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ABSTRACT

A study done by using a meteorological wind report from Mason City, IA tall tower, which reports wind speed at 200 meters, 150 meters, 100 meters and 50 meters used to determine power output for a wind turbine. The wind turbine used was a GE 1.5sle wind turbine and it is used in Mason City. This study was created to analyze the yearly, seasonal, monthly and level output of the turbines if they were built at each of the four levels. The data was broken up into total power produced and average power produced. In addition, a calculation of how many days the wind fell below the speed criteria was done and used to determine a reasonable cause to the results that were found. Overall spring was the best time that wind would produce electrical power, and April overall was the best month for wind to produce electrical power. The higher up the wind turbine would be the better the power would be produced.

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1. Introduction

It is well known that wind produces electric power by the method of wind turbines. The wind turns the propellers, motion that is translated into electrical energy by a generator. That power can be harnessed and used to power the world. Wind energy is a clean and renewable resource. The negative impact of wind energy on the environment is very little compared to other sources of energy such as coal and oil. Coal and oil produces a large quantity of air pollution as wind energy does not produces any pollution. The United States is a leader in wind power and Iowa is one of the leading states when it comes to wind power generation. Iowa planned, back in 2011, to meet a goal of having 39% of its electric energy produced from wind turbines by 2015 (Walton et. al. 2014). During 2015, however, the US. Department of Energy reported that Iowa produced 32% of its electric energy for wind turbines. Iowa still has more to improve when it comes to wind energy.

The characteristics of the wind are always changing in Iowa, but the low level jets that produce a large amount of wind shear make the plains of Iowa an attractive site for wind mills. (Walton et. al. 2014).

The magnitude of wind shear, however, can be damaging to the wind turbines itself (Walton et. al. 2014). Takle et. al. 1978 found that wind power production at heights of 32 meters was greatest during the spring season and least during the summer. Speed during the summer time was the least active to produces wind power and that spring had the highest level of wind power production at heights of 32 meters. While the wind power production can be quantified in terms of potential power, the actual power produced and used is reliant upon what type of wind turbine is used (Takle et. al. 1978). It is important to understand what the wind is doing and what type of wind turbine that is being used to produce the maximum amount of power possible.

Wind turbines are the key to producing wind energy. Wind turbines are ideal for the conditions in Iowa and have the potential to be a great resource there. Wind turbines have a cut-in speed and a cut-out speed. A cut-in speed is the minimum speed that the wind needs to blow at for a constant ten minutes for the wind turbine to produce electric power. Anything less than that speed will not produce any electric power because the wind is not strong enough to move the propellers. The cut-out speed stops the wind turbine and the propellers to prevent any damage to the wind turbine. The wind turbine sits 80 meters from the surface of the ground (Moyer 2009). A power curve of generated power can indicate how much power can be produced given a specific wind velocity. As the wind speed increase so does the amount of power that is generated from the turbine until it reaches 14 meters per second wind speed (Moyer 2009). The wind turbine is only producing 1.5megawatts which, is the limit of the wind turbine and it cannot produce any more electric power. The turbine continues to produce only 1.5megawatts from 14 meters per second to 25 meters per second (Moyer 2009) (Fig 1). The importance of the wind turbine indicates how much power will be produced from the given wind.

Wind power is a relatively new technology that needs to be explored more and advanced further to get a better understanding of the technology. This research project set out to answer the following questions to help gain a more in-depth understanding of wind turbines and wind power. Given three different heights, at which level would a GE 1.5sle wind turbine produce the most electric power based on the wind at that level? During which season would the most electric power will be produced? For the data recorded, which year is the most productive? In addition, which month during the study period produced the most electric power?

2. Data/Methods

The data used in this study analyzed wind velocities to determine the potential electrical power generated from it. The source of the data comes from the Iowa Energy Center on CD-ROM. The tall tower in north central Iowa in Mason City is where the data was collected (Fig 2). The environment of the tall tower is a rural area with a stream near the wind farm (Walton et. al. 2014). The wind farm in Mason City, IA has fifty-five wind turbines that are around the tall tower. The period of the data was from November 1 2006 to January 28

2009. The time interval that was used to record the data was every ten minutes for that period. The tall tower had four different recording devices on it at different levels, positioned at 200m, 150m, 100m, and 50m from the ground. When data was not recorded the tall tower out printed “NaN” to represent an error in the data set.

The wind turbine used in this study was the General Electric Megawatt 1.5sle. The cut-in speed for this type of wind turbine is 3.5 meters per second, about 7 knots, of wind to produces electrical power. The cut-out speed for the turbine is 25 meters per second or about 49 knots. The power produced by the wind turbine was calculated based off each ten-minute wind report (Table 1). If the wind speed did not meet the cut-in speed, it was recorded as a zero kW because no power would have been produced. The average hourly power generated was calculated by adding all the available ten-minute reports together and dividing by the number of data points that were available. That output was used to calculate daily average power output and that was done by using the method of dividing by twenty-four to account for the numbers of hours in a day. The average daily power was then used to calculate average daily power and divide by each day of the month for the two-year period. The error in the data was determined by averaging the data point’s area that missing point and putting that average in as the missing point. Data from the 150m-level sensor was not included in analysis due to insufficient data records, including over three months of no data records between May 2007 to August 2007. All the measurements were in Kilowatts. To compare the data seasonally, the months were grouped into four seasons. Winter months are December, January, and February; spring was March, April, May; summer was June, July and August; and the fall months were September, October and November.

Table 1: Power Curve of a GE 1.5xle wind turbine adapted for (Kapsambelis 2014).

Power Curve	
Wind Speed (m/s)	Power (kW)
4	43
5	131
6	250
7	416
8	640
9	924
10	1181
11	1359
12	1436
13	1481
14	1494
15	1500
16	1500

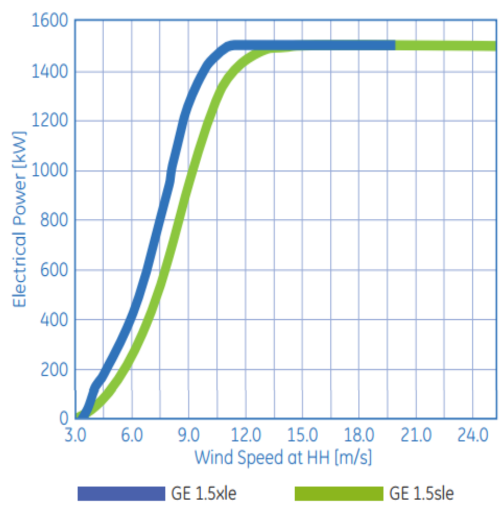

Figure 1: Power curve of a GE 1.5sle (green) and Ge 1.5xle (blue) wind turbine. (Adapted from (Moyer 2009).

Figure 2: Location of the tall tower (figure adapted from Walton et al. 2014)

The total output of each month was added together for the total output for each season. To find which level had the greatest energy produced, each level's total power output was computed and compared. To find the month that had the greatest output, the total of each month were compared to one another. The total output of each year was compared to find which output was the greatest. To compute the average power per year the total power was averaged for each year and compared against each other. The average power per season was calculated by averaging the total per for each season and comparing the values to determine which was strongest. The average power per level was computed by averaging the total power per level and comparing them. The total power per month was averaged to determine the average power per month.

3. Results

a) *Total Power Produced*

The study found spring to be the highest yielding season and summer to be the lowest yielding season (Fig 3). The reason that this may occur is because spring is a transitional season and this could lead to increased speed wind, which in turn increases the amount of energy that will be produced. The total yield that was produced during the winter was 13274 kW; spring was 15148 kW; summer's total yield was 10793 kW and the fall produced a total power output of 12571 kW.

The month that produced the most power overall was April and the month that produced the lowest amount of power was August (Fig 4). August is during the summer and there are not strong temperature spikes

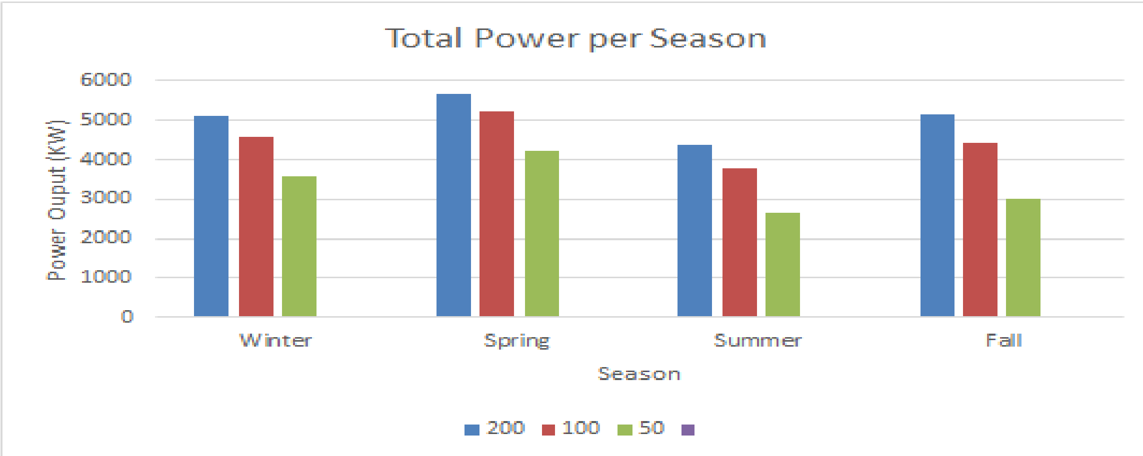

Figure 3: Analysis of the total seasonal output of power for 200 m (blue), 100 m (red), and 50 m (green) of the atmosphere.

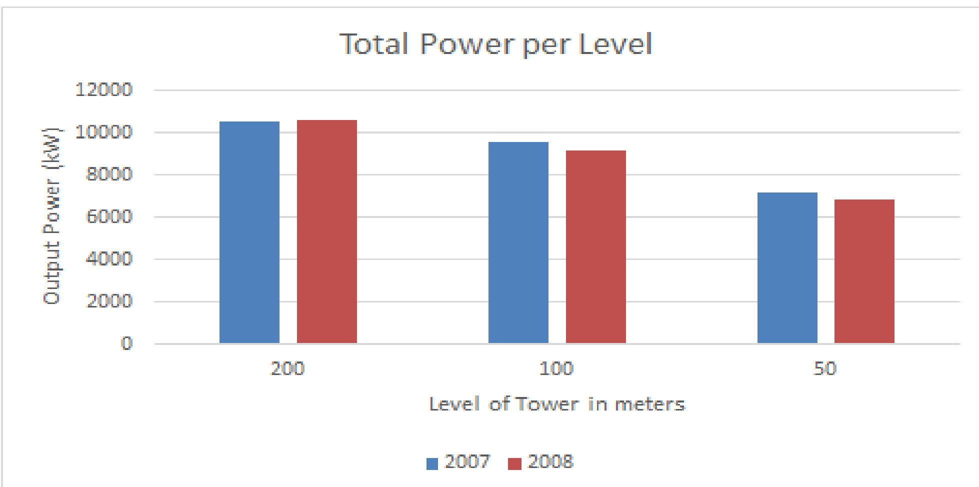

Figure 4: Determining the total power output for 2007 (blue) and 2008 (red) of the atmosphere.

like there is during the spring and fall. The individual month that produced the most power was December 2007. The year that produced more 2008 electrical power was 2007 (Fig 5).

The level of the tall tower that reported the highest output of power was the 200-meter level and the yield of the electrical power output decreased the closer the observations were to the ground (Fig 4). This occurred because the higher an air parcel goes up in the atmosphere the less friction it would have acting on it.

b) *Average Power Produced*

The average power that was produced was similar to the results of the total power produced. The season on average that produced the highest level of power was spring, which was only slightly

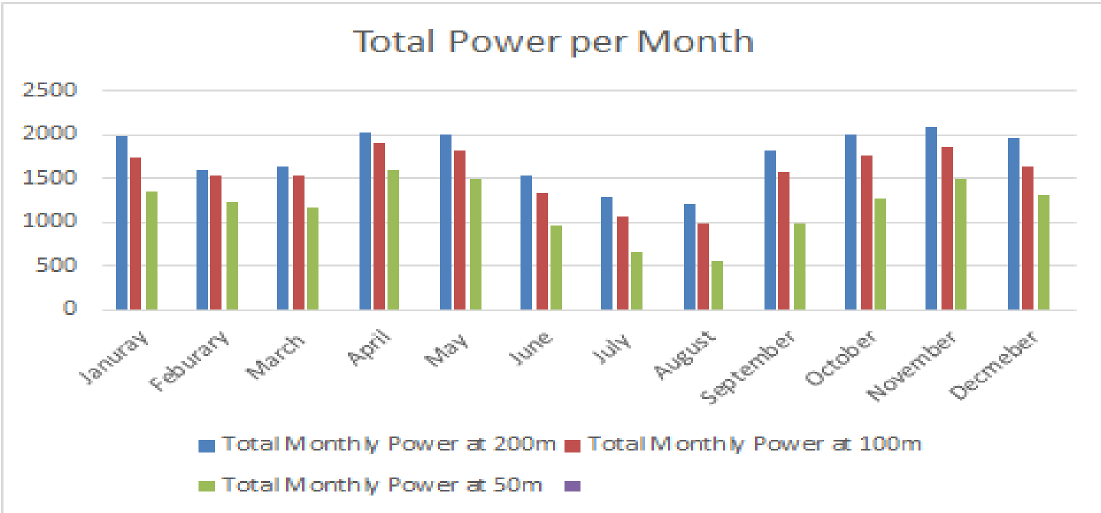

Figure 5: Analysis of the total monthly output of power for 200 m (blue), 100 m (red), and 50 m (green).

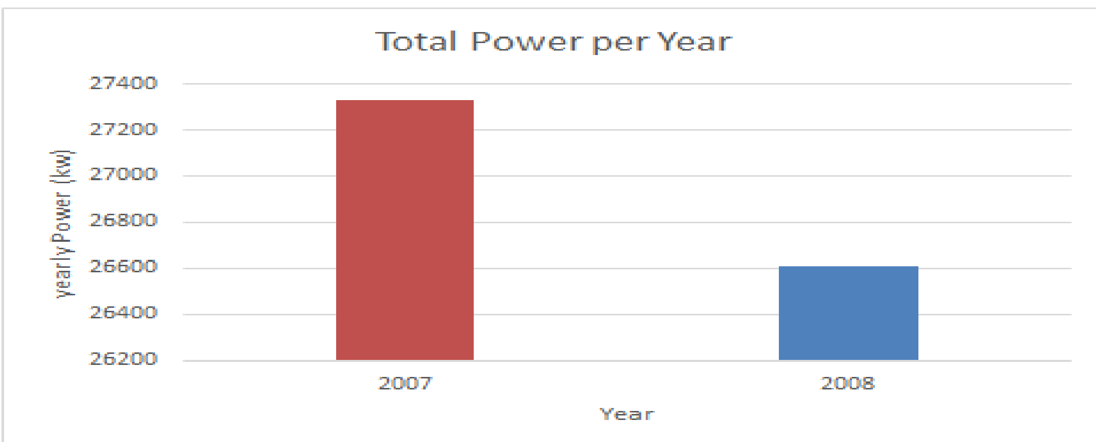

Figure 6: Illustrating the difference between the yearly total power 2007 (red), 2008 (blue).

more productive than fall (Fig 7). Both of these seasons had high wind speed throughout each level. The lowest producing season was summer. On average winter produced 796 kW of power; spring would produces 842 kW; summer would produces 534 kW and fall produced 824 kW of power.

The month on average that produced the most power over the two year period was April, which produced 917 kW of power and it was closely followed by November that produced 907 kW of power (Fig 8). On average, the month that produced the least amount of power was August, which outputted 458 kW of power.

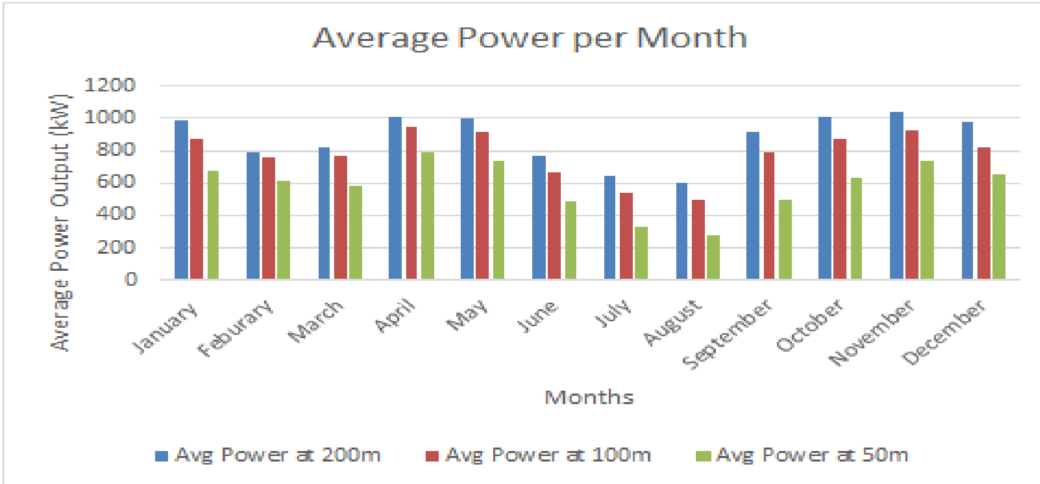

Figure 7: Determining the average monthly output of power for 200 m (blue), 100 m (red), 50 m (green) of the atmosphere.

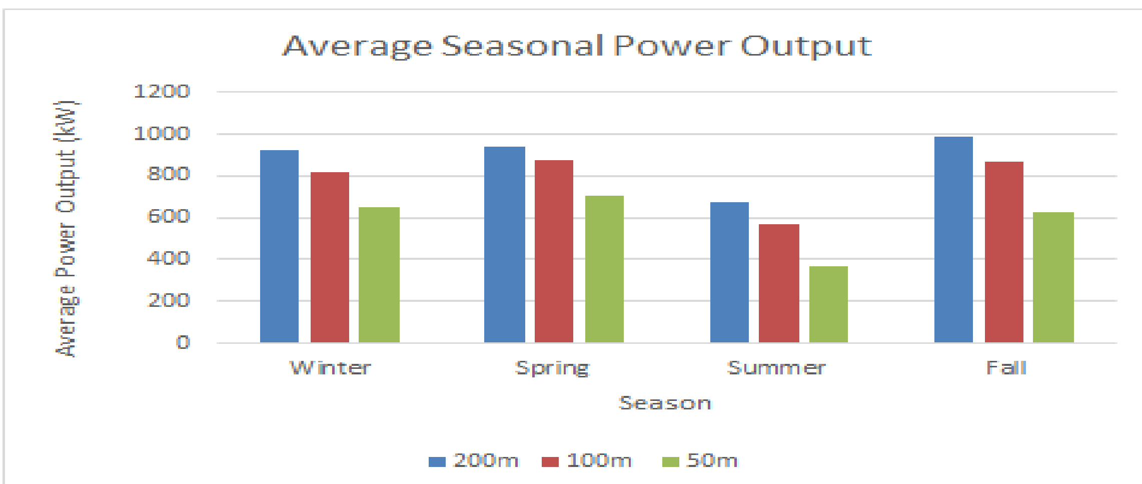

Figure 8: Analysis of the average seasonal output of power for 200 m (blue), 100 m (red), and 50 m (green) of the atmosphere.

The 2007 year, on average, produced more power than 2008. The 2007 power output was 759 kW compared to the 739 kW produced in 2008 (Fig 9).

The level that yielded the highest average power production was the 200 meter level, and the lowest producing level was 50 meters (Fig 10). The average output of the data mirror the total output produced and the same result as the total power produced.

c) *Monthly Cut-In Speed*

Every month of the given data had moments that did not meant the cut in speed. Most of the when this occurred was during the summer months of June, July and August (Table 2). The summer month that experience the most days below the

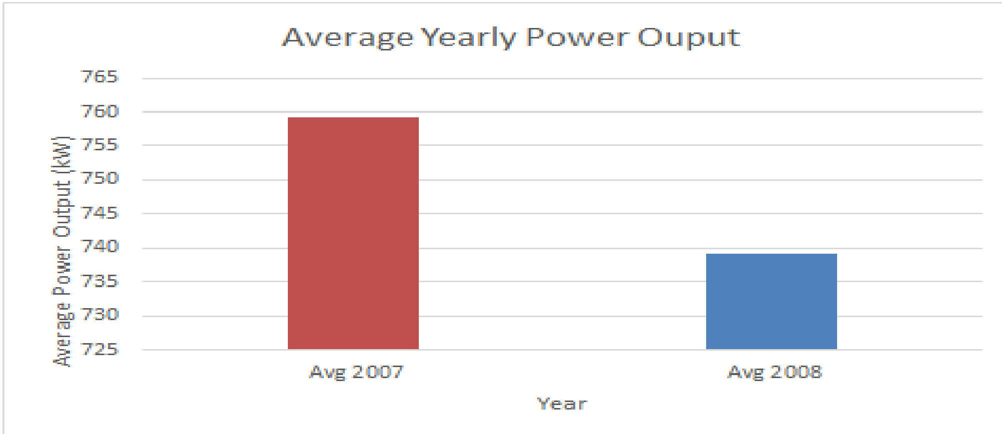

Figure 9: Comparing the yearly average power of 2007 (red) and 2008 (blue).

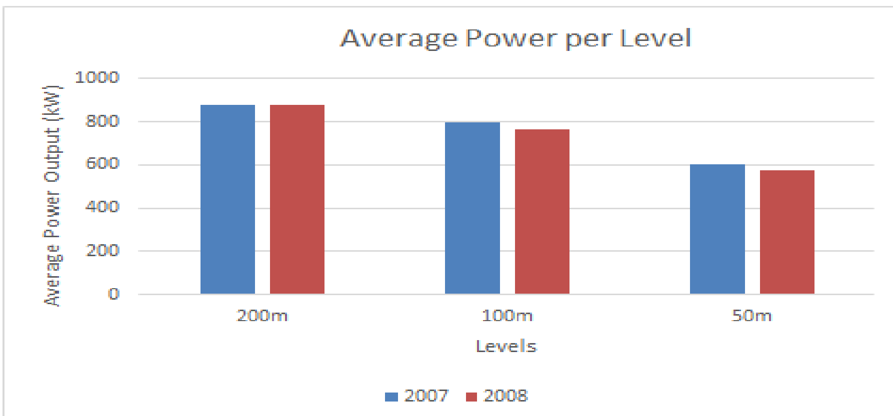

Figure 10: Breakdown of the average seasonal output of power for 2007 (blue), 2008 (red) of the atmosphere.

cut in speed was August for every level over the course of the data (Table 2). The months that experiences the few days were during the spring and fall months especially November for the course of the data (Table 2). Additionally, on average spring and fall months had few days that fell below the cut in speed of the wind turbine (Table 2). Winter and summer had on average more days that had the turbine not running because the winds were not strong enough to meet the cut in speed.

4. Discussion

a) Seasonal

As the previous study by Takle et. al 1978 found that spring is the season that produces the highest amount of electrical power compared to the other seasons. The results of this study as indicate that spring was the most productive season overall followed by fall then winter and finally summer. Spring and fall experience greater changes in pressure, which creates higher speeds in wind. The change in pressure is caused by temperature advection. Spring and fall also have more days where the temperature changes rapidly and the pressure gradient is tighter. The closer the pressure gradient the high the winds and the more will be produced. During the summer and winter seasons there are few days that experience large changes in the temperature, which results in few changes in pressure and therefore weaker winds. The weaker winds result in less power produced and less time the turbine is running. Another factor that could have contributed to the results is that spring and fall produced more power is that those months had few days that reported speed below the cut-in speed. Winter and summer had more days below the cut-in speed and therefore produced less power per season.

b) Monthly

The months resulted heavily on the season on which they occurred in. The spring and fall months will have higher output of power compared the months in the summer and winter. The reason there was slight changes between months for a given season was that one-month will experiences different weather and therefore have more or fewer moments above the cut in speed, which affects the wind power produced. April experiences more days above the cut in speed march because March was a transitional period between spring and winter. March experiences more days below the cut in speed during the early part of the month, and this caused it to have more days on average above the cut in speed compared to the other months in the spring season. November and May, experienced the fewest days below the required cut in speed. This is because both months are in seasons where the wind is on average stronger and both were at the end of those seasons when the atmosphere is in flux.

Table 2: Listed below is the number of days per month of the data period that was below the required cut-in speed for the wind turbine.

Months	Total Days Below Cut-In Speed	Average Days Below Cut In Speed
January	26.02	4.34
February	35.01	5.83
March	30.74	5.12
April	15.34	2.56
May	15.12	2.52
June	20.94	3.49
July	31.43	5.24
August	40.31	6.72
September	20.68	3.45
October	17.77	2.96
November	13.34	2.22
December	16.92	2.82

c) Level

The level that was the most productive out of the three was the 200-meter level. The cause of this result is there is less friction the higher up in the atmosphere then lower to the ground. The ground creates more friction on the air parcel and thus lower values of wind will be observed. The lower wind totals caused the 50-meter level to be the least productive. At higher levels, friction decreases and the power production increases higher on the tower. If a wind turbine was built at 200-meter, it would on average produce more power than wind turbines built at the other levels; however, building a wind turbine of that height can introduce problems. A 200-meters tall wind turbine would have the problem of cost efficiency. Building a turbine that high would cost a lot more than building a shorter turbine. In addition, the winds at that level will on average meet or exceed the cut-out speed, which could either damage the wind turbine or cause the wind turbine to not produce electric power until the winds fall below the cut-out speed. Additional concerns with building a turbine that high are the building requirements to build it. The extra material will increase the price per unit and there will need to be more engineering to account for the increase in height.

d) Yearly

The year 2007 was more productive than 2008, but this does not indicate how much power over the course of time the wind turbines will actually produce. There is not enough data to confidently establish an average or trend. The year 2007 may be an outlier and so could 2008. More data is needed to find an accurate trend of the yearly power output produced by the winds there. With that said one of the cause of why 2007 produces slightly more power is that during 2007 it experiences fewer days in fall and summer that were beneath the cut in speed compared to 2008. This indicates that during the fall and summer the winds were stronger during that time and therefore produced more electric power then compared to the fall and summer in 2008. In addition 2007's weather pattern over Mason City was much more active than 2008. There were more rain events in 2007, which implies that the weather was not very stable. This unstable and active atmosphere indicates that stronger winds would be more common in 2007 than in 2008. The reason for that is when storms occur there is a change in pressure, which leads to stronger winds.

5. Conclusion

The results indicate that the 200-meters level of the tall tower was the most efficient at producing power compared to the other levels, but given the many problems facing a turbine, this high a 100-meter wind turbine will be the most cost efficient and will be an improvement from the 80-meter wind turbines that are used today. The season that produced the most power was the spring season. The data also indicates that 2007 produced more power than 2008, but no true conclusion and be draw then because of the lack of data to accurately determine a yearly trend. The month that produced the most electric power was December 2007 and April produced the most power over the two years.

6. Future Works

Another project could look at taller towers and other wind turbines across Iowa to determine if the same result was observed there. This study would be significant because the data could be used to determine the best possible site for new wind turbines in Iowa. These methods could also be used to determine other power output from different wind farms in other states and other countries. This study could be significant to see what areas of the world are best suited for wind turbines and in what areas new wind turbines could be built.

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