Site-Dependent Wind Turbine Performance Index

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Abstract- This letter presents a method for estimating the dependence of turbine performance index on the specific site. The approach is based on the Weibull wind probability distribution function and manufacturer provided power curve. Instead of choosing a particular model for approximating the power curve, commonly used polynomial fitting is employed. A general approach to calculating the turbine performance index is derived, suitable for both fixed and variable speed wind turbines.

Keywords Wind Turbine, Curve Fitting, Weibull Distribution, Performance Index

1. Introduction

The suitability between a wind turbine and a wind site is the one of the key parameters of a wind project success [1] - [6]. If the rated speed is too low, the turbine is operated with a high capacity factor (CF) while losing a significant amount of energy in high winds. On the contrary, if the rated speed is too high, the turbine extracts most of the energy from the wind while operating with low CF. The concept of turbine performance index (TPI) is usually employed to evaluate the trade-off between the CF and the energy produced by a wind turbine [7]. By far, it was suggested in the literature to determine a turbine, most suitable for a given site, by varying the rated speed of an off the shelf turbine while keeping the rest of the parameters unchanged, looking for a theoretically optimal but practically non existing turbine [7] – [9]. The approach is correct if the turbine output power in the non-rated region is proportional to the cubic wind speed, which is true in case of variable speed turbines only. In other contributions, the power curve was shown to resemble a second-order polynomial function, parameters of which were assumed to be the same for different rated speeds [10], which is a relatively weak statement. Moreover, all the above mentioned references assumed that the ratios of the rated to the cut-in and furling speeds remain constant for the whole range of rated speeds, which is barely realistic. Hence, the most practical way to find the most suitable turbine for a given site is by comparing the TPI of several off-the shelf turbines.

In this contribution, an alternative way to tackle the problem of turbine-site matching is proposed. Rather than finding the best theoretical turbine for a given site (which is a complicated multivariable optimization problem if no simplifying assumptions are made), it is suggested to determine the best site for an available off-the-shelf turbine. As a result, while matching wind turbines to a given site, the amount of possible turbines is significantly narrowed by eliminating the unsuitable turbines a priori. Moreover, adopting the presented approach may assist wind turbine manufacturers to find the best locations for each of their products and market accordingly.

2. TPI derivation

The power output of a wind turbine is associated with two nonzero regions of the power curve, namely the non-rated (for wind speeds between the cut-in speed v_C and the rated speed v_R) and the rated (for wind speeds between the rated speed and the furling speed v_F) regions. The power curve is usually provided by the manufacturer as a discrete series of output power versus wind speed (Fig. 1) and may be fitted by an appropriate polynomial function in each of the regions, leading to the following general expression,

$$P(v)=P_R\begin{cases}0, & v\le v_C,\ v>v_F\\ \sum_{i=0}^{n}a_{1i}v^i, & v_C\le v\le v_R\\ \sum_{i=0}^{n}a_{2i}v^i, & v_R\le v\le v_F\end{cases}, \tag{1}$$

Where:

P_R is the rated power of the turbine and a_{1i}, a_{2i} are the polynomial coefficients. In a particular case of variable speed wind turbine, the output power is, as mentioned, proportional to the cubic wind speed in the non-rated region, i.e. the only nonzero coefficient is a_{13}. Moreover, in case of pitch regulated wind turbine, the output power equals P_R in the rated region, i.e. the only nonzero coefficient is $a_{20} = 1$ [11].

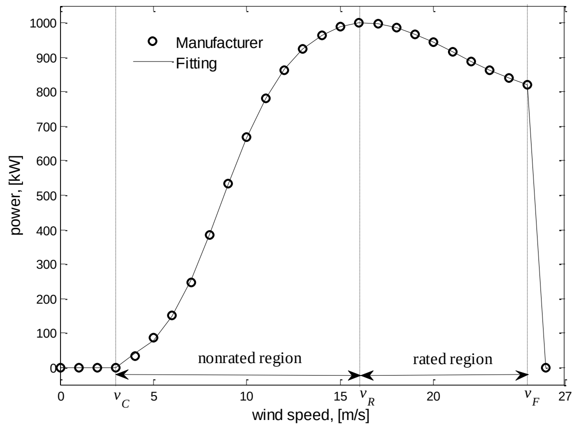


Fig. 1. Power curves of a general wind turbine: manufacturer supplied (dotted) and fitted (solid)

Turbine CF is defined by the ratio of average and rated powers,

$$CF=\frac{P_{AVE}}{P_R} \tag{2}$$

with

$$P_{AVE}=\int_0^{\infty}P(v)f(v)dv, \tag{3}$$

where $f(v)$ is Weibull PDF with site-specific scale parameter c and shape parameter k [12]. Combining (1) – (3), the CF was derived in [11] as

$$CF(k,c)=-\sum_{i=0}^{n}a_{2i}v_F^i e^{-(\frac{v_F}{c})^k}-\sum_{i=1}^{n}c^i\frac{i}{k}\Gamma(\frac{i}{k})\Omega(i) \tag{4}$$

with

$$\Omega(i)=a_{1i}\gamma((\frac{v_C}{c})^k,\frac{i}{k})-(a_{1i}-a_{2i})\gamma((\frac{v_R}{c})^k,\frac{i}{k})-a_{2i}\gamma((\frac{v_F}{c})^k,\frac{i}{k})$$

where $\Gamma(x)=\int_0^{\infty}t^{x-1}e^{-t}dt$ and $\gamma(y,x)=\frac{1}{\Gamma(x)}\int_0^{y}t^{x-1}e^{-t}dt$

are gamma and incomplete gamma functions, respectively.

TPI is defined as the product of capacity factor and average power [7],

$$TPI(k,c)=CF\cdot P_{AVE}, \tag{5}$$

and may be reformulated by combining with (2) as

$$TPI(k,c)=CF^2\cdot P_R. \tag{6}$$

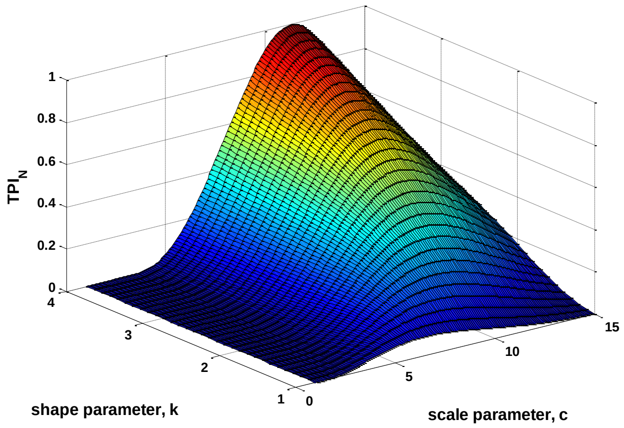
According to (6), the TPI for a given site is proportional to squared capacity factor; hence both TPI and CF attain maximum value for the same k and c. Since the turbine rated power is site-independent, it may be omitted by defining the normalized turbine performance index as

$$TPI_N(k,c)=\frac{TPI(k,c)}{P_R\cdot\max_{c,k}\left(CF^2\right)}=\frac{CF^2}{\max_{c,k}\left(CF^2\right)}. \tag{7}$$

Obviously, $0 \le TPI_N(k,c) \le 1$ and the (k,c) pair, resulting in $TPI_N(k,c) = 1$, defines the best site for a given turbine. Alternatively, when considering a particular turbine installation in several different sites, the one with the highest TPI_N is the most preferable one.

3. Example

Consider a NEG Micon 1000/60 fixed speed, stall controlled wind turbine power curve, shown in Fig. 1. Table I in [11] presents the coefficients derived from the 6th order polynomial fitting of the manufacturer provided data. The data was used to estimate the TPIN for wind sites with $1 < k < 4$ and $1 < c < 15$ according to (7).



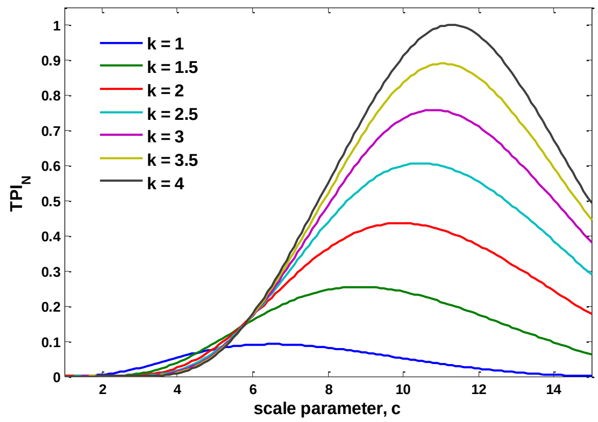


Fig. 2. Results for NEG Nicon 1000/60 wind turbine. Upper - $TPI_N(k,c)$; Lower - TPI_N dependence on the scale parameter for different k

The results are shown in Fig. 2. Apparently, for a given shape parameter k, the maximum TPI_N is attained at a unique optimal scale parameter. Moreover, the optimum scale parameters are dissimilar for different shape parameters. Two interesting outcomes should be mentioned. At the vicinity to the optimal scale parameter, the TPI_N increases with k, as predicted by [13]. However, when moving away to the left from the optimum scale parameter, there is surprisingly a point where the above observation is no longer true. For example, for $c < 5$, the TPI_N for $k = 1$ is higher than the TPI_N for $k = 4$. The other issue to point out is the non-unique site decision that occurs near $c = 6$, where the TPI_N is nearly the same for any $k \geq 1.5$.

4. Conclusion

An approach for calculating the Turbine Performance Index of a given wind turbine for different sites was proposed in the correspondence. The method, suitable for both variable and fixed speed turbine generators, is based on the Weibull wind probability distribution function and manufacturer provided power curve, approximated by a commonly used polynomial fitting. It was shown that the turbine performance index is proportional to the squared capacity factor and attains an optimum value at a unique scale parameter for a given shape parameter.

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