SAND2015-2202D

New Wake Effects Identified Using SCADA Data Analysis and Visualization

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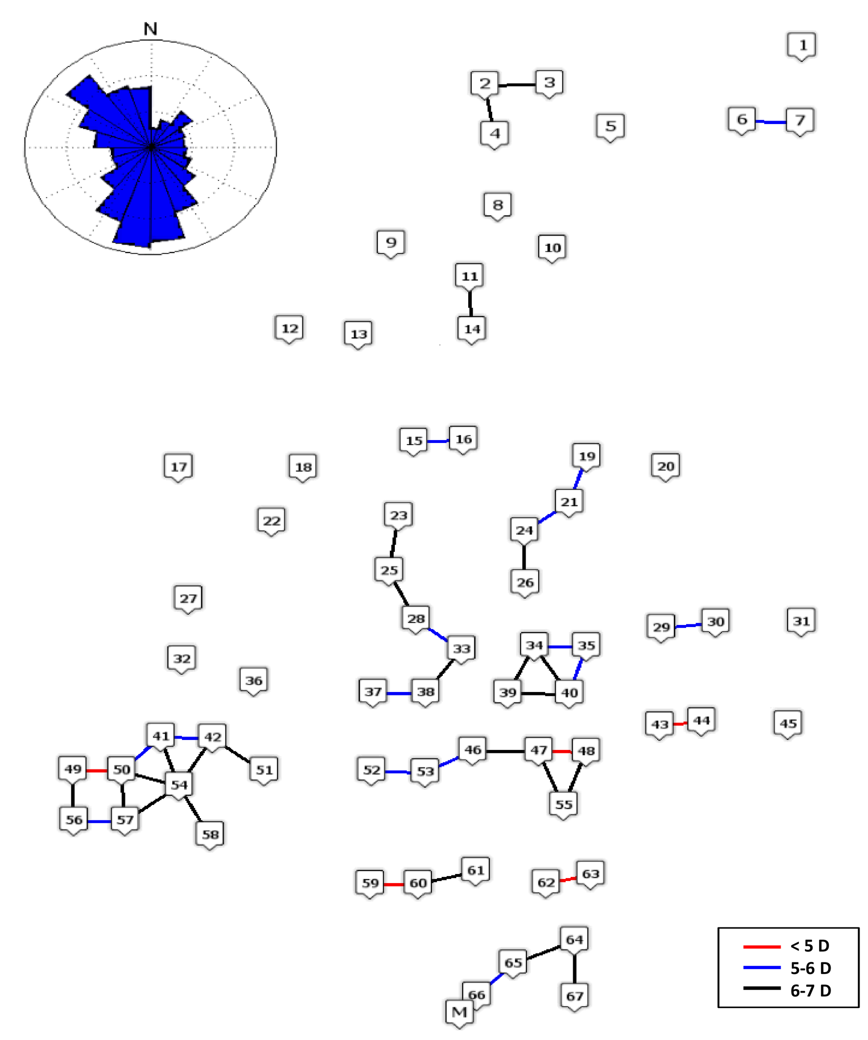
SCADA Data. Data was gathered over a 1.5 year period in 2012 and 2013 from the SCADA system at an onshore wind farm in the United States. The wind farm included 67 horizontal axis, three bladed, variable pitch turbines, along with one meteorological (met) tower. In this study, analysis was performed on a subset of the data collected from the turbines:

- nacelle wind speed,
- nacelle direction (position),
- rotor speed,
- blade pitch,
- and power output.

The met tower collected data on temperature, air pressure, wind speed, and wind direction, but do not play an important role in the analysis.



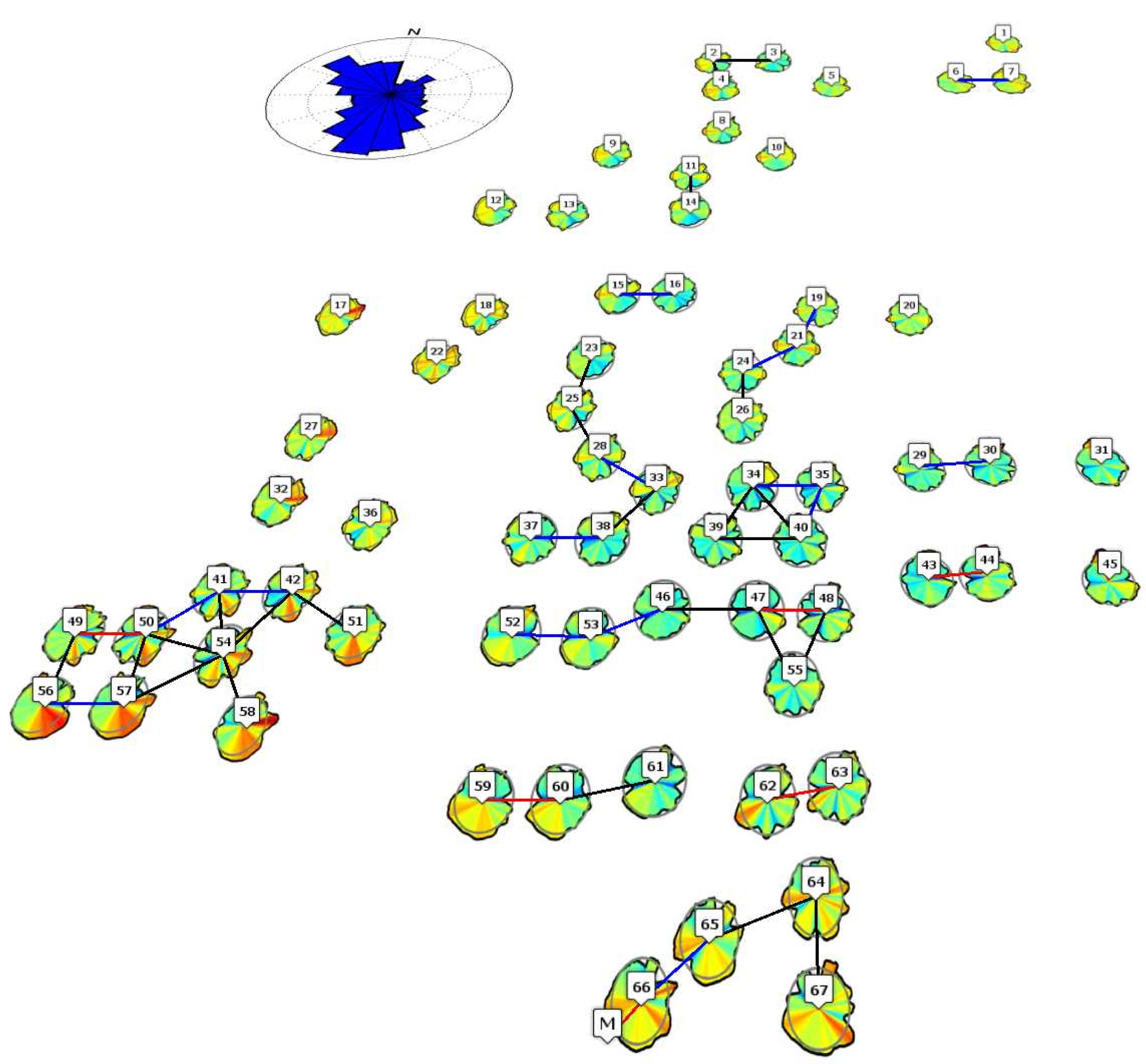
Visualizing Wake Effects. After data correction (including met tower wind direction, nacelle wind direction, and power curve based on pitch schedule), a method for visualizing wake effects was developed called *normalized instant power*. For turbine *i*, the *normalized instant power* is defined to be

$$P_N(t) = P_i(t)/\mu_{P(t)},$$

where $P_i(t)$ is the power of turbine *i* over the ten-minute interval t, and $\mu_{P(t)}$ is the average power over all turbines over the same interval. In addition, the power variability of a turbine is computed as

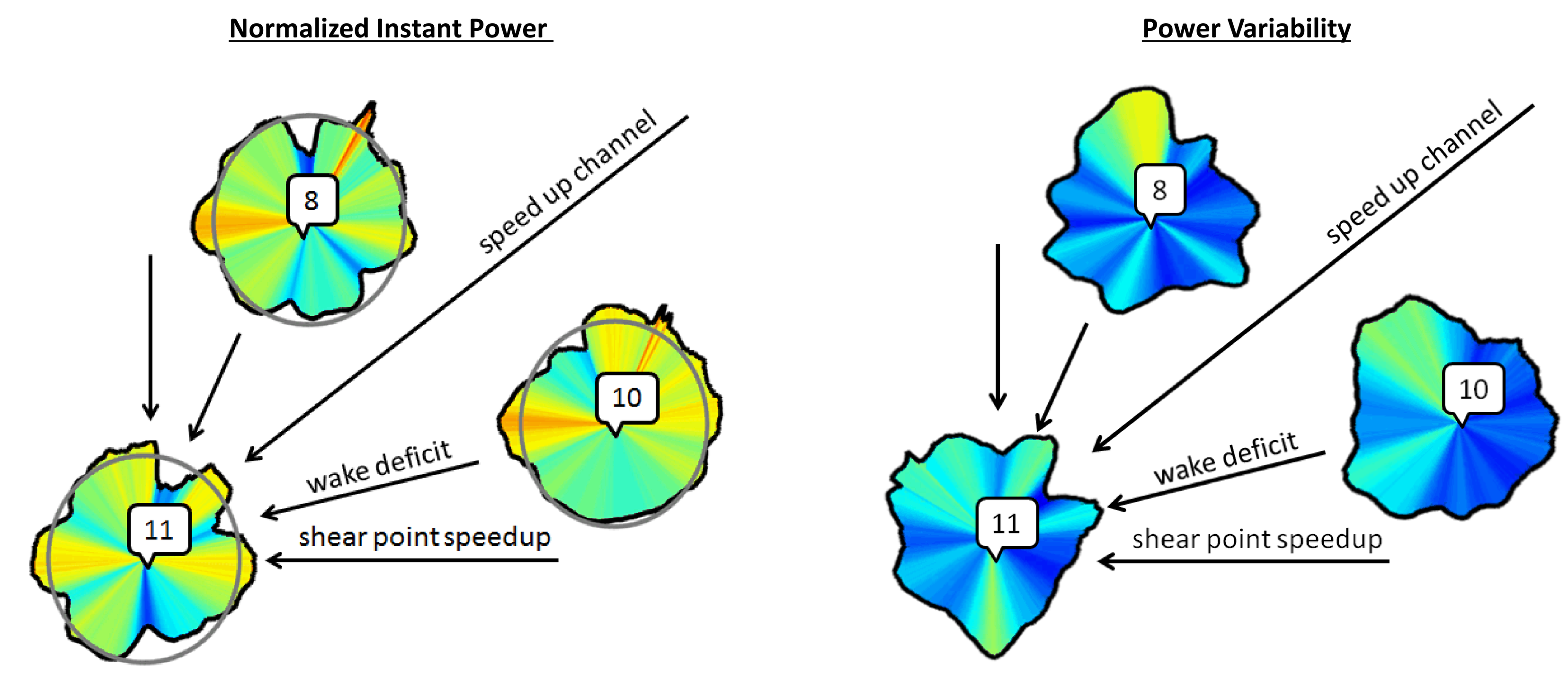
$$P_v = {}^{\sigma_P}/_{\mu_P},$$

where μ_P is the power produced by the turbine, and σ_P is the standard deviation of the power produced, both taken over the ten minute intervals. The resulting polar plots can be visualized in Google Earth (http://www.google.com/earth).



New Wake Effects. In addition to providing an overview of the wind farm, the normalized power and power variability plots can be used to understand wake effects on a more detailed scale. Four distinct features have been observed in the data:

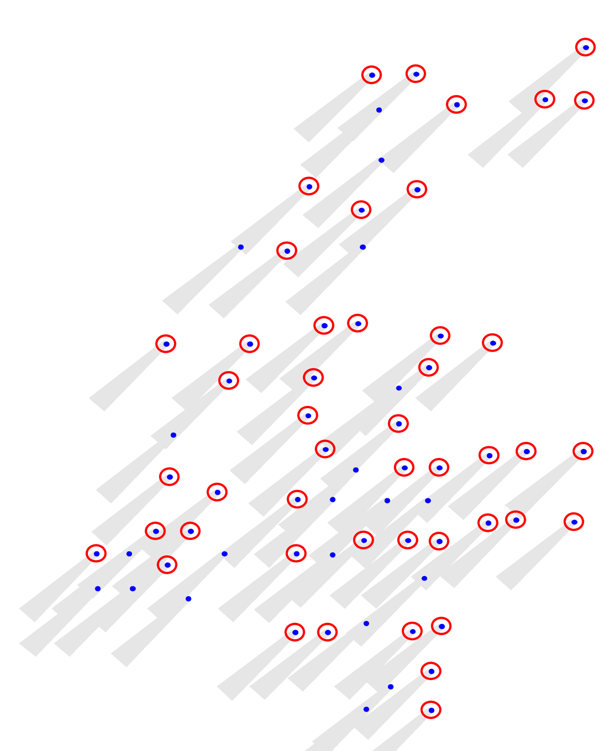
- wake deficit effects,
- speed up channels from two upstream turbines,
- shear point speedup from one upstream turbine, and
- shear point speedup from multiple upstream turbines or an upstream farm.

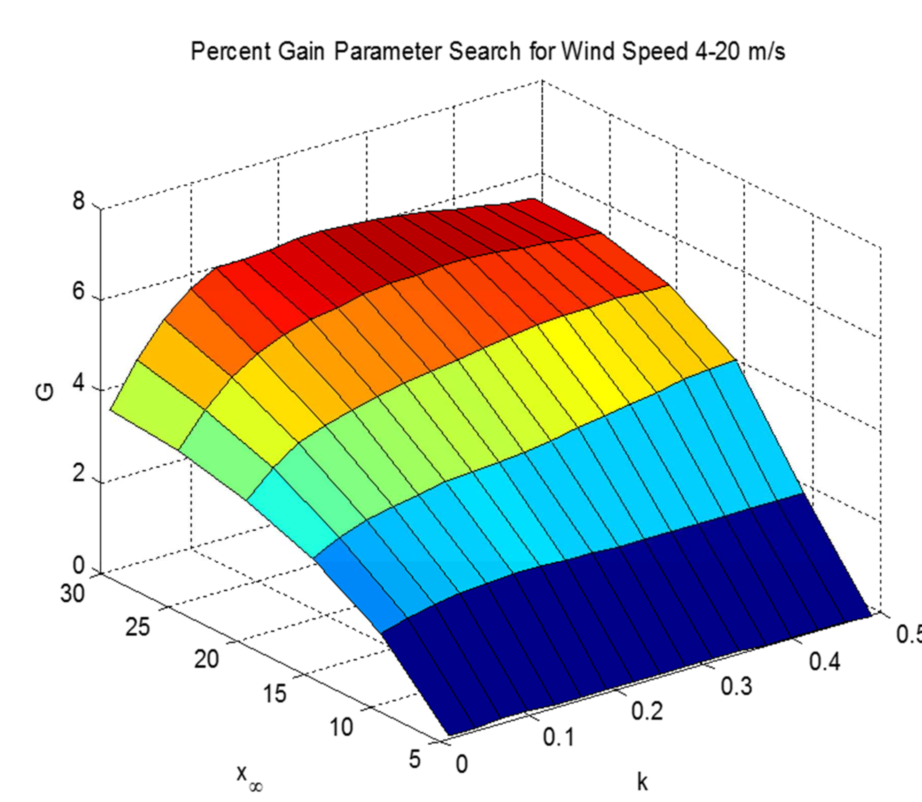


Quantifying Wake Losses. To estimate power lost due to wake effects, an approximation of the wind speed in the absence of upwind turbines needs to be computed. This can be done if the upwind turbines throughout the farm are identified and used to extrapolate the true wind speed for the shadowed turbines. Shadows were computed using the Park model [1]

$$D_w(x) = D_t + 2kx,$$

where $D_w(x)$ is the diameter of the wake as a function of the distance x behind the upwind turbine, D_t is the diameter of the turbine, and k is a roughness coefficient which depends on the geography of the wind farm (0.075 in the below example). Wind speed in the absence of wake was used to compute percent power gain G. Wind shadows were assumed to attenuate after distance x_∞.





Conclusions. Using visualizations, three wake effects were observed: deficits, speed up channels, and shear point speed ups. In some cases, the speed ups serve to mitigate the wake deficits.

Wake losses were found to be in the range of 3% to 6%, depending on the parameters used in the estimates. Using an independent method by Marden *et al.* [2], losses were computed at 2.5%. Most of the losses occur when the wind is blowing in the east or west directions. However, there are more turbines closely sited in the east-west direction than in the north-south direction, so that east-west losses do not contribute greatly to the overall losses of the wind farm. In addition, losses are minimal when wind speed is over 10 m/s (near rated capacity).

References.

1. Katic I, Høstrup J, Jensen NO. A Simple Model for Cluster Efficiency. *Proc. of the 1987 European Wind Energy Conference*, Rome, 1987; 407-410.
2. Marden JR, Ruben SD, Pao LY. A Model-Free Approach to Wind Farm Control Using Game Theoretic Methods, *IEEE Transactions on Control Systems* Technology; 21(4):1207-1214, 2012.

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NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. Wind farm SCADA data was provided by a strategic industrial partner. See also SAND report No. 2014-16983C.

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