Determining the Effect of Wind Shear Events on Power Output of Individual Wind Turbines on an Iowa Wind Farm

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Introduction

In 2006, the U.S. Department of Energy set a goal that 20% of our energy needs would be met with wind energy by 2030. Iowa wind farms frequently experience high wind shear (high vertical gradient of the horizontal wind) that may affect wind farm efficiency. The purpose of this study is to establish an understanding of how wind shear affects power output of individual turbines in large scale wind turbine operations.

Methods

- Horizontal wind speed and direction data in ten min averages for 50, 100, and 150 levels of a 200-m tower was obtained from the Iowa Tall Tower Network for September 2007 to April 2009.
- Power data at 10 min intervals were obtained for five 1.5 MW turbines in an Iowa wind farm from March 2008 to December 2010.
- Wind speed and directions were interpolated to 80-m (turbine hub height) and categorized by high and low speed shear then averaged and compared.
- Power shear factor and wind shear values were calculated for each ten min interval.
- Data from 5 turbines were statistically analyzed for high shear and low shear environments occurring for 26-27 August 2008.

Results

Power Shear Factor Calculation

$$P_{sf} = \frac{P}{\frac{1}{2}\rho C_p A \vec{V}^3}$$

Where ρ is air density, C_p is the power coefficient, A is area, and V is the wind velocity at hub height. This calculation is derived from the power equation. The power shear factor is unity in no shear environments and greater or less than one in low shear environments and high shear environments respectively.

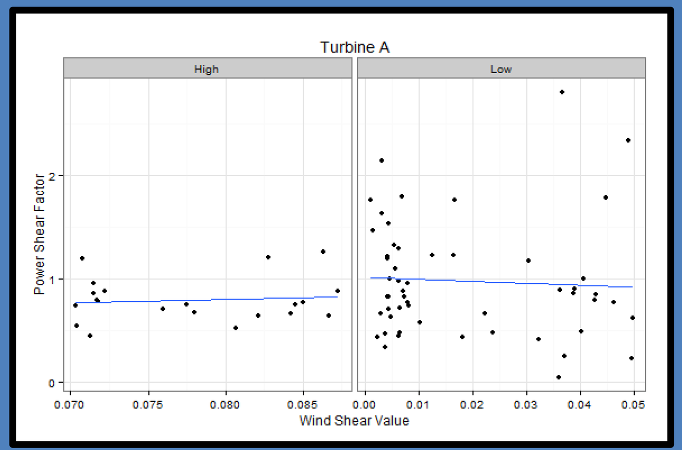

FIG 1: Turbine power factor as a function of wind shear for turbine A.

Turbine A		
Shear	High	Low
Mean P_{sf}	0.793	0.982
Mean D_s	14.01º	10.21º
Standard Deviation of P_{sf}	0.217	0.555
P-Value	0.038	

Table 1: Shear category, mean and standard deviation of power shear factor, mean direction and p-value for turbine A.

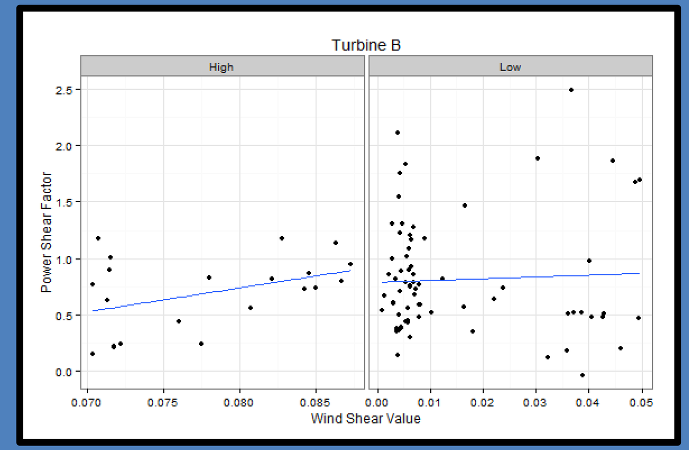

FIG 2: Turbine power factor as a function of wind shear for turbine B.

Turbine B		
Shear	High	Low
Mean P_{sf}	0.690	0.810
Mean D_s	14.01º	9.23º
Standard Deviation of P_{sf}	1.969	7.886
P-Value	0.203	

Table 2: Shear category, mean and standard deviation of power shear factor, mean direction and p-value for turbine B.

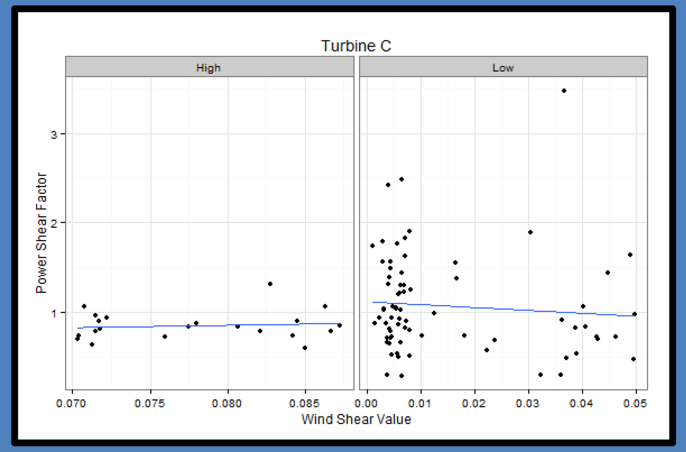

FIG 3: Turbine power factor as a function of wind shear for turbine C.

Turbine C		
Shear	High	Low
Mean P_{sf}	0.846	1.068
Mean D_s	14.01º	9.35º
Standard Deviation of P_{sf}	0.161	0.559
P-Value	0.003	

Table 3: Shear category, mean and standard deviation of power shear factor, mean direction and p-value for turbine C.

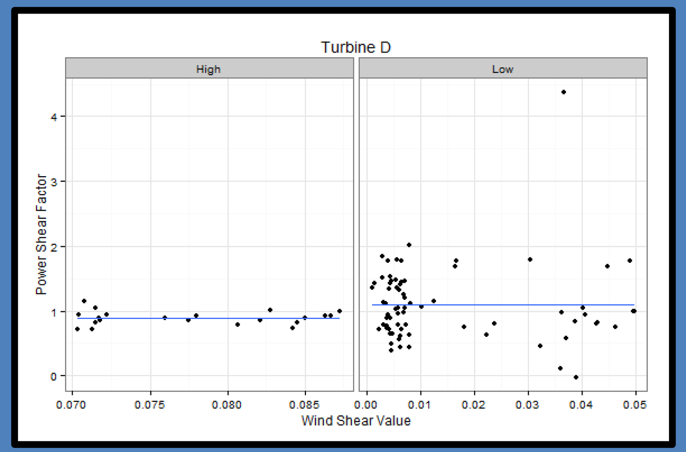

FIG 4: Turbine power factor as a function of wind shear for turbine D.

Turbine D		
Shear	High	Low
Mean P_{sf}	0.887	1.094
Mean D_s	14.01º	9.35º
Standard Deviation of P_{sf}	0.111	0.586
P-Value	0.005	

Table 4: Shear category, mean and standard deviation of power shear factor, mean direction and p-value for turbine D.

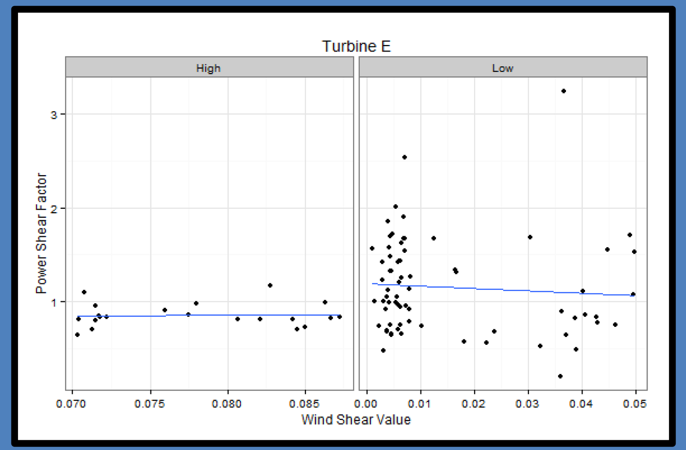

FIG 5: Turbine power factor as a function of wind shear for turbine E.

Turbine E		
Shear	High	Low
Mean P_{sf}	0.851	1.152
Mean D_s	14.01º	9.35º
Standard Deviation of P_{sf}	0.128	0.505
P-Value	$1.3*10^{-5}$	

Table 5: Shear category, mean and standard deviation of power shear factor, mean direction and p-value for turbine E.

Methods Cont.

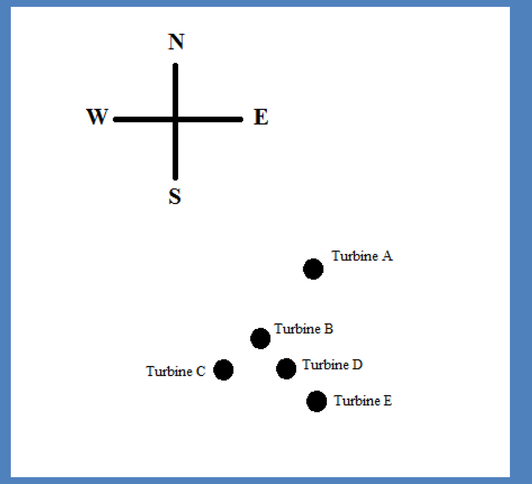

FIG 6: Turbine layout

Case 1		
Shear	Average 80-m Wind Direction	Average 80-m Wind Speed
High	Southeast 153 Degrees	8.69 m s^{-1}
Low	Southeast 147 Degrees	7.77 m s^{-1}

Table 6: Case 1 parameters

Figure 6 is a map of the turbine locations the orientation of the selected turbines. Table 6 gives wind direction and speed for Case 1 (26-27 Aug 2008).

Conclusions

- High shear environment yields a lower power output.
- At four of five turbines, results were proven to be statistically significant ($p<0.05$) by a t-test.
- We speculate that turbines in high speed shear environments are producing power below optimum levels because the angle of attack is not optimum.

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