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Wind Speed and the Power Output of a Wind Turbine

Hands-on Experimental

[redacted]

Inglemoor High School

Physics HL IA

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#3

Wind Speed and the Power Output of a Wind Turbine

Introduction

A wind turbine is a device that converts the kinetic energy of wind into a form of mechanical energy (Selin). The force of the wind on the turbine's blades causes the turbine to move. This spinning of the turbine then turns a motor, which produces the electrical current (Selin). As the interest in renewable energy has increased, the demand for wind energy has risen as well. Some industry leaders believe that by the year 2030 we will get 15-20% of our energy from the wind (Kidwind). This push for renewable sources of energy comes from the desire to reduce the negative environmental impacts to the air, water, and wildlife. The use of wind turbines as a source of renewable energy is a possible solution to this problem. If the percentage of energy gained from wind turbines increased as in the predicted scenario above, we would see the cumulative amount of $CO2$ that's put into the atmosphere reduce by 7,600 metric tons (Kidwind).

The power a wind turbine is able to generate is dependent on several factors: wind speed, the density of the air, the size of the rotor, and more (Physics Classroom). In order to fully harness the power of the wind turbine and ensure the most efficient method of producing renewable energy is being used, it is necessary to fully understand these factors. Thus, this experiment serves to answer the question, how does wind speed affect the power output of a wind turbine? The expected outcome of this investigation is that as the wind speed gets larger, the rate of power production will increase as well until the turbine reaches its maximum power output. This can be predicted because it is the scientifically accepted outcome and this investigation will be aimed at proving this.

Research Question

How does wind speed affect the power output of a wind turbine?

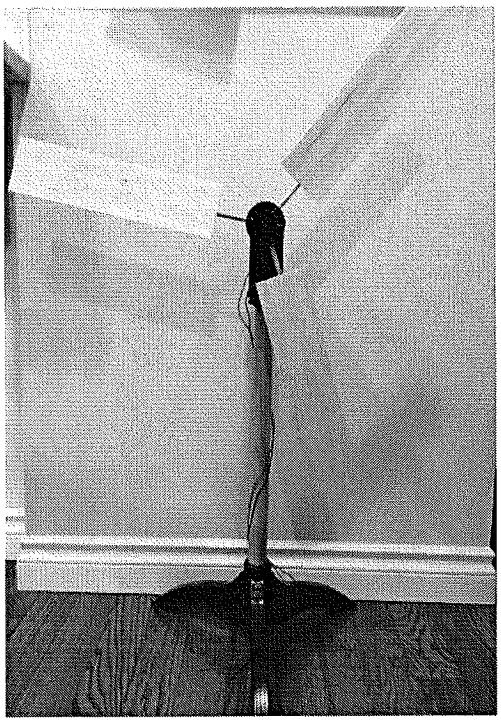
Methods

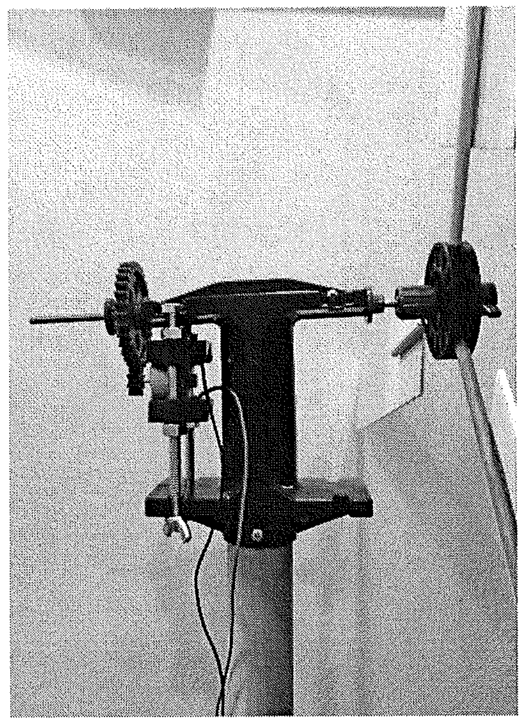
In order to identify the connection between the power output of a wind turbine and wind speed, a model wind turbine, which will be built by the investigator, will be tested at various electric fan-generated speeds. The power output of a turbine can be determined through the equation $P=V \cdot I$ (Physics Classroom). Therefore, both current and voltage will be measured. For the purpose of replication, see detailed materials list and steps below:

- Model Wind Turbine
- Anemometer
- Two multimeters (one capable of measuring voltage and the other current)
- A large household box fan

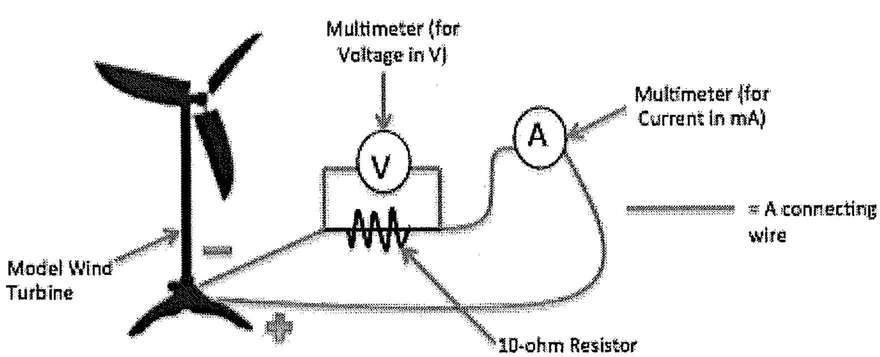
- Measuring Tape
- A 10 ohm resistor
- Two sets of leads
- Two sets of clip cords

The model wind turbine that was constructed for this investigation was the following:

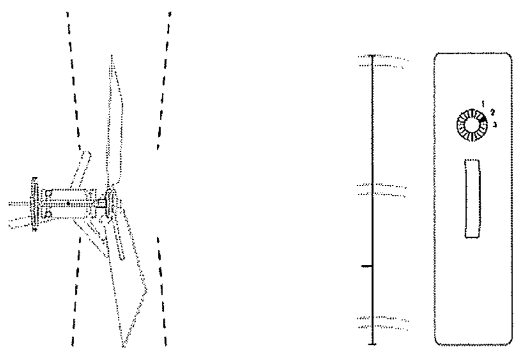




1. To begin, a circuit was constructed by connecting the wind turbine, 10-ohm resistor and both multimeters. The circuit resembled the following:



2. Once the circuit was constructed, the wind turbine was placed directly in front the box fan (as pictured in the diagram below) with the center of the fan being in line with the center of the box fan. The rotor diameter also needed to be kept inside the fan diameter to avoid any added drag.



(Kidwind)

3. To ensure that the center of the turbine and box remained aligned throughout the investigation and that the rotor diameter remained inside that of the fan, three straight pieces of tape served as reference lines: one from the bottom of the center of the fan out towards the wind turbine, one from one side of the fan out, and another from the remaining side of the fan.

4. Then, the fan was turned on at the lowest possible speed and the wind turbine was slowly moved away from the fan until the blades were unable to spin on their own (staying on the path of the tape). At the last point that the blades moved, the current and voltage readings were observed and recorded. Due to the nature of the wind turbine and multimeters, the readings were not constant. Therefore, it was necessary to identify three given values for both current and voltage and find the average for each.

5. The wind speed at that location was then determined and recorded by holding the anemometer in the center of the blades directly in the path of the fan.

6. Then, this procedure was repeated, however, the fan was turned to the maximum speed and the turbine was moved along the tape until the current/voltage no longer increased. At this point, the current and voltage were observed and recorded. The wind speed at that location was then be recorded following the procedure given in step 4.

6. Next, the investigation found six value points of wind speed in between the highest recorded wind speed and the lowest. There was an approximately equal distance between each selected value.

7. Then, the current and voltage levels at the first selected value for wind speed were identified. To do so, the anemometer was kept level to the middle of the wind turbine's blades and moved along the tape to find the distance turbine needs to be placed from the fan and the level that the fan needs to be on in order to produce the desired speed. Once this was determined, the current and voltage were observed and recorded at those conditions (in the same method that was explained in step 4).

8. Step 7 was repeated for the rest of the selected wind speeds and at each speed the current and voltage was recorded and averaged.

9. Lastly, the investigation solved for the power output at each speed by using the equation P=IV. These values for power output were recorded.

While the investigation was in progress, it was necessary to make sure that the path of the turbine's plane of rotation was kept clear of any objects to avoid damage. A limit of the investigation was that, despite making efforts to ensure the proper measurement of the wind speed, the wind hit the turbines at different locations depending on the distance that it was away from the fan. This could have affected the accuracy of the experiment, however, not by enough to make it invalid.

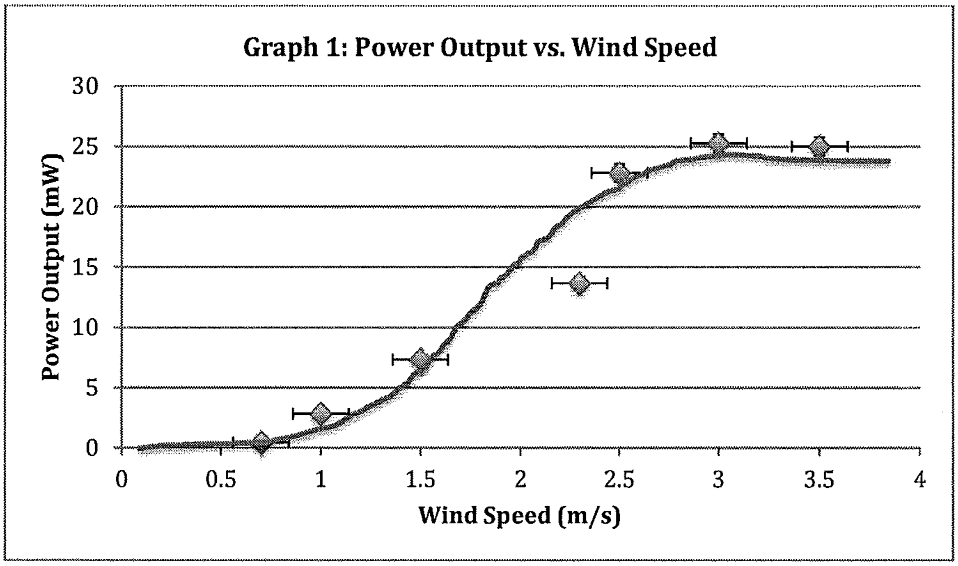
Results and Analysis

Raw Data-

Table 1: Wind Speed, Current, Voltage and Power Output of a Wind Turbine

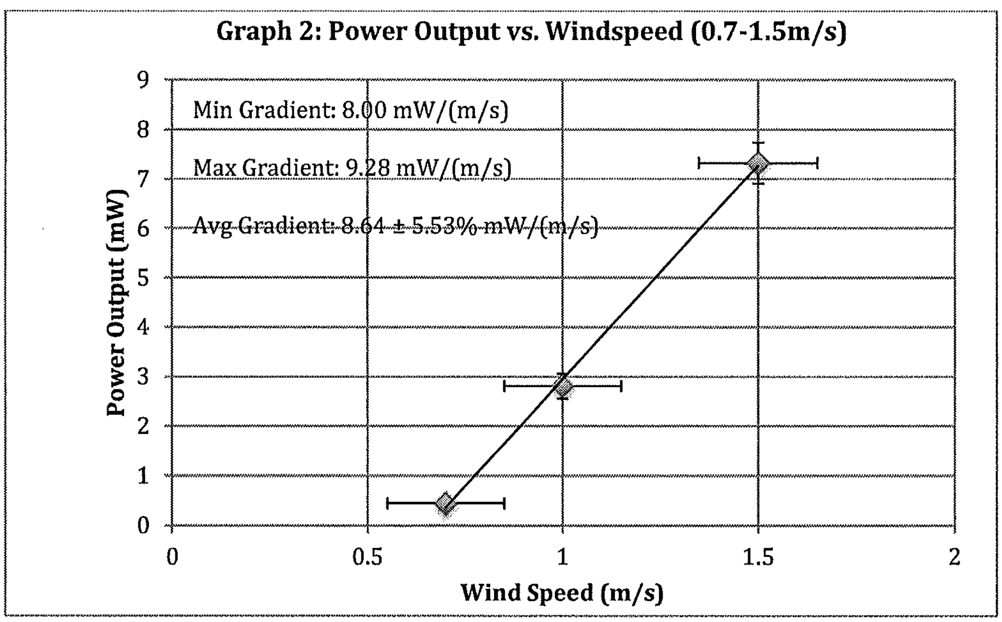
Wind Speed (m/s)	I1 (± .5 mA)	I2 (± .5 mA)	I3 (± .5 mA)	I avg. (± .5mA)	V1 (± .01 V)	V2 (± .01 V)	V3 (±.01 V)	V avg (± .01 V)	P (P=IV)
0.7	6.71	8.51	5.19	6.80	0.054	0.062	0.079	0.065	0.44 mW (±22.8 %)
1.0	16.7	17.4	15.9	16.67	0.164	0.179	0.162	0.168	2.81 mW (±8.95%)
1.5	28.6	29.7	27.5	28.60	0.257	0.246	0.266	0.256	7.32 mW (±5.66%)
2.3	35.7	36.8	35.9	36.13	0.378	0.369	0.386	0.378	13.7 mW (±4.03%)
2.5	48.5	47.0	46.7	47.40	0.487	0.463	0.493	0.481	22.8 mW (±3.13%)
3.0	49.3	48.8	52.2	50.10	0.508	0.493	0.511	0.504	25.3 mW (±2.98%)
3.5	51.5	48.9	49.9	50.10	0.516	0.483	0.495	0.498	25.1 mW (±3.01%)

Interpretation: In the table, I represents current and V represents voltage. This table shows the collected current and voltage at each speed, as well as the power output (determined through the equation P=IV). The raw data table suggests that as the wind speed increases, the amount of power output gets larger as well. However, the relationship between these can become more apparent through graphing.



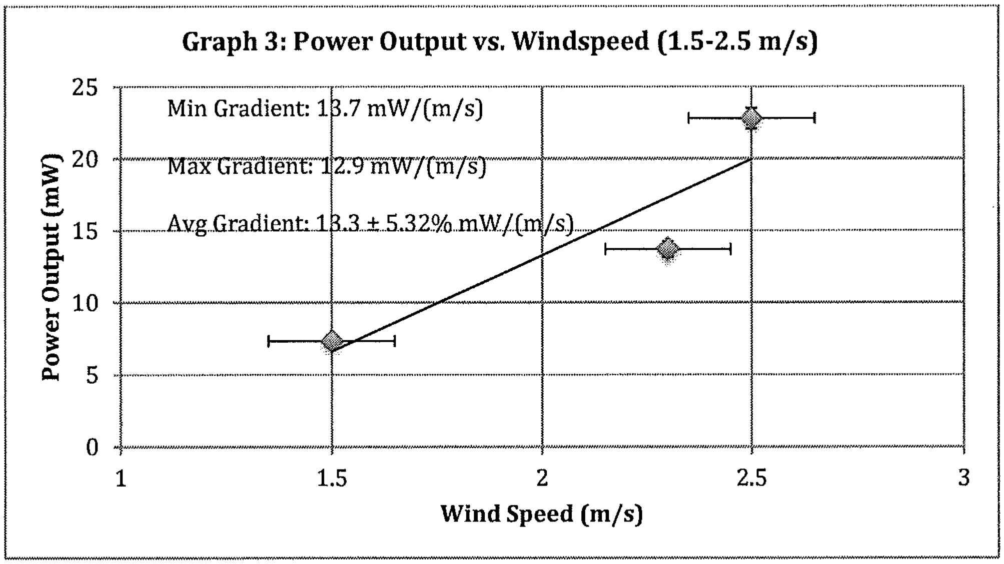
Interpretation: The shape of Graph 1: Power Output vs. Wind Speed suggests that the traditional power curve relationship that is used to explain the relationship between wind speed and power output in a wind turbine. However, to confirm this relationship it is necessary to further process the graph and compare the gradients at various points.

Processed Data-

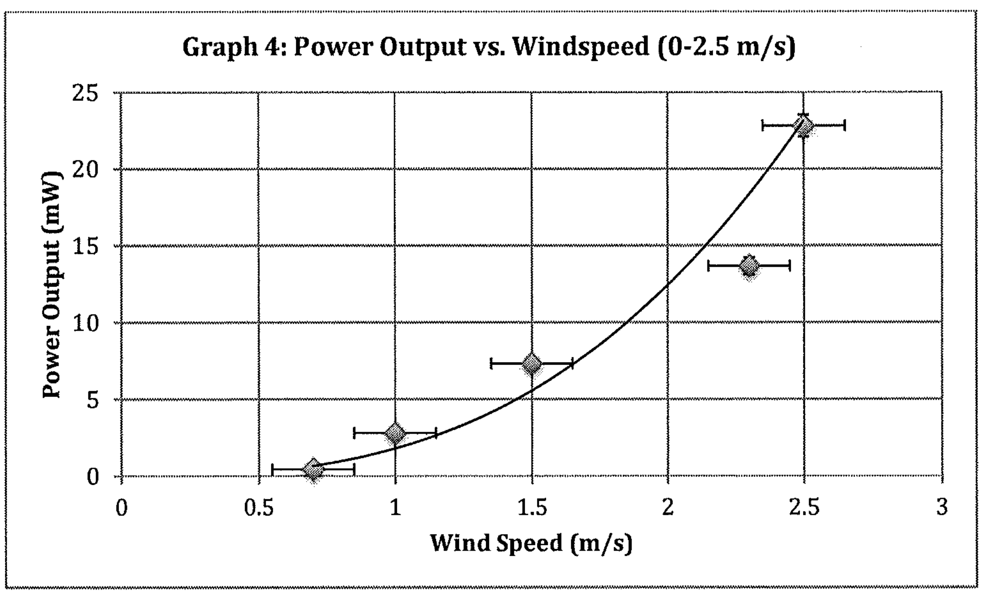


Interpretation: This graph reveals the approximate gradient for the first three value points of wind speed (0.7 through 1.5 m/s). This gradient is 8.64± 5.53% mW/(m/s). However to confirm if Graph

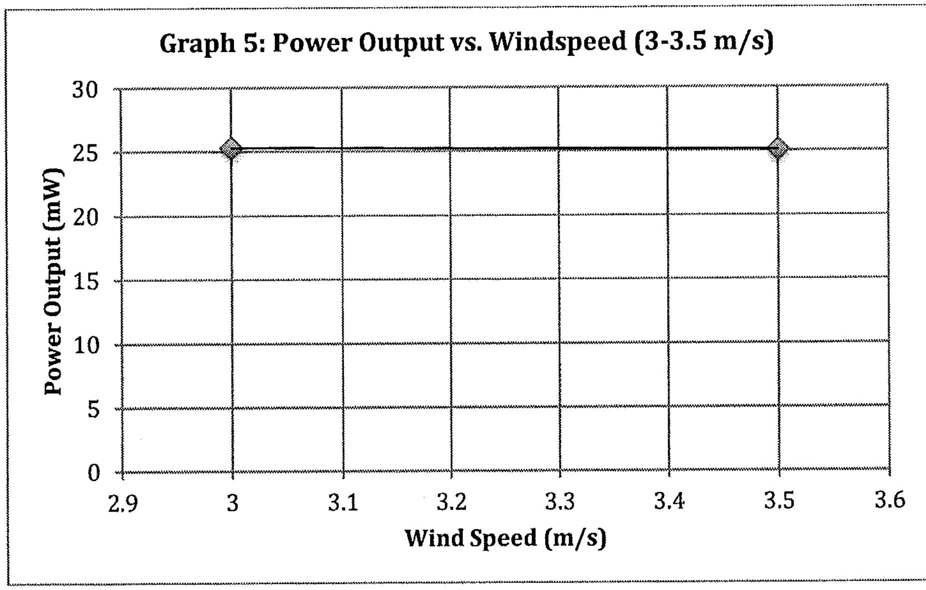
1: Power Output vs. Wind speed follows the traditional power curve model that is utilized to model similar data, it is necessary to observe the gradient at different sections of the data.



Interpretation: This graph reveals the approximate gradient for wind speeds 1.5 m/s through 2.5 m/s. This gradient is 13.3 ± 5.32% mW/(m/s). With a greater gradient than Graph 2, the process data is supporting the traditional power curve model.



Interpretation: In this graph, the increasing gradient between 0 m/s and 2.5 m/s confirms that until the maximum power output of the turbine, the rate of power production increases as the wind speed increases as well.



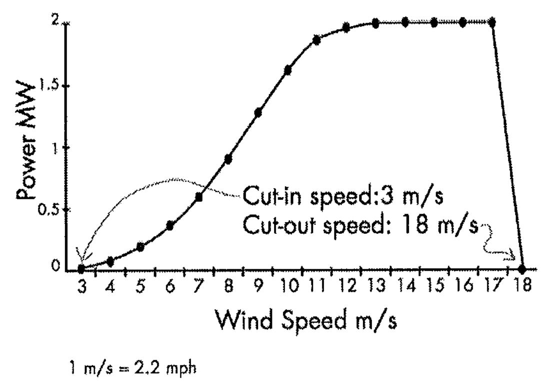
Interpretation: Graph 5 reveals that the approximate gradient between the last two wind speeds is 0 W/ (m/s). This gradient reveals that at a certain speed (3 m/s for this model turbine), the wind turbine will reach its maximum power output. This supports the traditional power curve model used to measure the impact of wind speed on the power output of a wind turbine. Due to the gradient being zero, any uncertainties become somewhat irrelevant because the gradient will remain the same regardless of uncertainties.

Assessment of Uncertainties-

Throughout the investigation, it became apparent that uncertainties were present due to the inconsistent nature of both the wind turbine itself and electric fan that was used to simulate wind. Additionally, the anemometer, which was used to measure the wind speed, had a published uncertainty of .15 m/s and this was taken into account throughout the experiment. However, the accuracy of the data wasn't greatly impacted by these uncertainties because the curve and gradient trends that were revealed throughout data collection remained consistent with the accepted trends and relatively the same.

Conclusion and Evaluation

The Wind Speed and the Power Output of a Wind Turbine investigation was designed to identify the effect of wind speed on the power production of a wind turbine. In the wind energy industry, all wind turbines are rated using power curves, which describe the power output of a wind turbine over a range of wind speeds like the sample shown below:



(Kid Wind)

Upon completion of the investigation, the accuracy of this traditional analysis can be confirmed. The data collected in the experiment followed the same power curve, which had an increasing slope until the maximum power output was reached. The similarity of the investigation's curve and scientific curve is best exemplified in Graph 1: Power Output vs. Wind Speed. For the model wind turbine, the gradient increases from 8.64± 5.53% mW/(m/s) between .7 m/s and 1.5 m/s to 13.3 ± 5.32% mW/(m/s) between 1.5 m/s and 2.5 m/s. After this point, the maximum power production is reached at 3 m/s, which is shown by the zero gradient past 3 m/s. In the accepted scientific context, a similar pattern is present which is shown in the above example. The wind turbine begins to produce power at a certain speed and the rate at which power is produced increases until it reaches its maximum power production level.

While steps were taken to minimize uncertainties, they remained present in the form of random errors. There errors were most likely to occur during the process of data collection. For example, in an ideal situation, the current and voltage would be recorded at the same time. However, because they were measured on two different multimeters this wasn't possible. While this didn't drastically alter the values, measuring the values simultaneously could've increased the accuracy. In addition, slight estimation was used when recording the values read on the multimeter because the multimeters didn't read one consistent value for each speed due to the inconsistent nature of a model wind turbine. Instead, the reading varied between relatively similar values. However, by taking three values for each speed (the largest value given, the smallest one, and one in the middle) and averaging them out the inconsistent readings was addressed.

While knowing the power a turbine can produce is useful, it doesn't tell you how much energy the turbine will produce. To determine this, both the speed of the wind and the time that the wind blows must be known. So, for future tests, it would be interesting to determine the amount of energy that a turbine could produce at various speeds. However, while one could use a relatively similar procedure to determine the effect of wind speed on the amount of energy a turbine can produce, it would be useful to acquire a wind source with more levels so the turbine could stay the same distance away from the fan. This would reduce the possibility of errors. An overall strength of this investigation was that there was already a commonly accepted power curve that is used to compare the power output of a wind turbine at different wind speeds. This increased the accuracy of the final conclusion because it further supported the findings.

Word Cited

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