Effect of wind distribution on perceived performance of wind turbines

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Abstract: This paper provides an introduction to the analysis of the effect of wind distribution on the performance evaluation of wind turbines. The most common practice in the industry is to create databases of results obtained in different sites and perform a statistical analysis of these results. This simple methodology hides some physical effects originated by the specific climatic conditions of the different sites.

The quality of these tests has a clear influence on the result, however, the effect of quality and measurement uncertainty is not included in this document to allow the analysis of the wind distribution effect in a separate way.

It is clear that the power curves and the performance of the turbine depends, among others, on turbulence levels, shape of boundary layer and inflow angle but as it is measured in terms of energy the wind distribution also has to be introduced in the analysis.

The first part of this paper describes the effect of wind distribution on the perceived performance. The study done by the authors shows that apparent losses for the same measured power curve could range from 2% to 5% depending on average wind speed and shape of Weibull distribution

The second objective of this paper is to describe simple procedures that eliminates this effect from the comparison. The statistical analysis done with the production of all measured power curves with the design wind distribution of the turbine provides the best estimate of its real performance. The use of normalized losses allows a quick determination of performance for the specific values of the wind farm. Another alternative is to create an average power curve with all measurements and compute the performance of turbine for these values. In this case all power curves should be normalized to a common density.

It is important to note that performance of turbines is a key parameter in the evaluation of the viability of a wind farm and that any increase in the accuracy of its determination will impact positively on business certainty.

Keywords: Power Curves, turbine performance, uncertainty.

Introduction:

The evaluation of energy output of wind farms has become an essential part of the viability analysis of a wind farm. The quality of that evaluation depends strongly on the accuracy of wind data as wind turbines just convert kinetic energy of the air to electrical energy. Obviously, the deeper the knowledge of wind the better the accuracy of the prediction of energy.

The first variable that is necessary to know is the expected average wind speed with its associated hourly distribution and be capable to determine it during the lifetime of the wind farm based on the available measurements. It is possible to find in the literature many works that provide different methods to make the so called long term correction of wind distribution. Some examples can be found in [1-2].

The knowledge of wind distribution is only the first step in the analysis of the wind. The response of a wind turbine depends on the characteristics of the wind [3-8], and therefore, shall be determined from the very beginning to allow an accurate evaluation of possible energy output. The output of the turbine depends, among others, on turbulence levels, shape of boundary layer, inflow angle and wind veer. These wind characteristics could change with wind direction, season, hour of the day, etc. The analysis of these wind characteristics and their variation is essential to determine with enough precision the output of a wind farm. To provide a better representation of flow characteristics many advances in CFD have been applied to determine the flow in wind farms [9-11] and to determine the energy output with improved accuracy [11-13].

The third link in the chain of determining the energy output is to evaluate the ability of turbine to convert available kinetic energy into electricity. The classical way of evaluating the performance of the turbine is to compile a series of measurements following the same International Standard [14] and obtaining the statistical parameters that defines that expected behavior of turbines. There are some examples of this statistical treatment in the literature [15-16].

The analysis of the wind and the performance of the turbine are then used in the pre-construction energy estimate. This process is described in [17] and basically consists on predicting the amount of energy delivered by a wind power plant. The main outcome of this process is the net energy estimate with its probability distribution characterized by average value and standard deviation.

The results are usually expressed as a probability distribution of energy. For example, the P50 value is the amount of energy that has a 50% probability of being exceeded and the P90 is the amount of energy that has a 90% probability of being exceeded.

The net energy is obtained from the gross energy by application of empiric factors that usually are smaller than one, then the P50 net energy is obtained just multiplying the P50 gross energy by these factors. The standard deviation of the net energy is used to account for uncertainties in the evaluation of energy production. These uncertainties are originated, among others, by site measurement, spatial variation, vertical extrapolation, wind variability and power plant performance.

One of the empirical factors applied to obtain the net energy is the performance of the turbine. Its value should be determined with enough accuracy because it has a clear effect on the viability of the wind project. An overestimation of performance could lead to financial losses and, on the other hand, an underestimation of performance could reduce the profitability to unacceptable levels putting in risk the whole project. This problem is even more evident in auctions, where wind power is competing against other technologies and an excessive reduction of P50 could make impossible to have any chances to win.

The performance of a turbine is a concept with a definition that is in some cases subjective. The authors consider the performance of a turbine as a measure of the capability of the turbine to follow the Power Curve specified by the manufacturer when working inside of their associated ranges of climatic conditions.

As the measurement of the performance is based on energy output it makes this variable dependent on wind distribution. It is obvious that a turbine that fulfill its power curve for all bins will have the same performance (100%) for all possible wind distributions but due to the fact that some authors reports losses of the order of 2.4% [15-16] the effect of different wind distribution shall be analyzed.

In the most pessimistic case two mistakes are made in the definition of wind turbine performance for a specific wind farm. The first one is originated by the treatment of results of Power Curve Test. In some cases, the measured power curves are not available and the only data is the value of performance for the site specific wind distribution. The combination or results with different wind distribution originates a difference with respect to the real value. The second one happens when the value of turbine performance is not particularized to the local conditions of the site.

In the following chapters the effect these two mistakes are analyzed and a simple procedure to particularize the value of turbine performance for a specific wind distribution is described.

Effect of using different wind distribution on the evaluation of performance

The effect of using different wind distribution on the evaluation of performance is relatively easy to obtain. To illustrate the problem the following analytical exercise has been done. An approximate power curve for zero turbulence has been defined by using a constant value of Cp up to reach nominal power. For velocities higher than the rated one the power is maintained constant and equal to nominal one. A second power curve simulating a reduction of performance is created with the same procedure but including an effectiveness factor in the region of partial production. Both power curves are combined with different wind distributions and the AEP difference in percentage is obtained. The results are presented in Figure 1.

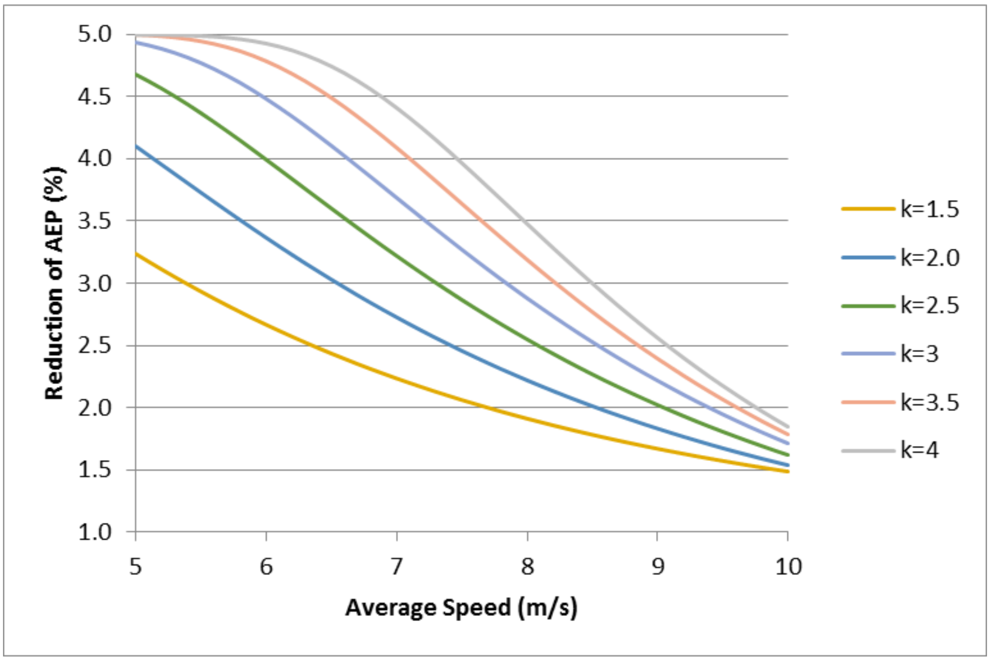

Figure 1. Effect of wind distribution on AEP losses (%)

For this simple analysis the performance on the region of partial production has been set to 95%, therefore, the 5% losses are observed only for these wind distributions that have no hours at nominal power. The design point of this turbine would be an average velocity of 7.5 m/s and a Weibull shape factor of 2. For the design point the losses are 2.46%. The maximum value of losses observed is 5% and the minimum one is 1.48%. This example clearly illustrates the importance of use the same wind distribution when analyzing the performance of wind turbines. In the rest of the paper it is assumed that the reference wind distribution is the one that correspond to its design point. The value of the average velocity used for designing a turbine could be easily estimated by its IEC class.

The effect of this variation of production on the average performance could be estimated by the uncertainty associated to the variability of error. Assuming a triangular probability of occurrence of the different values, the associated uncertainty, $U(Perf)$, is:

$$U(Perf) \approx \frac{|\varepsilon_{max} - \varepsilon_{min}|}{2\sqrt{6}}$$

Where ε_{max} and ε_{min} are respectively the maximum and minimum deviation of AEP observed in the results of Figure 1.

With the results presented in Figure 1 the value of the uncertainty associated to the average of performance values obtained for different wind distribution is 0.71%. Therefore, the average performance of this turbine would be 97.54% ± 0.71%. It could look a small number compared with the value of average performance but what in fact this is saying that losses of the turbine are 2.46%± 0.71%. It means that the standard deviation is a 29% of the variable that is being measured. Even though someone could consider this number as small, from a technical point of view is not acceptable to convert a physical effect to an uncertainty if this could be avoided with a simple treatment.

The previous evaluation of uncertainty can be done more accurately by using a monte carlo method. This method allows also to analyze the effect of sample size on the evaluation of average performance and in its uncertainty. The working principle is as follows: for every sample size, n, analyzed a high number of simulations are done. In these simulations a random process selects the average wind speed and the shape of the Weibull distribution for the n samples of every simulation. The results of simulation are presented in Figure 2 in terms of average, standard deviation, maximum and minimum values.

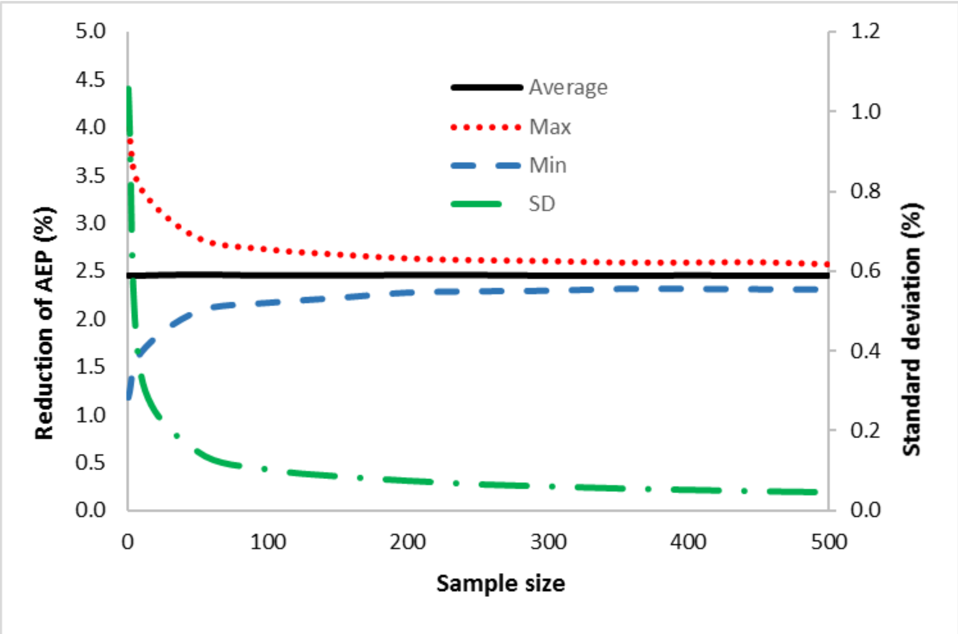

Figure 2. Effect of sample size on performance values

The results presented in Figure 2 indicates that for a sufficient large sample size the effect of using different wind distributions when evaluating the average performance of turbines introduce a small uncertainty. For instance, for a sample size of 200 turbines the expected standard deviation is 0.0752 but the influence of small sample sizes is evident. The value for n=10 is 0.3406 (about 12% of the variable to be determined). This uncertainty shall be combined with the uncertainty of measurements of the Test, that usually are of the order of 5%, to get the confidence interval for average performance. It is important to know that as this uncertainty is directly related to wind distribution is fully correlated with the Test uncertainties.

Procedure to particularize the turbine performance for specific wind distribution

From Figure 1 is evident that the use of average values for the wind farms introduce a bias in the pre-construction analysis. Assuming that the values provided by [15-16] are correct and that the value of average reduction of performance is about 2.5% the expected variation of this variable in the range analyzed in this document is between 1.5% and 5%. The effect of reducing expected losses from 5% to 2.5% could have a dramatic effect on financial result of that wind farm. By contrast the wind farm that has a real reduction of 1.5% could have higher revenue, but this revenue could never happen if the project was lost.

When analyzed the results presented in [15-16] it is evident that they provide a very good approximation of the average results but with variations of the order of 10-15% in some of the wind farms which means that these procedures based on average values are very good to obtain the average value of tens or hundreds of wind farms but with very little applicability to define the real performance of a specific wind farm. These methods could be good enough for big corporations with sufficient wind farms but they do not suit very well with the needs of companies with small number of wind farms.

The effect of wind distribution can be easily minimized by applying a very simple procedure. First step is to normalize the values of Figure 1 by dividing the reductions of AEP by the reduction of AEP expected for the reference wind distribution. This normalization is required to adequate the reduction to different values of reduction at reference wind distribution. Then the value of performance reduction to be applied at a specific site would be:

$$\Delta P(V,k) = \Delta P\left(V_{ref},k_{ref}\right) F_W(V,k)$$

where $\Delta P(V,k)$ is the reduction of performance expected for average wind speed, V, and shape factor, k, $\Delta P\left(V_{ref},k_{ref}\right)$ is the reduction of performance at reference point and $F_W(V,k)$ is the normalized function shown in Figure 3.

The values of $\Delta P\left(V_{ref},k_{ref}\right)$ could be obtained from works similar to [15-16] or computed internally by the company that decides to use this procedure, based on its own database of power curve measurements.

An open question is the validity of function defined in Figure 3 for other turbines. The function F_W depends on the particular characteristics of the turbine; therefore it is necessary to have a procedure to particularize it to the specific turbine to be installed in the wind farm. This function can be obtained by data published by the manufacturer of the turbine. It is common practise to provide power curves at different densities, then it is possible to use the power curves for two adjacent densities to simulate the effect of a reduction of performance.

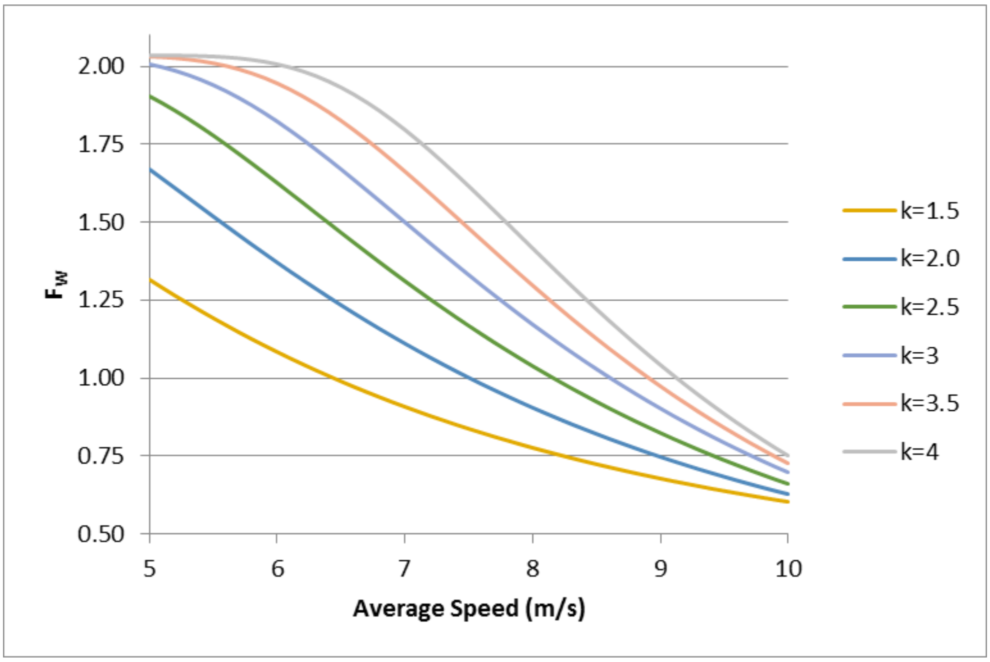

Figure 3. Normalized variation of performance as function of wind distribution

As an example, the power curves for density 1.225 and 1.2 kg/m^3 from [18] are used to obtain the normalized reduction of performance for that specific wind turbine.

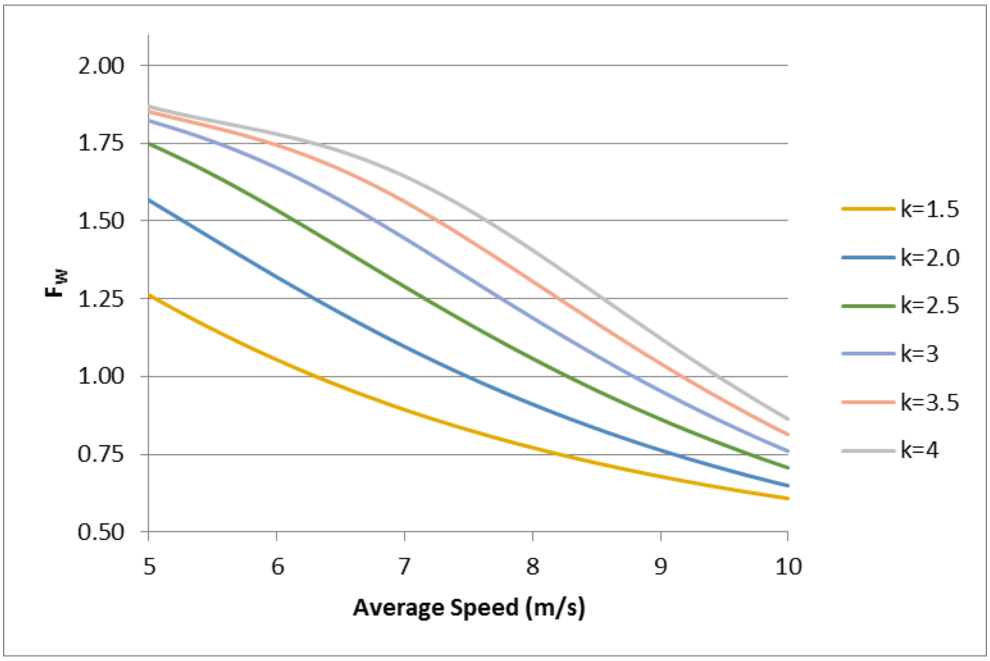

Figure 4. Normalized variation of performance for V112-3.3

In this case the reference wind distribution has been defined with an average of 7.5 m/s and k=2 even though the turbine is Class II to allow an easy comparison with Figure 3.

The effect of other variables such as different turbulence range, inflow angle or shear exponent could change slightly the shape of this function. The same process could be done with a Climatic Specific Power Curve if more than one density is provided. In any case the use of the function derived from the General Specification power curves would provide a much better pre-construction energy estimation than the current approach where no correction is applied.

Conclusions

The study presented in this document shows that apparent losses for the same measured power curve could range from 2% to 5% depending on average wind speed and shape of Weibull distribution.

The effect of this variability on the evaluation of apparent performance of a turbine could be reduced increasing the sample size of the database when it is not possible to perform a consistent comparison by using a common wind distribution to analyze all power curves.

As the apparent performance of turbines is one of the factors used during pre-construction energy estimates it is extremely important to have the maximum available accuracy when determining its value for a specific wind farm. The current method based on average values obtained from measurements is well suited to provide a good estimate of average values of a sufficient number of wind farms but does not provide enough accuracy for individual wind farms.

The use of the simple method proposed by the authors will improve the accuracy of estimation of energy production for individual wind farms. A higher accuracy in the determination of production of wind farm could lead to a reduction of the current uncertainties applied in the current pre-construction models.

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