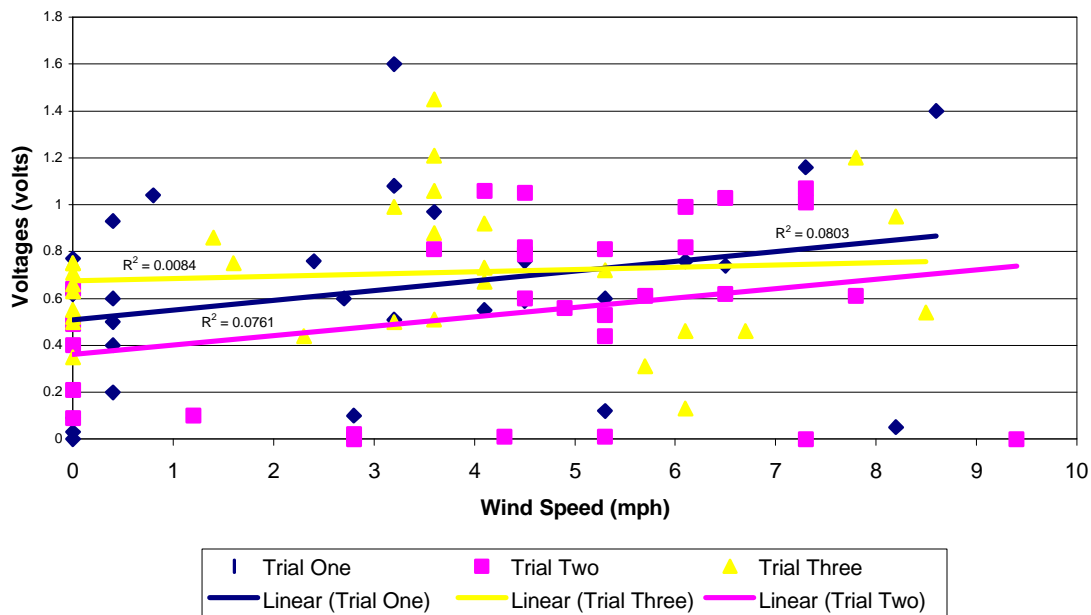


Fig. 6. – This graph shows the voltage vs. wind speed for the trials of four feet blades.

The angle tests showed that the best angle was between ten and twenty degrees (See Figures 7-12). For the first three trials, twenty degrees had the highest voltage, and for the last three trials, ten degrees had the highest voltage. The first three trials tested zero, twenty, forty, sixty, and eighty-degree angles, and the final three trials tested ten, thirty, fifty, seventy, and ninety degree angles. Figure 13 is a graph comparing the results of the ten and twenty degree tests. At low speeds, the twenty-degree test had more voltage, but the ten-degree test's voltage increases at a larger speed than the twenty-degree test.

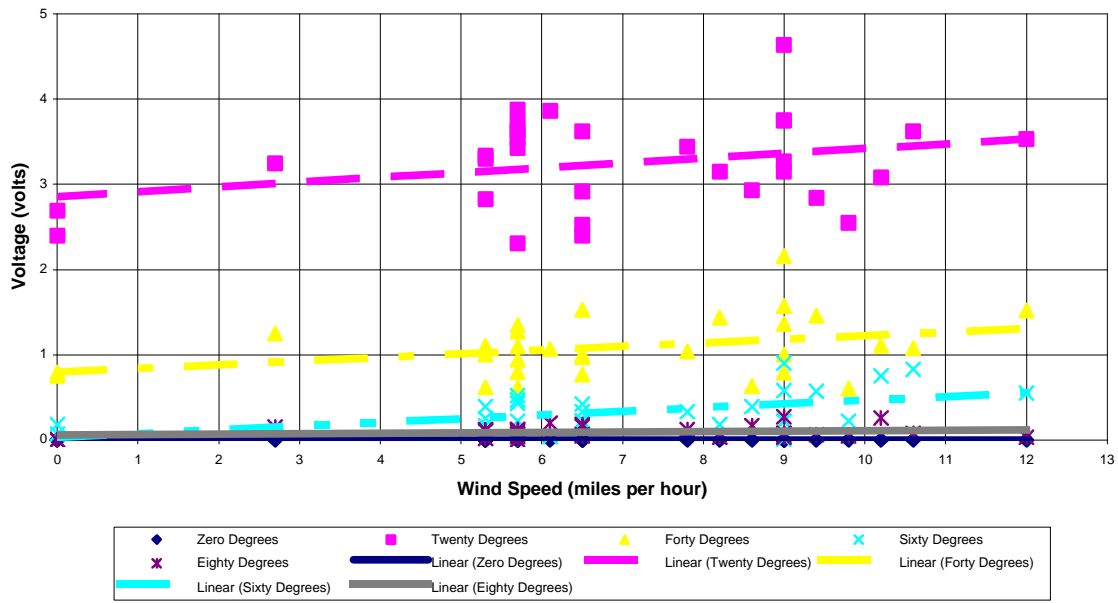


Fig. 7. – This figure shows voltage vs. wind speed for varying angles (trial 1).

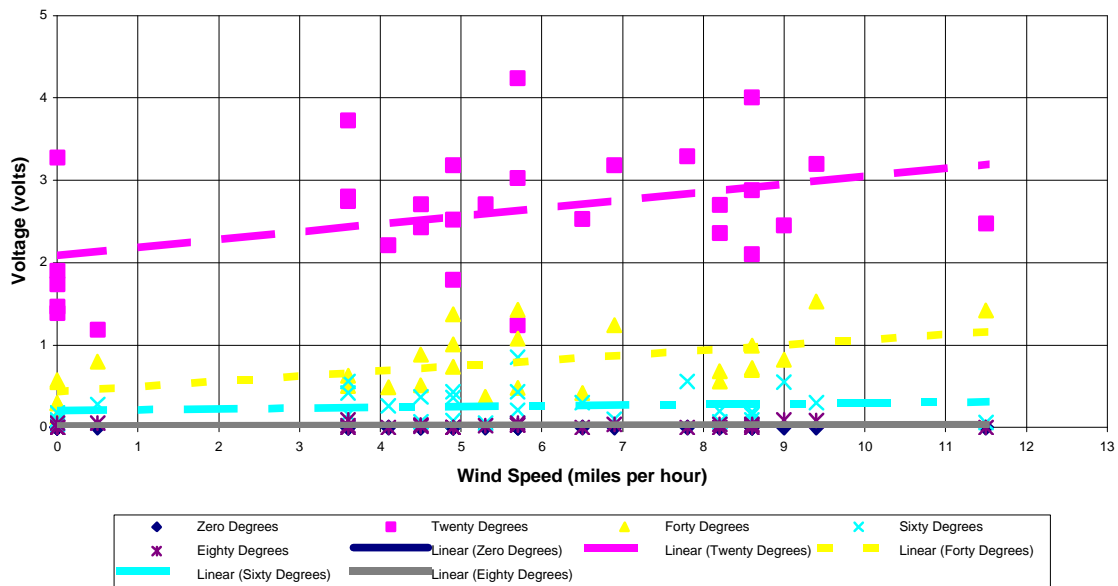


Fig. 8. – This figure shows voltage vs. wind speed for varying angles (trial 2).

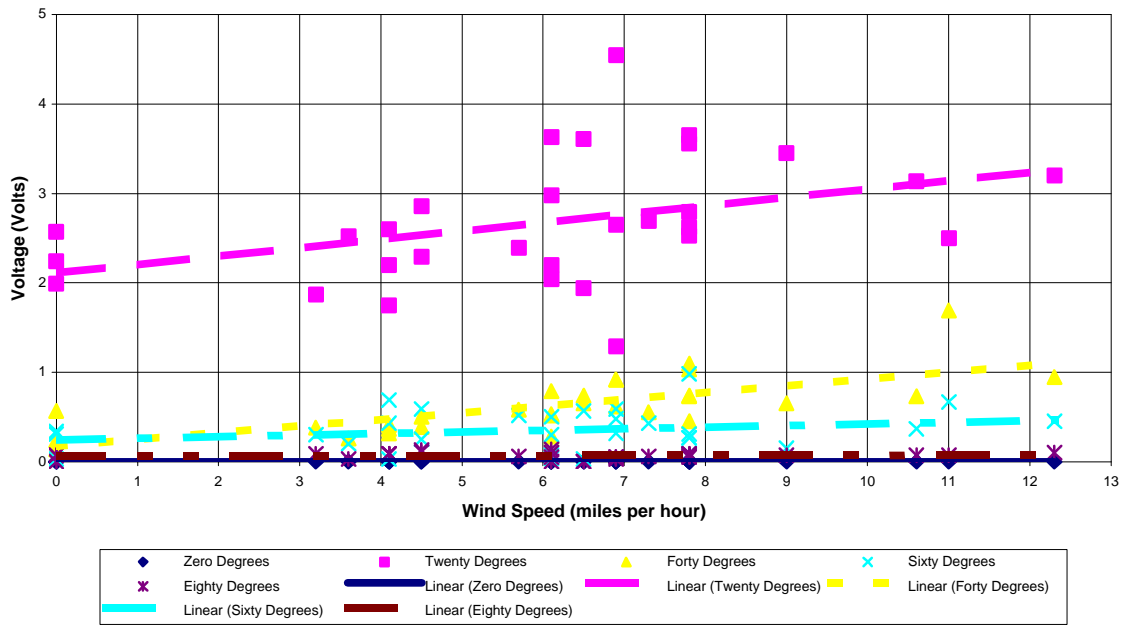


Fig. 9. – This figure shows voltage vs. wind speed for varying angles (trial 3).

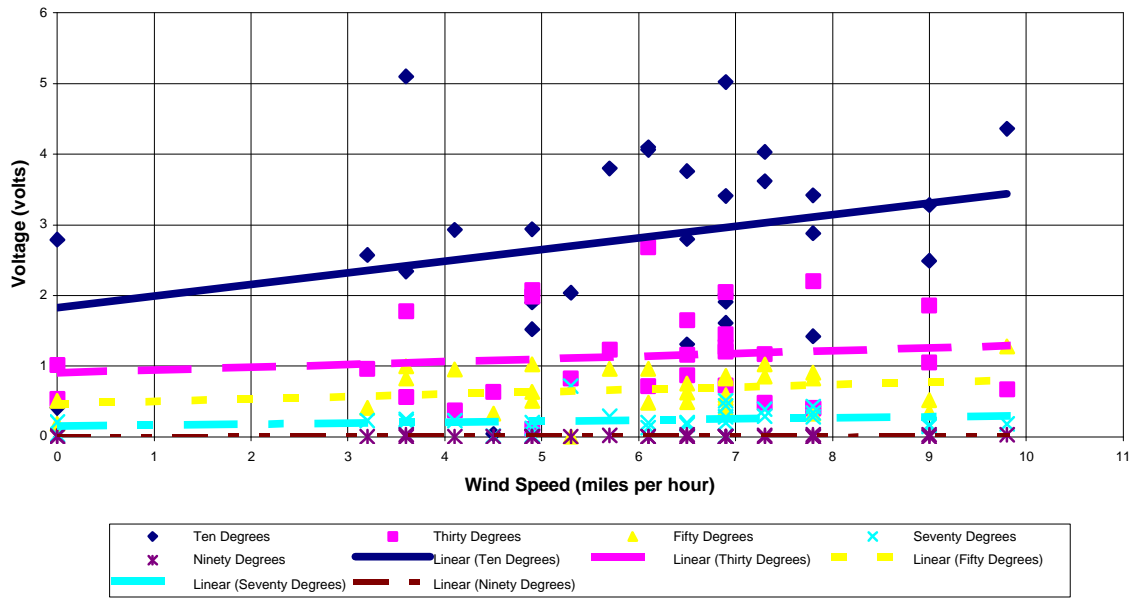


Fig. 10. – This figure shows voltage vs. wind speed for varying angles (trial 1).

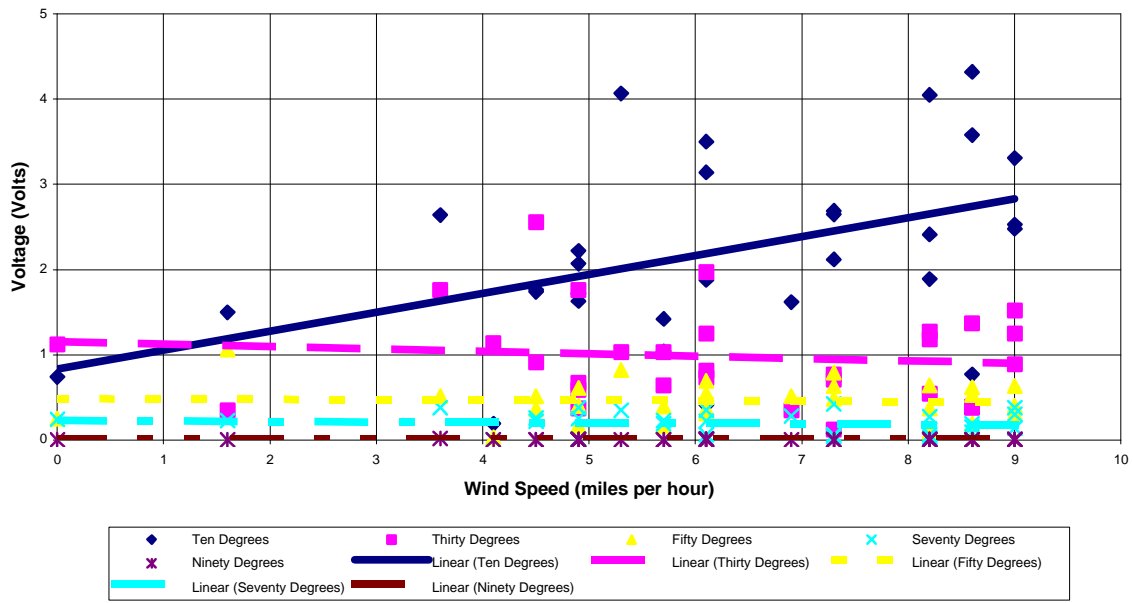


Fig. 11. – This figure shows voltage vs. wind speed for varying angles (trial 2).

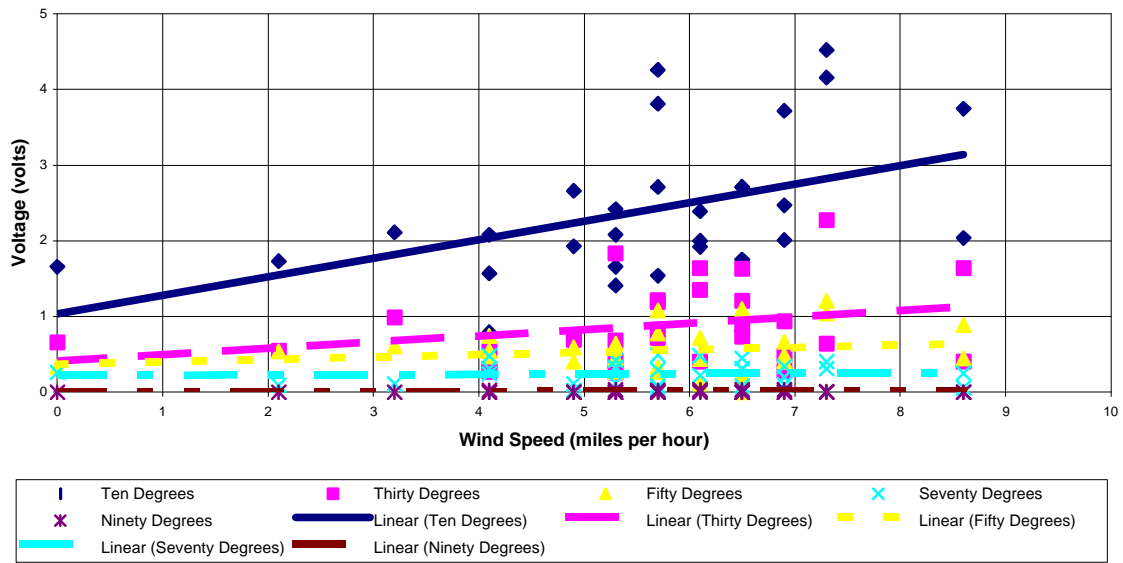


Fig. 12. – This figure shows voltage vs. wind speed for varying angles (trial 3).

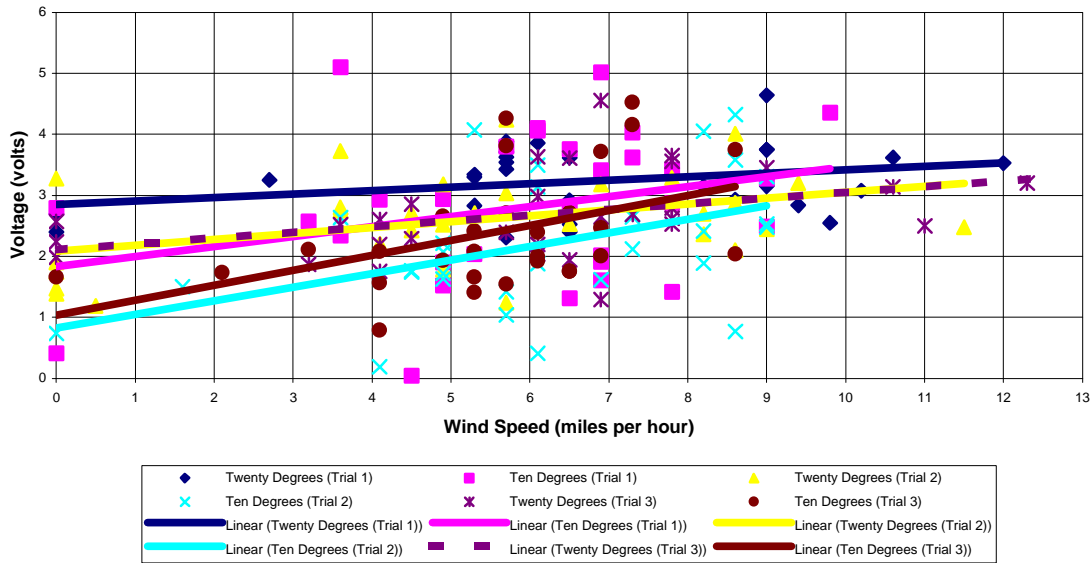


Fig. 13. – This figure shows voltage vs. wind speed for varying angles for the ten and twenty degree angles.

Figures 14, 15, and 16 all showed that the one-foot blade (group one) produced the most voltage. Next was the one-foot blade (group two) which produced the second greatest amount of voltage. The least amount of voltage was produced by the two-blade turbine (See Figures 14, 15, and 16). The variables that were kept the constant were the blade angle at twenty degrees, the height at eleven feet, and the number of blades at four.

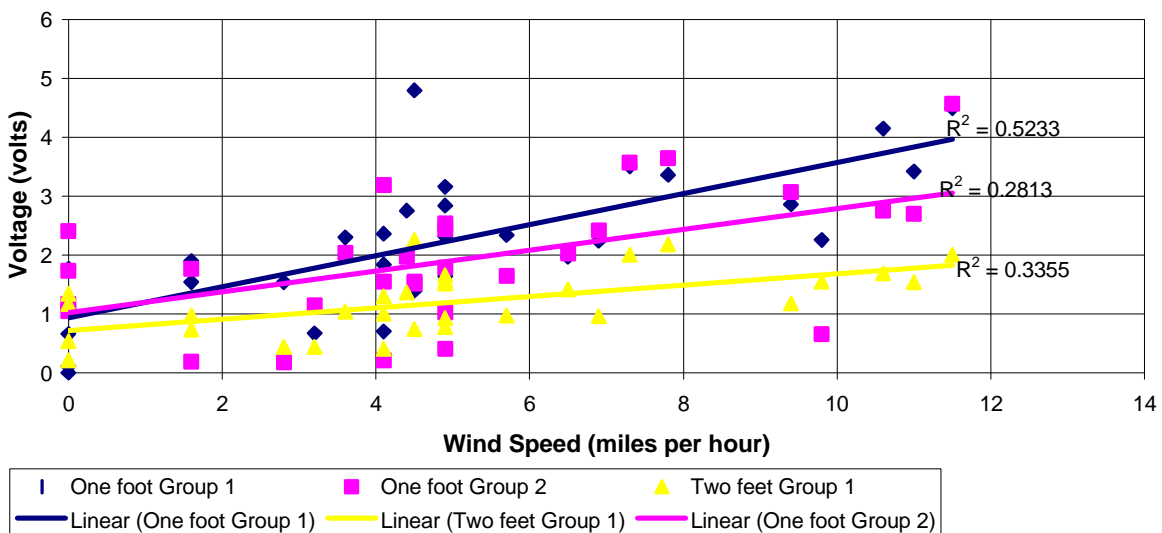


Fig. 14. – This graph shows voltage vs. wind speed for length of blades (trial 1).

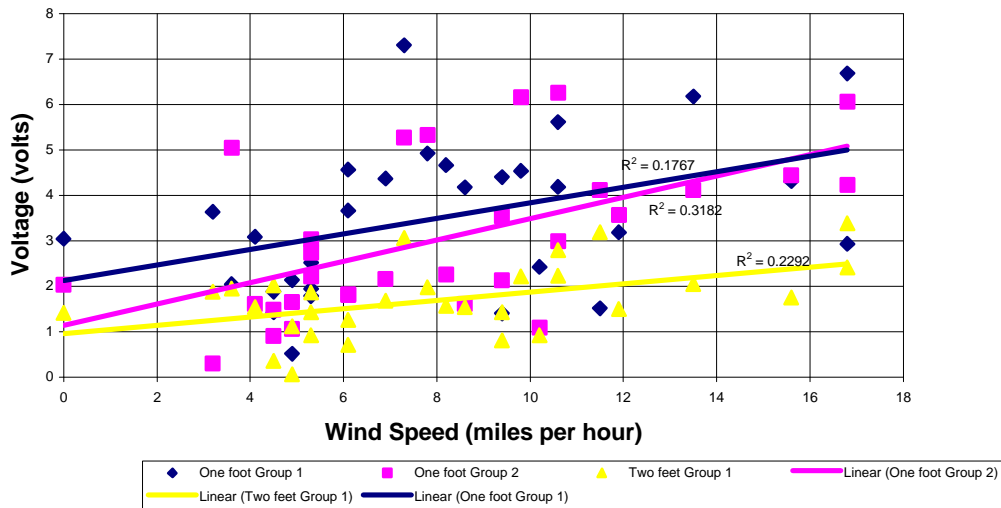


Fig. 15. – This graph shows voltage vs. wind speed for varying length of blades (trial 2).

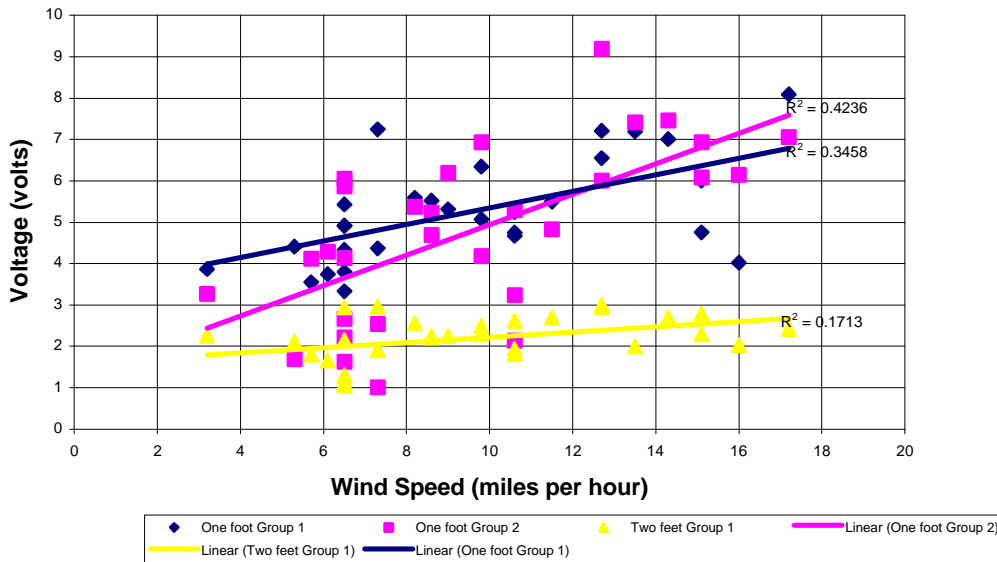


Fig. 16. – This graph shows voltage vs. wind speed for varying length of blades (trial 3).

Figures 17, 18, and 19 show how the trials, one, two and three, compare for each of the length of the blades, one foot- group one, one foot- group two, and two feet.

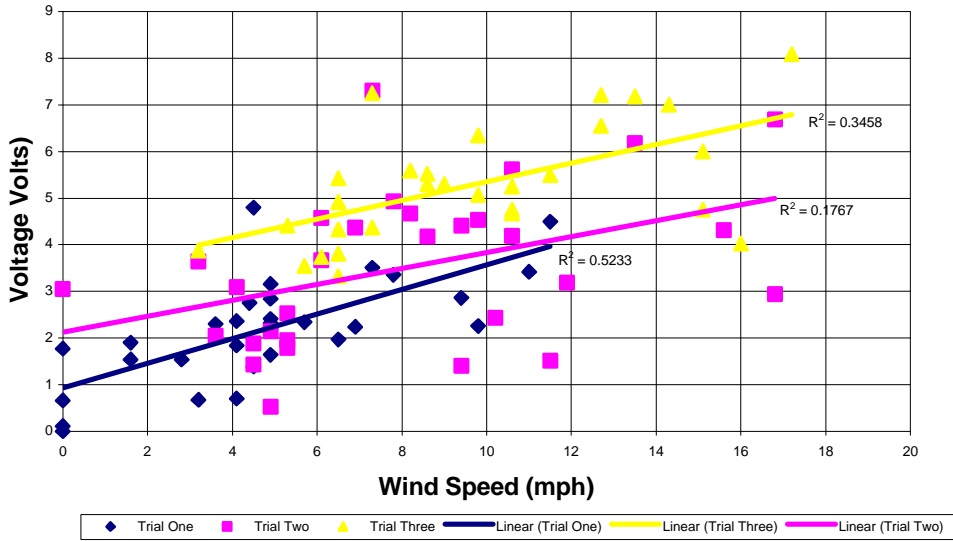


Fig. 17. – This graph shows voltage vs. wind speed for varying length of one-foot blades (group one) for all three trials.

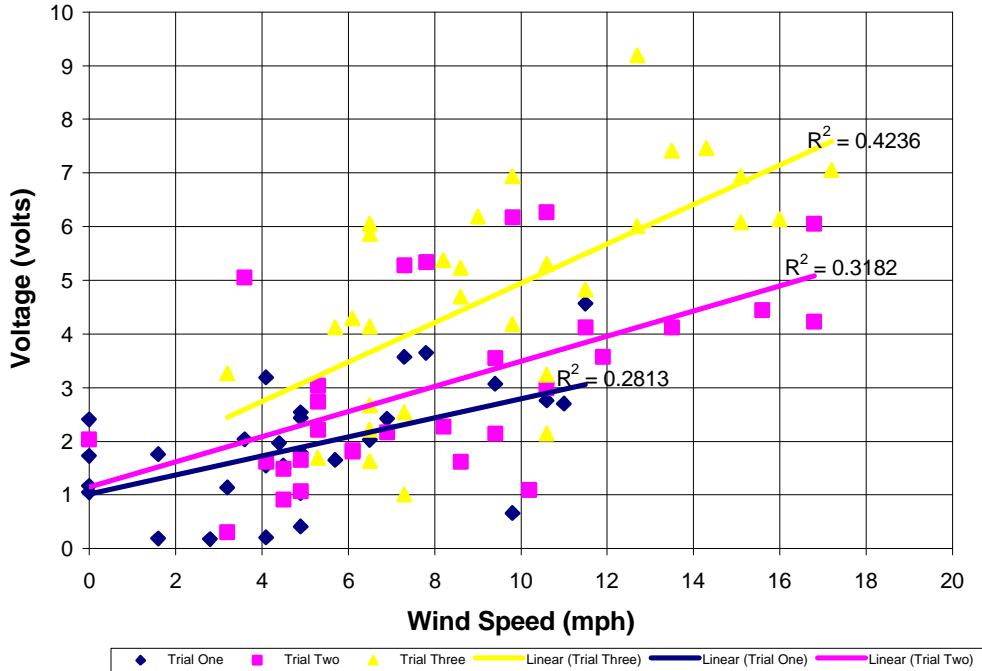


Fig. 18. – This graph shows voltage vs. wind speed for varying length of one-foot blades (group two) for all three trials.

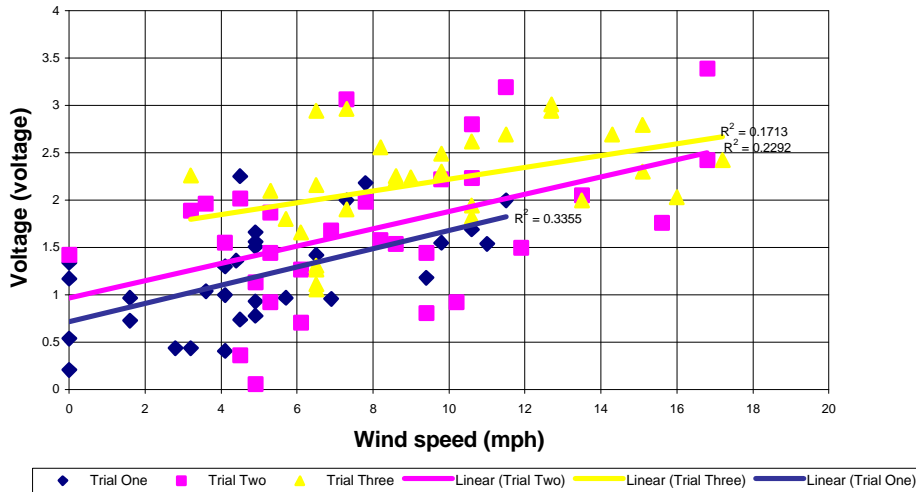


Fig. 19. – This graph shows voltage vs. wind speed for varying length of two- foot blades (group one) for all three trials.

Figures 20 to 22 show data from the three trials of height testing. The graphs show that the eleven-foot-high turbine made the most electricity. According to Figure 23, the eleven-foot-high turbines, which produced the most voltage of the three heights tested, gave constant results for all three trials because all the points on the graph are in one general area. Four two-foot blades set at twenty-degree angles were kept constant during the height section of the experiment.

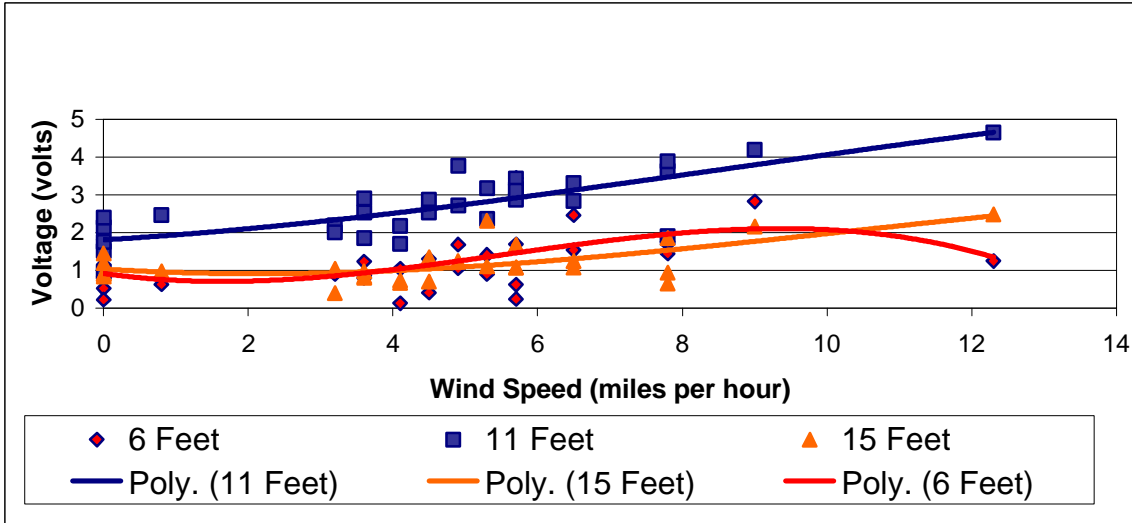


Fig. 20. – This graph shows voltage vs. wind speed for the varying height (trial 1).

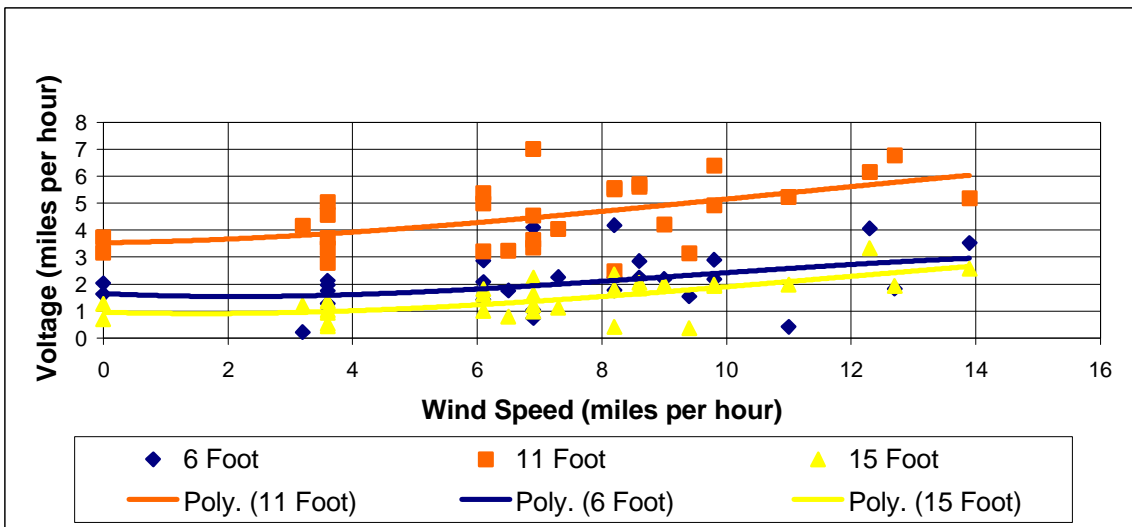


Fig. 21. – This graph shows voltage vs. wind speed for the varying height (trial 2).

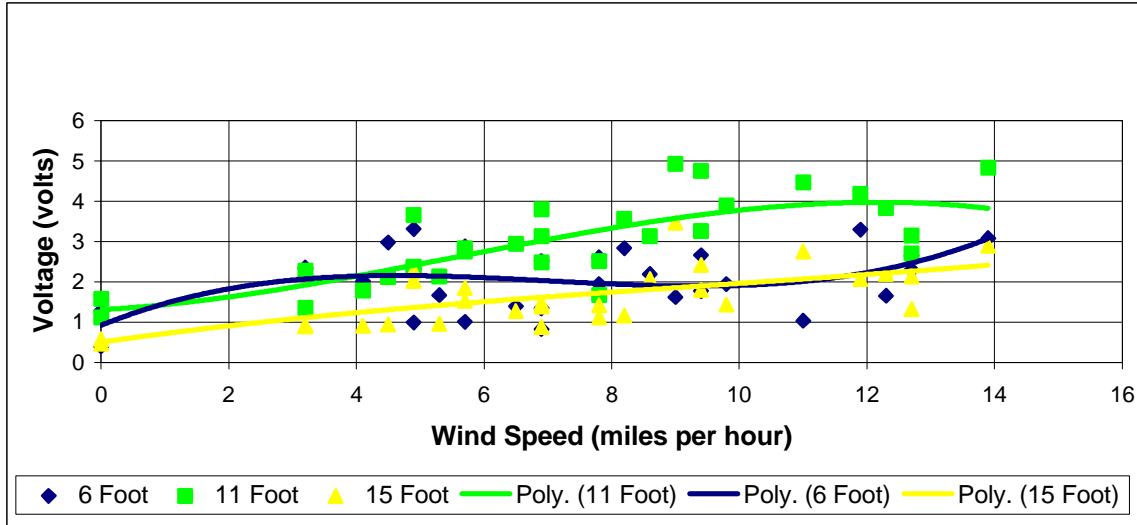


Fig. 22. – This graph shows voltage vs. wind speed for the varying height (trial 3).

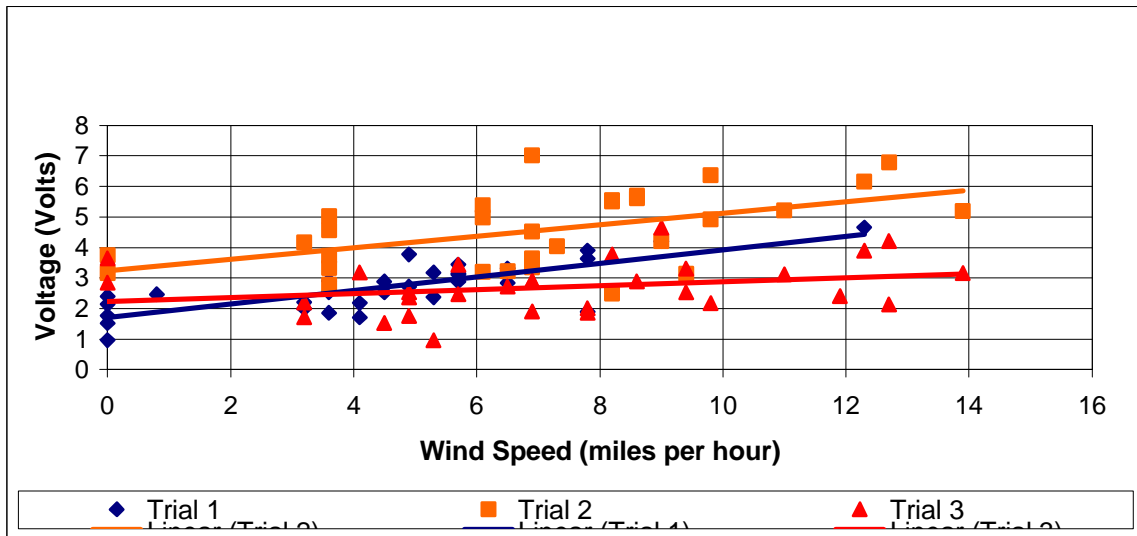


Fig. 23. – This figure shows voltage vs. wind speed for the 11-foot poles for all the trials.

A scatter plot was used to compile all the data from three trials for four variables into one graph. The wind speed was the independent variable that determined the voltage for each trial. A linear trend line was used to find a general trend for the data. Figure 24 compares the average wind speed to the average voltage for the different number of blades. Each trial consisted of five different numbers of blades. One turbine had two blades, another had three blades, another had

four blades, another had six blades, and another turbine had eight blades. It is evident from the graph that four blades produced more voltage than others. The maximum voltage produced by four blades was .65. All other turbines had voltages below .45. Two data points were plotted on the graph because all the trials were split up into three ranges. The ranges were low(0-5), medium(5.1-9), and high(9.1 and up) wind speeds.

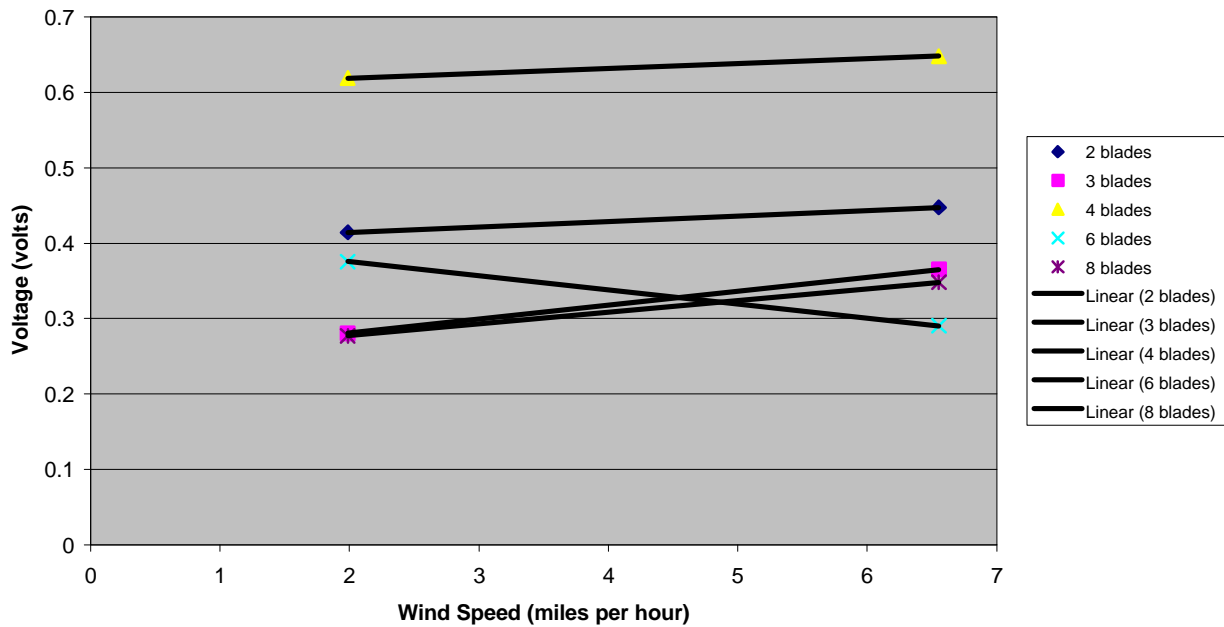


Fig. 24. This figure shows the wind speed vs. voltage for the number of blades.

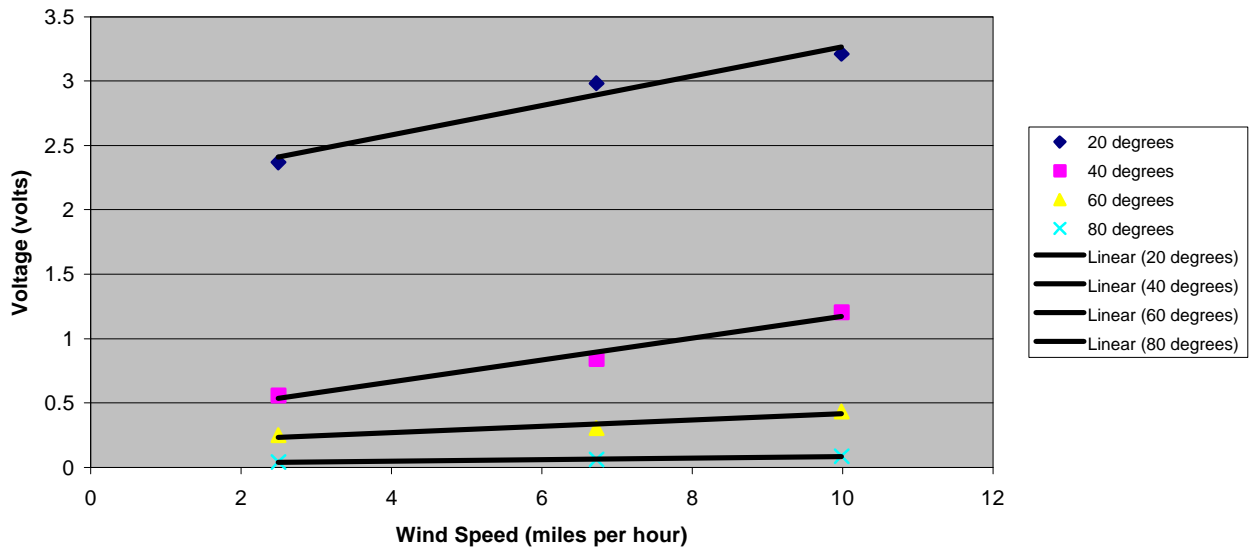


Fig. 25. – This figure shows the wind speed vs. voltage for the blade angle.

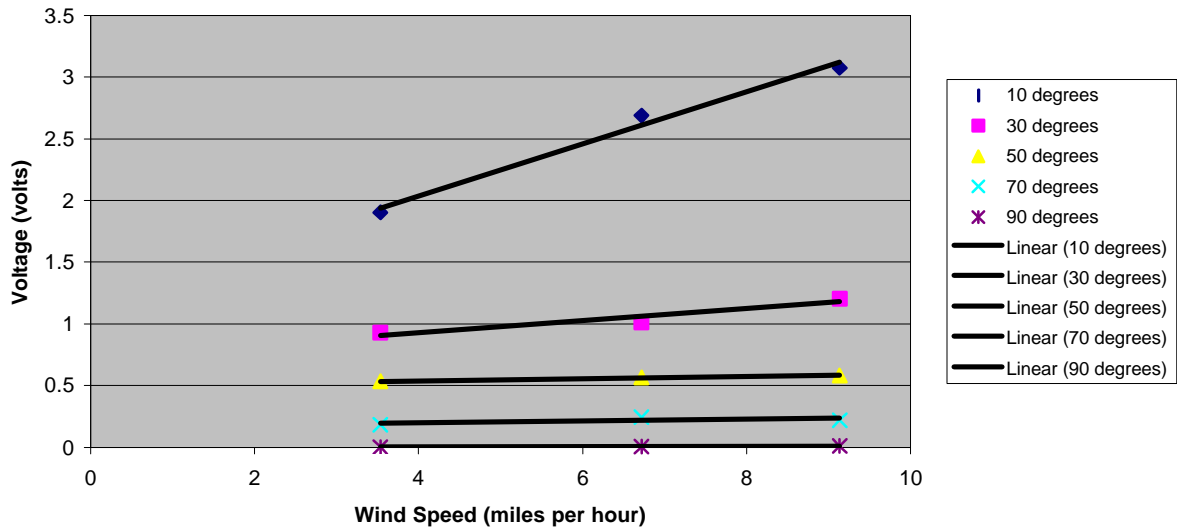


Fig. 26. – This figure shows the wind speed vs. voltage for the blade angle.

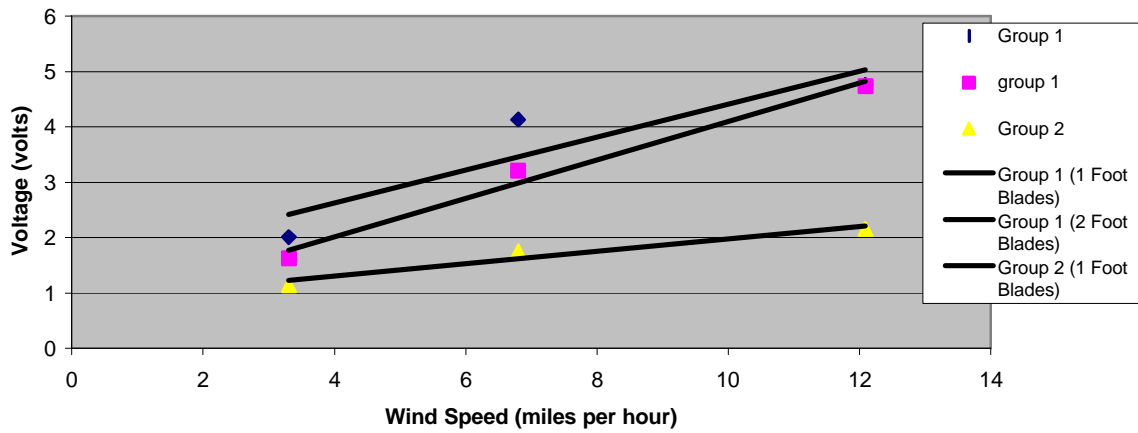


Fig. 27. – This figure shows the wind speed vs. voltage for the blade length.

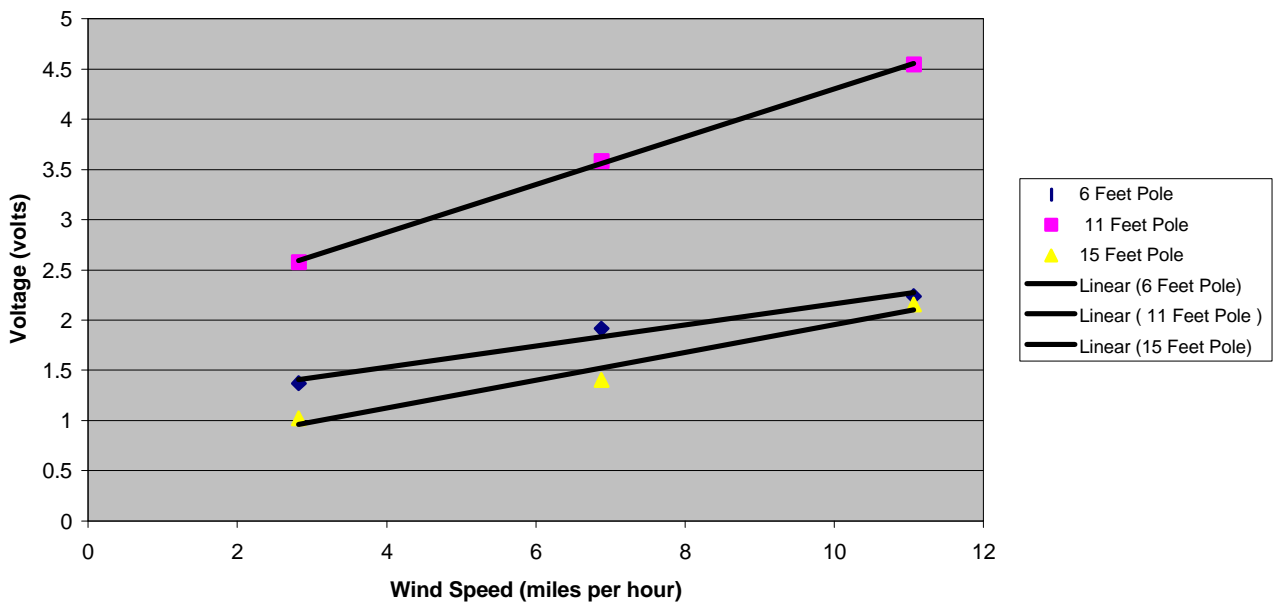


Fig. 28. – This figure shows the wind speed vs. voltage for the height.

## DISCUSSION AND CONCLUSION

The hypothesis in this experiment was rejected. This hypothesis stated that the forty-degree angle, fifteen-foot height, two-foot long blades, and eight bladed turbines would produce the most voltage.

The fourth part of the hypothesis that stated the wind turbine design that will produce the most constant voltage would have eight blades was rejected. This was rejected because in figures 3, 4, and 5, the best performing design was the four bladed wind turbines. This hypothesis might be true because it caught the optimum amount of wind without the blades overlapping.

The part of the hypothesis for the blade angle of forty degrees would produce the most voltage was rejected. The angle tests showed that the best angle was between ten and twenty degrees (See Figures 7-12). The atmospheric drag on the back of the blades, probably produced these results. Figure 11 reveals, that twenty degrees is probably more favorable at low speeds, but at higher speeds, the ten-degree blades begin to produce more voltage than the twenty-degree blades, and thus, more favorable for higher wind speeds as a result.

The part of the hypothesis that stated the two-foot long blades would produce the most voltage was rejected; the one-foot blades produced more voltage in this study (See Figures 14-16). The one-foot blade produced the most voltage because it was easier for the wind to push the smaller blade instead of the larger blade. Another reason that the one-foot bladed turbines produced more voltage was that it weighed less than the two-foot blades so wind did not have to work as hard to turn them.

The part of the hypothesis stating that the height of fifteen feet would perform the best was also rejected. One possible reason the height of eleven-foot worked better than the predicted fifteen-foot is because it was high enough to avoid some of the wind turbulence and low enough to stay stable when the wind blew strong (See figures 30 – 32).

Figures 24 and 26 compare the average wind speed and the average voltage for blade angle. The first three trials dealt with twenty, forty, sixty, and eighty-degree angles. Figure 25 deals with ten, thirty, fifty, seventy, and ninety-degree angles. There were two graphs because

one graph would be cluttered, and the data was collected at different times. The wind speed and voltage for both graphs were average and plotted. Figure 24 reveals that the twenty degree angle produced the most voltage. In Figure 25, the ten-degree angle produced the most voltage. To compare the ten and twenty degree angles, two common points were selected from both graphs; on each graph, four and nine miles per hour points were selected. At nine miles per hour, the ten-degree angle produced approximately 3.1 volts and at four miles per hour it produced approximately 2.1 volts. Between four and nine miles per hour, there is a difference of one volt. For the twenty-degree angle at nine miles per hour, the turbine produced approximately 3.2 volts and at four miles per hour it produced approximately 2.6 volts, which is a difference of .6 volts. This difference reveals that the slope of the ten-degree line is larger than the twenty-degree line, which indicates that the ten-degree angle will be better for low winds.

Figure 27 compares the wind speed to voltage for blade length. There were two groups that tested one-foot blades, and one group that tested two-foot long blades. Both one-foot blade groups recorded higher voltage than the two-foot blades group. It was observed that the one-foot blades were sturdier than the two-foot blades, allowing them to catch more wind. As a result, one-foot blades produced more voltage than the two-foot blades.

Figure 28 shows the average wind speed and the average voltage for height for three trials. Overall, the eleven-foot high turbine produced the largest amount of voltage. The eleven-foot turbine was high enough to receive less turbulence than the six-foot turbine but low enough to be sturdy, producing more voltage than the fifteen-foot turbine. It was concluded that the eleven-foot turbine was the best at producing voltage at all wind speeds, especially at high wind speeds.

There were a few limitations to this experiment. The blades were not shaped in a way that would be most productive. In addition, the poles were not as sturdy as they could have been. The caulking that held the bolts to the blades did not always hold. Further, the blades were made of wood not metal, whereas the most productive blade material is metal; this was proved in the early 1900's. Having the testing on flat land where there would be less turbulence, and having a wind turbine that rotates to the direction at which the wind is strongest may have improved the results of this experiment.

Several factors influenced data collection. Two wind turbines fell off the poles because they either were not assembled correctly or the threads that screwed the poles together had been stripped. In addition, some blades broke off during high wind speeds. Also, the strong winds may have thrown off the angles of the blades while they were being tested.

New questions have been raised as a result of this experiment. If the wind turbines had been tested on flat land where there was not as much turbulence, would they have produced more voltage? If the blades of the turbines had been metal and not wood, would the voltages produced have been higher? Did the surrounding electrical towers have an effect on the voltages our wind turbine produced? Would the results be any different if the materials used, such as the poles, had been sturdier? These questions could be addressed by further experimentation.

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