Use BEM theory and Prandtl correction coefficient to obtain aerodynamic coefficients of horizontal-axis-wind-turbine

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February 9, 2020

ECHAHID HAMMA LAKHDAR UNIVERSITY - EL-OUED
Under the Supervision of the DGRSDT and in collaboration with the CRTI
International Pluridisciplinary PhD Meeting (IPPM'20)
23-26, 2020 1st Edition, February
Theme: Modern Technology and Fineness Life

IPPM templat (En/Fr) – 02 pages Max

Use BEM theory and Prandtl correction coefficient to obtain aerodynamic coefficients of horizontal-axis-wind-turbine

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abstract— **In order to use the wind energy optimally, we must obtain an ideal design for the turbine blades, so we had to develop the accounts to analyze the performance of the blades and subject them to this purpose. Several elements with neglecting the dynamic interaction between these elements, as well as the inclusion of the correction factor for Prandtl to find the loss of the TSL tip and TSH root to make the study more realistic in this paper.**

***Keywords*— aerodynamic; Bem ; Blade ;TSL ; TSH ; Prandtl.**

I. Introduction

The critical importance of exploiting renewable energy resources, including wind energy, researchers have to develop wind turbines with an optimal performance, so methods have been developed and implemented to analyze and improve dynamic performance, and the appropriate method for relying in the code design process is tested on the accuracy and sensitivity of the results required. Developing in this study the BEM theory, this method gives a solution to a closed model with relatively simple procedures.

The method was originally developed from combining the theory of the amount of movement and the blade element theory to reach useful relationships for use in the design of turbine blades, with some modifications in the coefficient of clearance As for Brunet, this parameter was used by (Faisal mahmuddin 2015)[1] , the results were compared to the corrected BEM theory calculations with the Qblade program, where a match in the results was obtained with a slight difference, and from the works we also find (Chi-Jeng-Bai et al 2016)[3], where he worked On developing turbines by introducing the correction to Prandtl , where the power was calculated using the weibull method and matching it with the results of CFD, note a significant match between the results of BEM theory and the results of CFD in the lift factor Cl and the coefficient of resistance Cd[2], from these works we conclude that the correction factor plays an effective role in giving results closer to reality Especially in the tip area and the root zone.

II. Mathematical Modeling

In the present study, the Blade Element Momentum (BEM) theory is adopted as the main computation method. The method is combination of momentum theory and blade element theory. The blade element theory sometimes is also called strip theory.

- *Momentum Theory*

From momentum theory, when assuming that the blades could produce power without rotation, the axial force (F) can be obtained using the following equation[4]

$$dF = 4a(1-a)\rho_a V^2 \pi r dr \ldots\ldots\ldots\ldots\ldots (1)$$

Where ρ_a is air density, V the wind velocity far downstream, r the distance of the element from hub and a the axial induction factor which could be written as

$$a = \frac{V - V_d}{V} \ldots\ldots\ldots\ldots\ldots (2)$$

Where V_d is the wind velocity far upstream. When rotation is introduced in the model, the thrust (T) can be obtained using the following relation[4]

$$dT = 4a'(1-a)\rho_a V \Omega \pi r^3 dr \ldots\ldots\ldots\ldots\ldots (3)$$

Where a′ is the angular induction factor which can be written as

$$a' = \frac{\omega}{2\Omega} \dots\dots\dots\dots\dots (4)$$

Where ω is blade rotation speed, and Ω the angular speed.

- *Blade Element Theory*

In the blade element theory, the elements are considered to have infinitesimal thickness. These strips are aerodynamically independent and do not have interference between them. With those assumptions, the axial and thrust forces can be written as[4]

$$dF = \frac{1}{2}\rho_a BCW^2 dr[C_L \cos\phi + C_D \sin\phi] \dots\dots\dots\dots\dots (5)$$

$$dT = \frac{1}{2}\rho_a BCW^2 r dr[C_L \sin\phi - C_D \cos\phi] \dots\dots\dots\dots\dots (6)$$

Where B is number of blades, ϕ the inflow angle, W the resultant velocity, C the airfoil chord, and C_L and C_D the lift and drag coefficients, respectively.

- *Blade Element Momentum (BEM) Theory*

The main principle of the BEM method is to combine the equations from momentum theory and blade element theory to obtain useful relations. Equating Eq. (1) with Eq. (5) and Eq. (3) with Eq. (6), the following relations can be obtained.

$$\left.\begin{aligned} 8a(1-a)V^2\pi r &= BCW^2[C_L \cos\phi + C_D \sin\phi] \\ 8a'(1-a)V\Omega\pi r^2 &= BCW^2[C_L \sin\phi - C_D \cos\phi] \end{aligned}\right\} \dots\dots\dots\dots\dots (7)$$

Substituting W into Eq. (7) and rearranging them, the following relations can be written[4].

$$\frac{a}{(1-a)} = \frac{\sigma_r}{4}\frac{[C_L \cos\phi + C_D \sin\phi]}{\sin^2\phi} \dots\dots\dots\dots\dots (8)$$

$$\frac{a'}{(1+a')} = \frac{\sigma_r}{4}\frac{[C_L \sin\phi - C_D \cos\phi]}{\sin\phi\cos\phi} \dots\dots\dots\dots\dots (9)$$

Where σ_r is known as local solidity ratio which can be written as

$$\sigma_r = \frac{BC}{2\pi r} \dots\dots\dots\dots\dots (10)$$

- *Tip and Root Losses*

Losses will be experienced by the blade at the tip and root. The losses need to be also considered. An approximate method of estimating the tip losses effect has been given by L. Prandtl as follows[1].

$$F = \frac{2}{\pi}\cos^{-1}\left(exp\left(-\frac{B}{2}\frac{R-r}{r\sin\phi}\right)\right) \dots\dots\dots\dots\dots (11)$$

Where R is the maximum rotor radius. By including the tip and root losses effect, the relations shown in Eqs. (8) and (9) are modified to be

$$\frac{a}{(1-a)} = \frac{\sigma_r}{4F}\frac{[C_L \cos\phi + C_D \sin\phi]}{\sin^2\phi} \dots\dots\dots\dots\dots (12)$$

$$\frac{a'}{(1+a')} = \frac{\sigma_r}{4F}\frac{[C_L \sin\phi - C_D \cos\phi]}{\sin\phi\cos\phi} \dots\dots\dots\dots\dots (13)$$

As can be seen in Eqs. (12) and (13), there are several unknown variables which need to be determined which are a, a′, and ϕ In order to determine these variables, equations above need to be solved simultaneously using a standard iteration method. After the axial and angular induction factors can be determined, they are used to compute the turbine thrust forces and power.

III. THE RESULTS

Figure 1: it is noted that the angle of attack AOA maintains its optimum value, and this is due to the presence of the turning angle in the blade, as we note the decrease in the angle of rotation and the angle of flow along the blade.

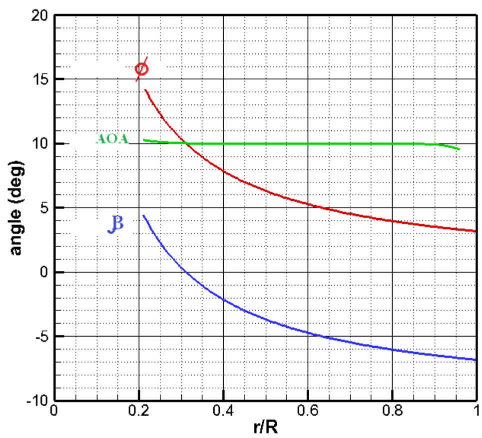

Figure (1): Angle changes with respect to the diagonal stations

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Figure 2: we notice the decrease in the length of the chord over the span of the blade.

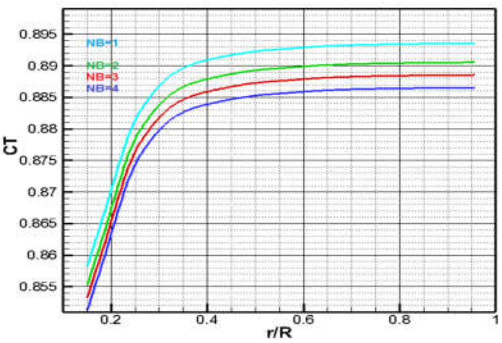

Figure (2): blade chord changes in relation to the diagonal stations

Figure 3: From It is noticed that the torque increases with increasing values of the diagonal stations, and this is very logical, because the torque is what is the force multiplied by the arm.

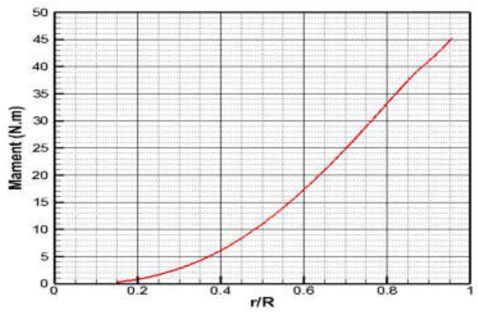

Figure (3) : The distribution of torque over each element of the blade

Figure 4: Growing Torque by increasing the number of wings is due to the multiplicity of the arms, so torque is a force multiplied by the arm, so applying the same force, no matter how small, is on several arms. We note that the value of the applied torque is large.

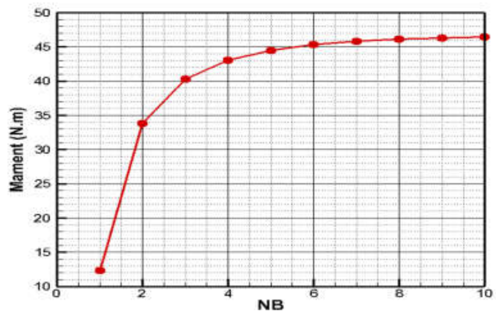

Figure (4) : Effect of the number of blades on the torque in terms of the distance stations

Figure 5: we note that the coefficient of axial force decreases with increasing number of blades and this is due to the decrease in axial force due to the widening of the contact surface between the blade and air, which leads to an increase in losses.

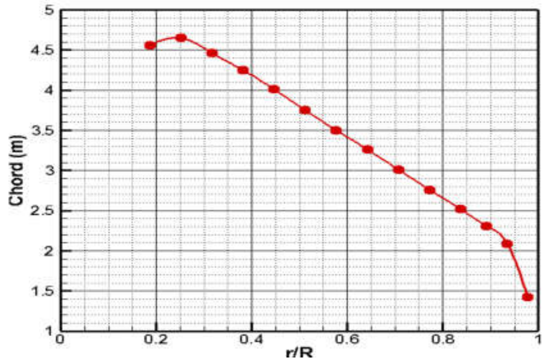

Figure (5): The effect of the number of blades on Axial force coefficient.

IV. CONCLUSION

Through the previous results, we note that the theory of the amount of movement of the blade element BEM, has a very important effect in the design of an ideal aerodynamic blade, but the effect of the correction of Prandtl plays an important role in giving results close to reality, with this correction the study becomes more powerful and effective because there is a loss in the tip area And the root, they must be perceived to reach good results.

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