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A PRELIMINARY APPROACH FOR WIND TURBINE SELECTION IN A SPECIFIC WIND REGIME

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Abstract. *This work aims to present a simplified tool for preliminary wind turbine selection in a given wind regime. This tool is quicker time wise compared to other options available in the industry. In Brazil, for example, the currently installed wind turbines are not matched properly with wind conditions. One of the several consequences involved includes the low capacity factor in some wind farms. In this regard, a methodology that approaches this scenario was developed to identify the most appropriate wind turbine for a given wind regime. The procedure consists of comparing, on the same graphic scale, wind turbine power curves combined with the Weibull cumulative distribution function, using a range of Weibull shape factors representative of the local wind characteristics and for each annual average wind speeds, based on international standard: IEC 61400-1. Three wind turbines of the same rated power but with different IEC classes were chosen. Thus, the most appropriate wind turbine for the local wind regime was selected based on the simplified tool.*

Keywords: *Wind regime, Weibull cumulative function, wind turbine selection procedure.*

1. INTRODUCTION

This work aims to present a simplified tool for preliminary wind turbine selection with respect to a given wind regime. This tool presents a time gain advantage for wind turbine selection compared to other options available in the industry.

2. METHODOLOGY

The present tool consists of comparing on the same graphic scale wind turbine power curves combined with the Weibull cumulative distribution function $F(V)$ for each annual average wind speed (V_m), based on IEC 61400-1 (Burton *et al*., 2001). The function $F(V)$ represents the time fraction or probability that the wind speed is equal or lesser than a given wind speed, V, Eq. (1), where k and c represents the Weibull shape and scale factors respectively (Lysen, 1983; Manwell *et al*., 2009). The typical value of k for the northeast region in Brazil is approximated to 4.

$$F(V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right] \tag{1}$$

The *F(V)* is obtained when *k* and *c* are known. The scale factor *c* was estimated by Eq. (2) (Lysen, 1983; Manwell *et al.*, 2009):

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{2}$$

Thus, the power produced (*P*) by the turbine for a given wind speed ranging from 1 to 25 m/s with a bin width of 1 m/s is multiplied by *F(V)*:

$$P\left(F(V)\right) = P \cdot F(V) \tag{3}$$

The power produced by the wind turbine according to the local wind characteristics is normalized to compare the curves drawn on the same scale:

$$P^* = \frac{P\left(F(V)\right)}{P_{máx}} \tag{4}$$

where $P_{máx}$ is the maximum power produced by the turbine.

3. CASE STUDY

Three wind turbines each of a 2 MW rated capacity by three different turbine manufacturers were selected, their names have been withheld. Figure 1 shows the power curves of these wind turbines for a standard density of $\rho = 1.225$ kg/m^3:

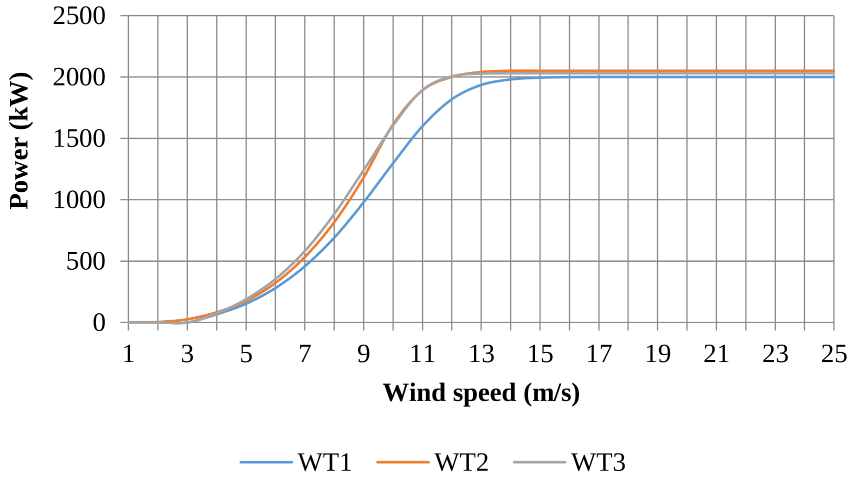

Figure 1. Power curves of the WTs.

Table 1 shows the characteristics of these turbines and the IEC standard 61400-1. For example, WT1 is a turbine defined by the IEC standard as class I where the mean wind speed is 10 m/s, and it has a rotor diameter, cut-in , and rated speed of 92 m, 4 m/s, and 15 m/s , respectively. The hub height of all the three turbines is equal.

Table 1. Characteristics of the selected WTs.

Wind Turbines	**WT1**	**WT2**	**WT3**
Rated Power (MW)	2.0	2.0	2.0
Rotor diameter (m)	82	82	90
Cut-in (m/s)	4.0	3.0	4.0
Rated (m/s)	15.0	12.0	12.0
V_m(m/s) from IEC	10.0	8.5	7.0

A wind regime (*k=4)* is typical of the Brazilian Northeastern region (Rohatgi *et al*., 1993; Silva, 2003; Medeiros *et al*., 2011; Medeiros *et al*., 2013; Juárez *et al*., 2014). Based from this information, a comparative study between the three turbines was carried out with *k*=4, representative of the given wind regime. Three different scenarios were then analyzed. The value of *k* was fixed but the average annual wind speed (V_m) was varied according to Tab. 1. The first scenario represents *k=4* and V_m= 10 m/s, and the results are shown in Fig. 2:

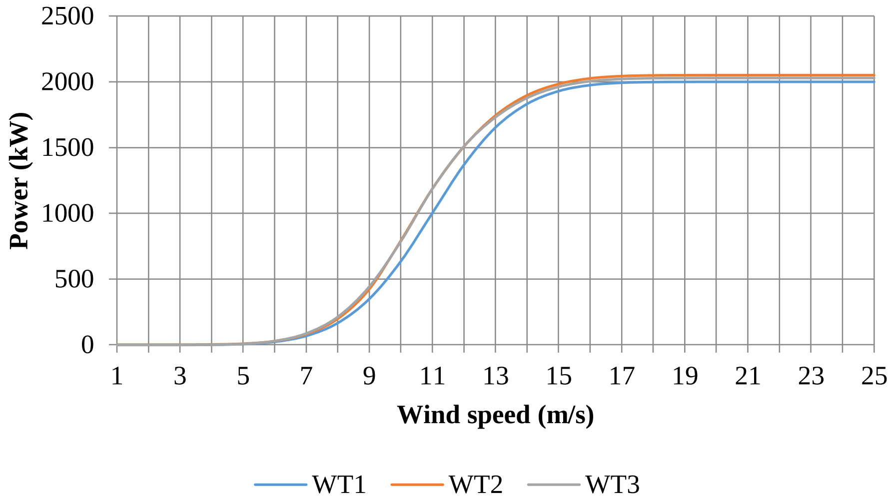

Figure 2. Power curves for *k=2* and V_m=10.0 m/s.

It is observed that, by applying *F(V)*, the turbines present a decline at the beginning of production at cut-in between 5.0 and 6.0 m/s when compared to the curves provided by the manufacturers in Fig. 1. The application of *F(V)* also shows that the rated wind speed goes to around 16 m/s.

It can be noted from Fig. 3 that it is possible to identify the difference between the power produced by the turbines between 8.0 and 14.0 m/s.

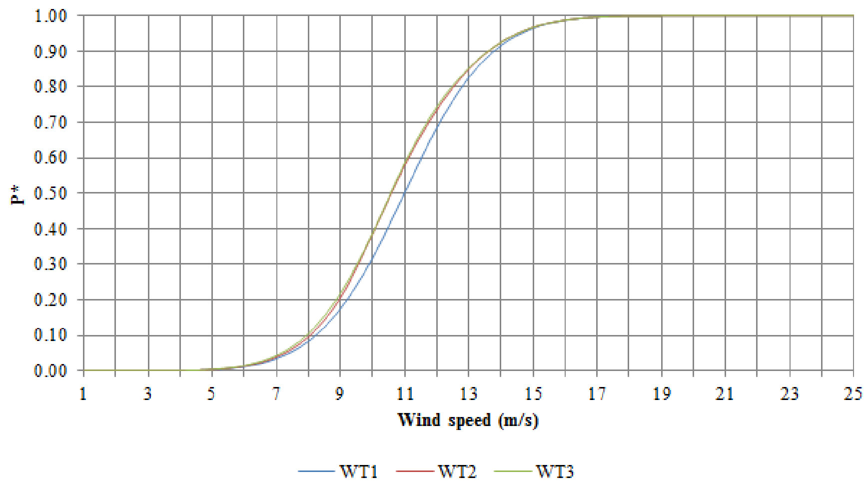

Figure 3. The normalized power curves

From Fig. 3, WT1 can be seen to be operating at 68% of its rated power at 12 m/s, whereas WT2 and WT3 at 73% and 74% respectively. However, at 15.0 m/s WT1 operates at 96% and 97% for WT2 and WT3. That is, a turbine designed to operate at an average annual wind speed of 10.0 m/s would not be appropriate in this wind regime. This is obviously from the power production point of view. For the first scenario (*k=4* and V_m= 10 m/s), the values obtained for *F(V)* are shown in Tab. 2.

Table 2. $F(V)$ for $k=4$ and V_m=10 m/s.

Wind Speed (m/s)	$F(V)$ %	Wind Speed (m/s)	$F(V)$ %
1	0.01	14	92.52
2	0.11	15	96.72
3	0.55	16	98.80
4	1.71	17	99.64
5	4.13	18	99.92
6	8.38	19	99.98
7	14.96	20	100.00
8	24.15	21	100.00
9	35.78	22	100.00
10	49.08	23	100.00
11	62.78	24	100.00
12	75.33	25	100.00
13	85.45	-	-

The wind regime is given for $k=4$ at V_m=10.0 m/s which means that the speeds are concentrated around 10.0 m/s. According to Tab. 2 and Fig. 3, note that the turbines would operate effectively over a range of speeds from 7.0 to 14.0 m/s. This shows that WT1 would probably not operate at its rated power most of the time. WT 2 or WT 3 would produce more power in this case. Table 3 summarizes the results.

Table 3. P^* for a wind speed range at V_m=10.0 m/s.

V (m/s)	P^*%		
	WT1	WT2	WT3
7.0	3	4	4
8.0	8	10	11
9.0	17	21	22
10.0	32	39	39
11.0	50	58	59
12.0	68	73	74
13.0	92	93	93
14.0	96	97	97

For the pair $k=4$ e V_m= 8.5 m/s, Fig. 4 was obtained. In this scenario, comparing with the last case, it is noted that wind speeds below rated power decreased where power produced increased at lower wind speeds.

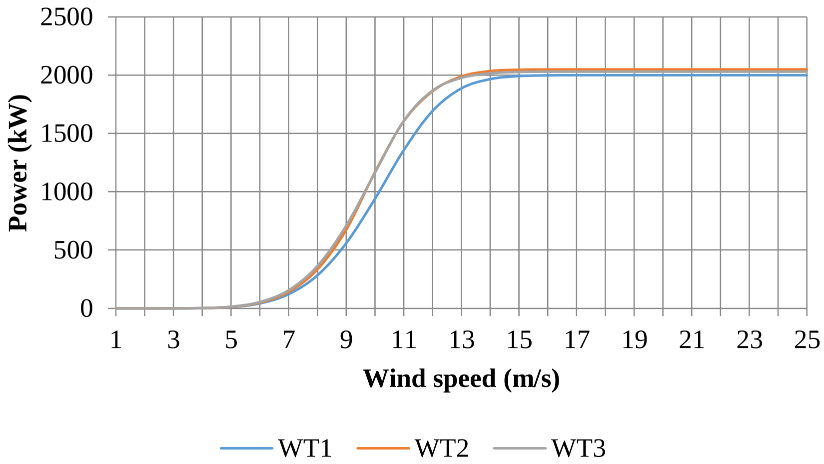

Figure 4. Power curves for $k=4$ and V_m=8.5 m/s.

According to Fig. 5, it can be seen that for a speed of 12 m/s WT1 operates at 85% of its rated power, whereas the WT 2 and WT 3 operates at 91% e 92% respectively. At 15 m/s, all WTs would be operating at 100% of their respective rated powers.

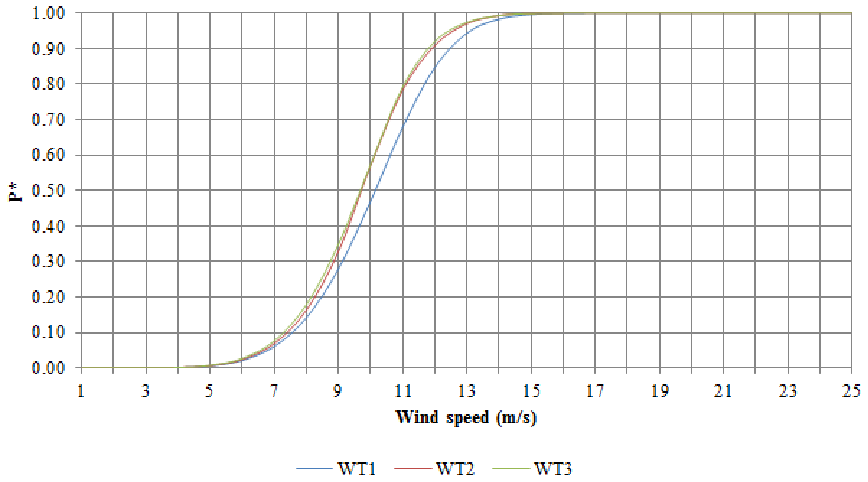

Figure 5. Normalized power curves.

However, according to Tab. 4, it is observed that a speed of 15 m/s would be almost improbable. That is, for the pair $k=4$ and V_m=8.5 m/s, the wind speeds would occur at around 8.5 m/s and probably would not attain their rated speeds. WT 2 or WT 3 would also be suitable for this pair.

Table 4. $F(V)$ for $k=4$ and V_m=8.5 m/s.

Wind Speed (m/s)	$F(V)$ %	Wind Speed (m/s)	$F(V)$ %
1	0.01%	14	99.30%
2	0.21%	15	99.86%
3	1.04%	16	99.98%
4	3.26%	17	100.00%
5	7.76%	18	100.00%
6	15.43%	19	100.00%
7	26.69%	20	100.00%
8	41.12%	21	100.00%
9	57.19%	22	100.00%
10	72.56%	23	100.00%
11	84.94%	24	100.00%
12	93.15%	25	100.00%
13	97.51%	-	-

Table 5 summarizes the ratio $P*$ with respect to the wind speed range, according to $F(V)$, for power production.

Table 5. $P*$ for a wind speed range at V_m=8.5 m/s.

V (m/s)	$P*$%		
	TE1	TE2	TE3
7.0	6	7	8
8.0	14	16	18
9.0	28	33	35
10.0	47	57	57
11.0	68	78	79
12.0	85	91	92

Figure 6 was obtained for the pair $k=4$ and V_m=7.0 m/s. It is observed that when V_m is decreased (from 10.0 to 7.0 m/s), the power curves tends to approach the power curves provided by the manufacturers.

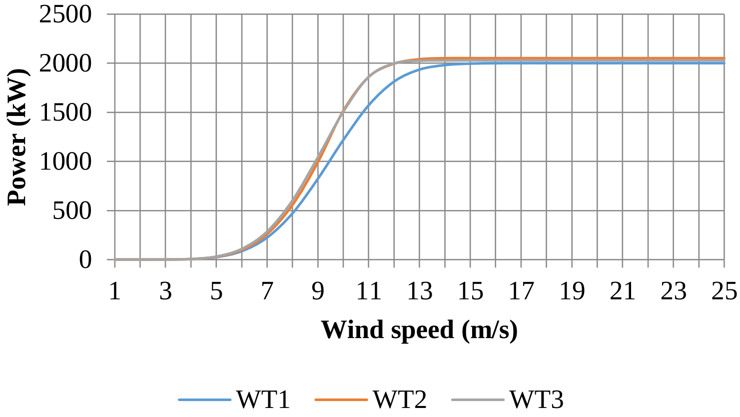

Figure 6. Power curves for $k=4$ and V_m=7.0 m/s.

From Fig. 7, for a wind speed of 12 m/s, it can be seen that WT1 would produce 91% of its rated power, whereas WT 2 and WT3 97% and 98% respectively. At 15 m/s, the WTs would produce 100%. However, wind speeds above 11.0 m/s would be improbable, according to Tab. 6.

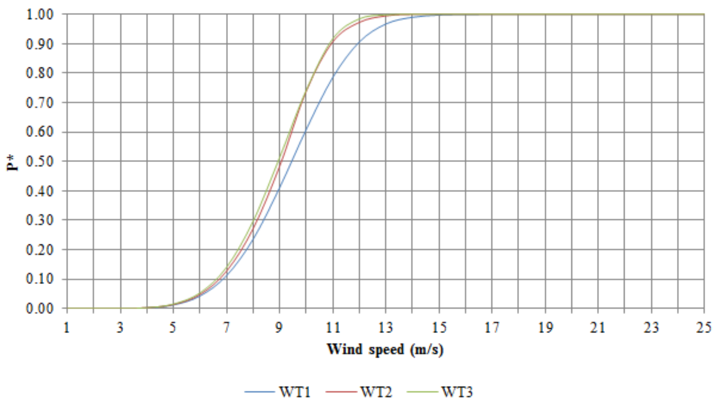

Figure 7. Normalized power curves.

Table 6. $F(V)$ for $k=4$ and V_m=7.0 m/s.

Wind Speed (m/s)	*F(V)* %	Wind Speed (m/s)	*F(V)* %
1	0.03%	14	100.00%
2	0.45%	15	100.00%
3	2.25%	16	100.00%
4	6.94%	17	100.00%
5	16.11%	18	100.00%
6	30.53%	19	100.00%
7	49.08%	20	100.00%
8	68.38%	21	100.00%
9	84.19%	22	100.00%
10	93.99%	23	100.00%
11	98.37%	24	100.00%
12	99.71%	25	100.00%
13	99.97%	-	-

Table 7 summarizes the ratio of *P** for the wind speed range according to *F(V)* for power production at V_m=7.0 m/s.

Table 7. The ratio of *P** for a wind speed range at V_m=7.0 m/s.

V (m/s)	*P**%		
	WT1	WT2	WT3
5.0	1	1	2
6.0	4	5	5
7.0	11	13	14
8.0	24	27	30
9.0	41	48	51
10.0	61	74	74
11.0	79	91	92

A better view can be obtained in Fig. 8, where the power curve variation for WT3 is depicted. For *k=4*, the closest to the power curve given by the manufacturer is WT3 (V_m= 7,0 m/s). The power curve produced by the manufacturer shows that the wind turbine produces 29% of its rated power, but in this wind regime the turbine would produce only 14% if *V*= 7.0 m/s.

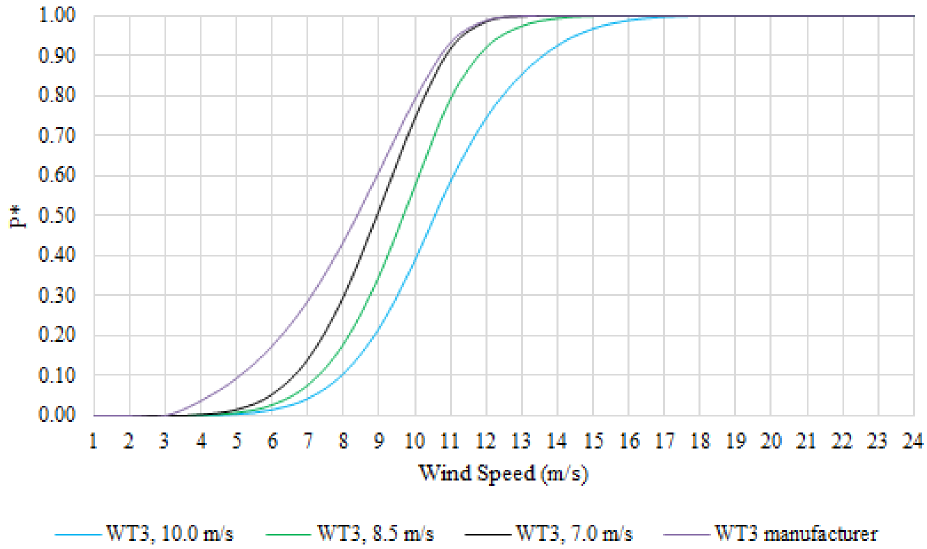

Figure 8. Power curve variation.

4. CONCLUSIONS

This study demonstrated that the analysis of power curves provided by the manufacturers (Fig. 1) may not be sufficient for a proper preliminary selection of WTs. The proposed procedure for this example showed that WT3 would be pre-selected based on the annual average wind data and the local wind regime (*k* = *4*).

In all the three scenarios analyzed (V_m=10.0, 8.5 and 7.0 m/s, for *k*=*4*), it was observed that WTs 2 or 3 would be more appropriate. However, WT3, although designed for V_m=7.0 m/s, would reach 98% of its rated capacity in this wind regime. Nevertheless, the rated speed of WT3 is 12 m/s and from Tab. 6 this value is improbable. Since the speeds would concentrate around V_m=7.0 m/s for *k*=*4*, WT3 would operate with only 14% of its rated power if the wind speed is kept constant at its average value.

For this wind regime (*k*=*4*), it would be ideal to design turbines that operate at lower rated wind speeds. This confirms the imminent necessity of developing projects for trade-wind regime, i.e., a turbine that suits our type of winds, typically Northeastern. This would probably mitigate the difference between the real and simulated capacity factors. In addition to the average annual wind speeds, the wind turbine survival speed is quite low as compared to wind regime having Weibull shape factor about 2.

Based on these facts, it would be appropriate to design wind turbines according to such characteristics, i.e., an IEC class S, for proper utilization of wind energy in this region of Brazil.

5. ACKNOWLEDGEMENTS

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