STUDY ON THE CALCULATION ALGORITHM FOR THE PARAMETERS OF THE POWER CURVES OF THE VERTICAL AND HORIZONTAL AXIS WIND TURBINES

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Abstract

This paper presents the calculation algorithm of the parameters of the power curves for the calculation of energy in the case of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAHT), and the indicative calculation of the energy generated - E (kW / hm^2 / year). Errors made in the assessment of the average annual wind speed are of great importance in these calculations. The installed capacity at the swept area is evaluated, and thus resulting the indicator "equivalent hours of installed capacity utilisation". Energy production depends on the location of the turbine.

Key words: wind turbine, parameters, power curves, characteristic number, power coefficient

INTRODUCTION

Specific parameters of the power curves, which are conceived according to wind speed, v=m/s, tip speed u, air density ρ, exposed area S, materialized in the unit power form equation at the turbine shaft level:

$$P_{arb} = C_P \cdot \rho \cdot \frac{v^3}{2} \cdot S$$

Starting from the values of constant speed (n = 50-400 rpm) and wind speed considered as a reference v = 5, 12, 15 m/s, the following parameters λ, C_P, P_{arb} were calculated. In the case of VAHT, $S = D \cdot H = 7{,}5 m^2$ where D = 2.5 m, H = 3, $\lambda = \frac{u_R}{v} = \frac{\omega \cdot R}{v}$u where n is the rotational speed of the wind turbine (rpm).

When calculating the wind turbine shaft power, and taking into account that the speed value was considered as a calculation benchmark, the constant $A = \rho \cdot \frac{v^3}{2} \cdot S$ is defined. The procedure is similar to HAWT by making use of specific mathematical relationships.

MATERIAL AND METHOD

The calculation algorithm of the power curve parameters for VAWD is as follows:

- Wind speed v is considered within the range v = 3-19m / s,

- Turbine rotational speed of turbine n has constant values for different calculation levels (n = 50, 100, etc.),

- Characteristic number λ, where $\lambda = \frac{u}{v} = \frac{R \cdot \omega}{v}$, $\omega = \frac{\pi \cdot n}{30}$, it follows that $\lambda = \frac{R \cdot \pi \cdot n}{30 \cdot v}$

- Power coefficient C_P is to be calculated using the mathematical relationship: $C_{Parb} = a \cdot \lambda^{\alpha} - b \cdot \lambda^{\beta}$.

In the case of VAWT, in the above relationships we make use of the following coefficients: α=2, a=0.11666, respectively β=3.5, b=0.01283.

-Wind turbine shaft power is calculated according to the following relationship:

$$P_{arb} = C_P \cdot \rho \cdot \frac{v^3}{2} \cdot S$$

As far as VAWD is concerned, we calculate the swept area by making use of the following relationship $S = D \cdot H$, where D = 2.5m and H = 3m. Capping of the turbine shaft power at P_{arb}=3,500W was considered

Following the above calculation algorithm, the parameters were subjected to recalculation in the following order P_{arb} = 3,500 → C_P → λ → n, using the following calculation equation for Power coefficient C_P, namely $C_P = \frac{P_{arb}}{\rho \cdot \frac{v^3}{2} \cdot S}$,

Characteristic number λ was calculated from the graph $C_{Parb} = f(\lambda)$ by using the graphical method (for each C_P calculated, the correspondence of the characteristic number λ was determined by reading the graph).

Wind turbine rotational speed n for turbine shaft power levels P_{arb} > 3,500 was calculated based on λ which was determined from the graph using the mathematical relationship: $n = \frac{30 \cdot \lambda \cdot v}{\pi \cdot R}$

The calculation algorithm for the power curve parameters for the HAWT is described below. The parameters of the power curves, which are conceived according to wind speed v = 3 ... 19 m / s, tip speed u, air density ρ, and exposed area S, shaped in the unitary power formula of turbine shaft power as follows:

$$P_{arb} = C_P \cdot \rho \cdot \frac{v^3}{2} \cdot S$$

Where:

- Wind speed v is considered within the range v = 3 ... 19 m / s for all values in that range,

- Wind turbine rotational speed n, for each table the speed was set constant for different calculation levels (n = 50, 100, etc.),

- Characteristic number λ, where $\lambda = \frac{u}{v} = \frac{R \cdot \omega}{v}$, $\omega = \frac{\pi \cdot n}{30}$ it results that

$$\lambda = \frac{R \cdot \pi \cdot n}{30 \cdot v}$$

- Power coefficient C_P is to be calculated with the relationship

$$C_{P_{arb}} = a \cdot \lambda^{\alpha} - b \cdot \lambda^{\beta}$$

In the case of HAWT, we use the following coefficients: α = 2, a = 0.2255, β = 3.5, b = 0.024805

- HAWT shaft power P_{arb} is to be calculated using the following mathematical relationship: $P_{arb} = C_P \cdot \rho \cdot \frac{v^3}{2} \cdot S$ where the swept area S is determined using the equation $S = \frac{\pi \cdot D^2}{4}$, where D = 3.1m; capping of the turbine shaft power at P_{arb}=3,500W was considered.

Following the algorithm above, the parameters were recalculated in the following order P_{arb} = 3500 → C_P → λ → n, using the following calculation formulas: Power coefficient C_P is

$$C_P = \frac{P_{arb}}{\rho \cdot \frac{v^3}{2} \cdot S},$$

Characteristic number λ was calculated from the graph $C_{P_{arb}}$ = f (λ) using the graphical method (for each calculated C_P, the correspondence of the characteristic number λ was determined by reading the graph).

Wind turbine rotational speed n for shaft power values P_{arb}> 3,500 was calculated as a function of λ established from the graph using the following relationship: $n = \frac{30 \cdot \lambda \cdot v}{\pi \cdot R}$.

For the indicative calculation of the energy generated E [kWh / m^2 / year] = 2.5 v^3 [m/s] (v: average annual wind speed at turbine axis elevation); errors made in the evaluation of the average annual wind speed are of particular importance. Should the installed power at the swept area is evaluated, it results the indicator we call "equivalent hours of installed capacity utilisation". Therefore, the energy production substantially depends on the location of the turbine.

RESULTS AND DISCUSSION

Results of P_{arb} calculation at constant rotational speeds (n = 50 rpm) are presented hereunder. In the case of VAWT, for the following parameters: v, λ, CP, P_{arb} at n = 50 rpm we obtain the values presented the table below.

Table 1

VAWT P_{arb} calculation

v	λ	C_P	$P_{arb.}$
3	2.18	0.36	46.82
5	1.31	0.17	100.96
7	0.93	0.09	152.40
9	0.73	0.06	202.73
11	0.59	0.04	252.50
13	0.50	0.03	301.92
15	0.44	0.02	351.13
17	0.38	0.02	400.17
19	0.34	0.01	449.11

As for HAWT, considering the following parameters: v, λ, CP, P_{arb} at n = 50 rpm we obtain the values presented the table below.

Table 2

HAWT P_{arb} calculation

v	λ	C_P	$P_{arb.}$
3	2.71	0.84	110.75
5	1.62	0.46	279.29
7	1.16	0.26	436.64
9	0.90	0.17	589.46
11	0.74	0.11	739.93
13	0.62	0.08	888.99
15	0.54	0.06	1037.12
17	0.48	0.05	1184.62
19	0.43	0.04	1331.64

CONCLUSIONS

Considering the values aforementioned of the P_{arb} parameter specific to the power curves of the wind turbines, the tip speeds are extremely high ranging from 40 to 130 m/s. The solutions put forward will probably lead to excessive aerodynamic noise. As these wind turbines are located near human settlements, this state of play can be annoying in terms of people's comfort. The specific masses of the rotors (kg/kW) also have large dispersion i.e. between 4 and 133 kg/kW, probably generated by some non-rigorous definitions. If compared to the statistical data, the specific indicative data are as follows:

›*Diameter* is slightly smaller (up to 3.8 m and it is competitive);

›*Tip speed* is much lower which is substantiated by noise protection;

›*Reference mass* for the *rotor* would be 30-40 kg / kW.

By reducing the tip speed our focus shifts towards slower turbines than those currently operating on the market. One of the issues for which more careful analysis is required is the soundness of the blading suitable for such slow turbines (λ_0 = 2 ... 3)

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