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POWER PREDICTION OF A THREE BLADED WIND TURBINE DESIGNED WITH THE NREL S809 PROFILE USING THE BLADE ELEMENT MOMENTUM THEORY AND AN ITERATIVE METHOD

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Abstract. *The wind energy is currently one of the most studied fields of electricity generation, whereas it is clean, safety, virtually endless and it is becoming continuously cheaper. Such price reduction must be followed by the maintenance of the generated power. This can be reached through the development of its aerodynamic performance. The component that mostly influence this performance is the rotor, which interferes on the air flow in order to absorb part of the wind kinetic energy and turn it into shaft mechanical energy. In this context, this work proposes an analysis of the aerodynamic performance of a rotor with three blades built with the NREL S809 profile, for various twist angles. In this analysis it was used the BEM (Blade Element Momentum) theory together with an iterative method of correlation among the angle of attack and the induction factors. Such study has a distinguished importance inasmuch as the prediction of the generated power of a wind turbine is a central subject in order to analyze its construction viability.*

Keywords: *BEM Theory, S809, Wind Turbine, Blade Design*

1. INTRODUCTION

The increasing awareness from general public about climate changes and global warming raised the search for alternative sources of energy that assure a sustainable future. In a general way, there is a consciousness that the world needs a new energetic paradigm, since the energy sources used in 20th century, for instance oil and natural gas, are not renewable. There are studies that affirm that the fossil energy reserves will be depleted in the next 30 years. (Quaschining, 2005)

On the other way, there was an increasing demand for energy, mostly for electricity, in the last 100 years. Therefore, a solution is needed to the problem that can occur in the global energy matrix.

In this context, nowadays, the pursuit for alternative sources of energy has increased considerably. Many renewable resources have been explored: the wind power, hydropower, solar energy and biomass.

Harnessing energy from wind, through wind turbines, is already usual and has a great importance in the world scenario. Countries like Germany, Denmark and the United States, have engaged the expansion and technology development of wind farms. The right incentives and subsides to wind power industry have provided the resources to its improvement and establishment in the world market, since it has achieved reached substantial quality and reliability. (Dutra, 2001)

This market increasing and technology development takes wind power to an indispensable option to the clean energy supplier by world leaders. The production of electricity from wind power reached 2,705 GWh in 2011. This represents a 24.3% increase over the previous year when it reached 2,177 GWh. (Empresa de Pesquisa Energética, 2012)

In 2011, the installed capacity for wind generation in Brazil increased 53.7%. According to the Power Generation Database (BIG), from the National Agency of Electric Energy (ANEEL), the national wind farm grew 498 MW, reaching 1,426MW by the end of 2011.

Concerning the feasibility of a wind turbine, one of the mainly factors in its design analysis is the study of its power curve. This consists in calculating the power coefficient versus tip speed ratio chart (C_p x λ), where the former is the ratio between mechanical power from the shaft and wind power (kinetic energy of the flow), and the latter is the specific speed at the blade tip. (Rocha *et. al.*, 2010)

In this work, it was applied the iterative method for the calculations of the power coeficient. In such method it is used NACA profiles to wind power applications. Nevertheless, there are studies that point that when the blade constructed with these profiles get dirty, its power drops until 40% compared when it was clean (Tangler & Somers, 1995). On the contrary, NREL profiles are projected specifically to Horizontal Axis Wind Turbines, operating even under the effect of roughness.

This type of airfoil is represented in the Figure 1.

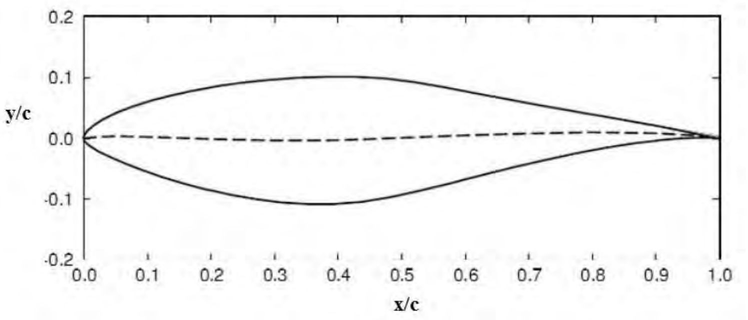

Figure 1. NREL S809 PROFILE. (Leishman, 2006)

For this profile, the upper surface has a smooth concavity which varies between 60% and 85% in relation to the chord, from which, the blade shape becomes convex. (Lindenburg, 2003)

This kind of airfoil, since it has an almost symmetric profile, is designed to operate with positive angles of attack. Therefore, it follows the boundary layer commonly localized in the upper surface. (Sayed *et al.*,, 2012)

2. METHODOLOGY

The method used in the present work to determine *a* (axial induction factor) and *a'* (angular induction factor) is iterative, in which the flow conditions and the induction factors are stipulated following these steps:

- We assume that in the initial iteration *a=1/3* and $a' = \frac{a(1-a)}{\lambda^2\mu^2}$;
- We calculate the angle of the relative wind φ as $\tan\varphi = \frac{U(1-a)}{\Omega(1+a')} = \frac{1-a}{(1+a')\lambda_r}$. Where $\varphi = \theta_p + \alpha$, θ_p is the pitch section angle, which varies from $\theta_p = -4\,^{\text{o}}$ until $\theta_p = 8^{\text{o}}$, α is the angle of attack, *U* is the wind speed, Ωis the rotor angular speed, *r* is the radius measured from the hub until the section in question and $\lambda_r = \frac{\Omega r}{U} = \frac{\lambda_r}{R}$ is the local speed ratio;
- We calculate the angle of attack through $\varphi = \alpha + \theta_p$, and, after that, C_l (lift coefficient) and C_d (drag coefficient) are determined by the following equations:

  C_l calculation:

  If $\alpha < -2.0$:
  $C_l = -0.08186$
  If $-2.0 < \alpha \leq 6.0$:
  $C_l = -0.102325\alpha + 0.122791$
  If $6.0 < \alpha \leq 17.0$:
  $C_l = -0.00700369\alpha^2 + 0.149918\alpha + 0.11554$
  If $17.0 < \alpha \leq 90.0$:
  $C_l = (2) \cdot (1.2) \cdot \sin\alpha \cdot \cos\alpha$
  If $\alpha > 90.0$:
  $C_l = 0.02$

C_d calculation:

If $\alpha < -1.2$:
$C_d = 0.0075$
Otherwise:
$C_d = 2 \cdot \sin^2 \alpha$

- We calculate the local thrust coefficient C_T:

$$C_T = \frac{\sigma'(1-a)^2(C_l \cos\varphi + C_d \sin\varphi)}{\sin^2\varphi}$$

- The new values of a and a' are expressed by:

$$a' = \frac{1}{\frac{4\cos\varphi}{\sigma' C_l}} - 1$$

If $C_T < 0.96$:

$$a = \frac{1}{1 + \frac{4\sin^2\varphi}{\sigma'^{C_l}\cos\varphi}}$$

If $C_T > 0.96$:

$$a = 1 \cdot (0.143 + \sqrt{0.0203 - 0.6427(0.889 - C_T)})$$

If the newest induction factors are within an acceptable tolerance of the previous guesses, then the other performance parameters can be calculated.

According to MANWELL et al. (2010) once the a and a' are determined, the power coefficient C_p is evaluated using the following sum:

$$C_p = \frac{8}{\lambda N}\sum_{i=1}^{N} F_i \sin^2\varphi_i\,(\cos\varphi_i - \lambda_{ri}\sin\varphi_i)(\sin\varphi_i + \lambda_{ri}\cos\varphi_i)\left[1 - \left(\frac{C_d}{C_l}\right)\cot\varphi_i\right]\lambda_{ri}^2$$

Based in this methodology, 13 cases were analyzed, and in each case θ_p assumes a fixed value that varies from -4^o to 12^o.

3. RESULTS AND DISCUSSION

By the methodology of the Blade Element Momentum (BEM) theory shown in the last section, computational calculations were made for each twist angle between-4^o and 8^o, using the algorithms developed in C code, in which the rotor angular speed was considered constant and equal to 24.5 rpm, the length of the profile was 2m, the chord was constant for each section and equal to 0.25m.

By the collected result data, charts were plotted and shown in Figure 2.

In applications where the tip speed ratio (λ) varies substantially between 4 and 11, the power production for twist angle $\theta_p = 3^\circ$ (Figure 2. d) presented more feasibility than the others, even, for this case, the maximum C_p was lower than in the cases $\theta_p = 4, 5, 6$ and 7°, it can be seen, by the comparison of Figure 2. (d) with Figure 2. (e) and (f), that the power coefficient of C_p for $\theta_p = 3^\circ$ keeps higher for a substantial range of λ values.

For twist angles values between -4^o to 1^o, considering $y(\lambda)$ the chart formation law of each C_p, let λ_0 be the value of maximum C_p in each chart, then for all λ in the domain of y, there is $\delta>0$ such that $| \lambda - \lambda_0| < \delta$, and $|y(\lambda) - y(\lambda_0)| > \delta$, i.e., the function has a rapid decay as it moves away from the peak.

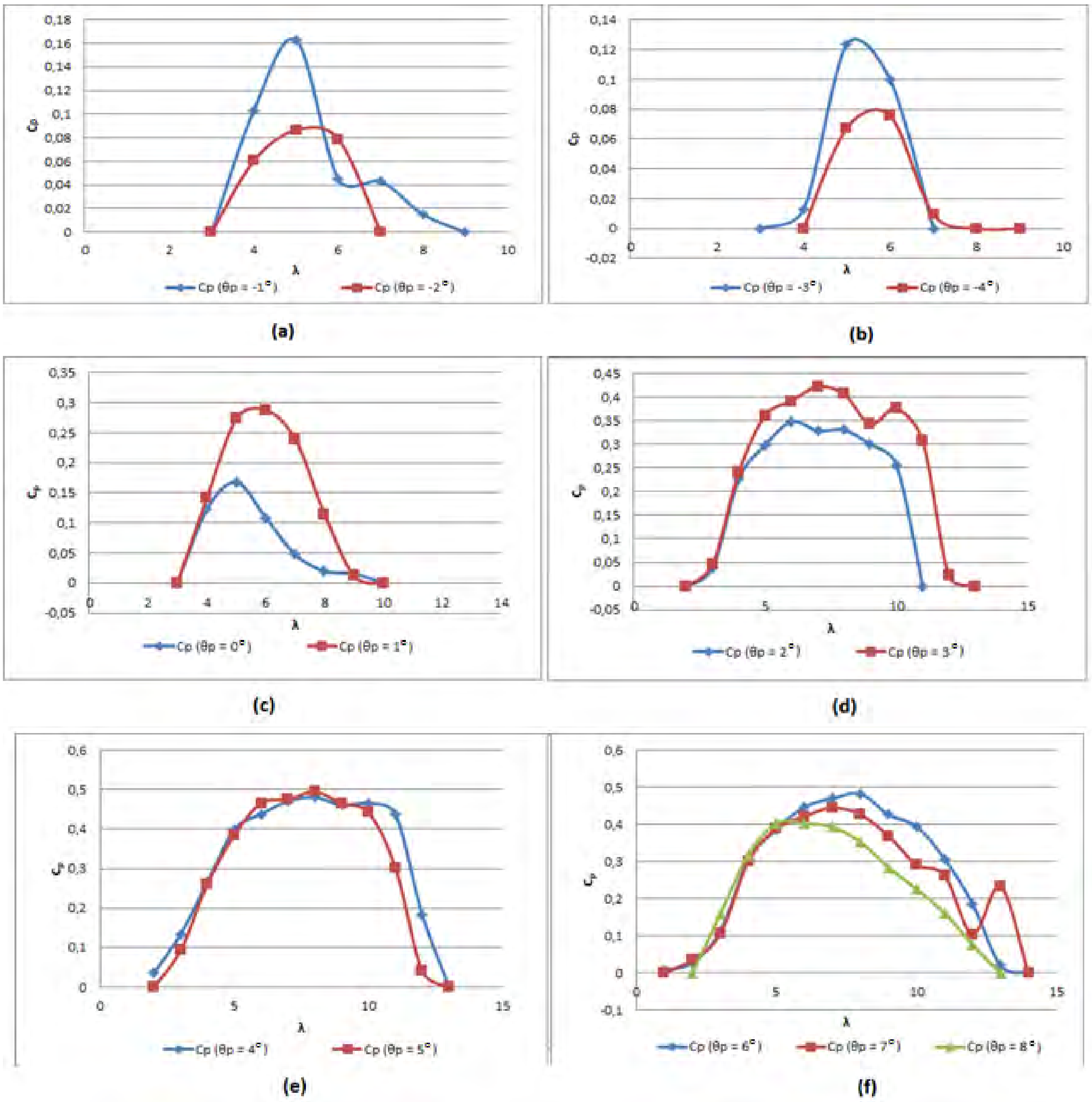

Figure 2. λ vs C_p chart for: (a) θ_p = -1° and -2°, (b) θ_p = -3° and -4°, (c) θ_p = 0 and 1°, (d) θ_p = 2° and 3°, (e) θ_p = 4° and 5°, (f) θ_p = 6, 7 and 8°.

4. CONCLUSION

It can be concluded that the best arrangement for the proposed airfoil is the one with twist angle equal to 3 degrees.

The charts C_p vs λ assume a peak design for $-4^o \leq \theta_p \leq 1^o$ and a Gaussian design for $2^o \leq \theta_p \leq 8^o$.

The method used in this work is a useful tool for both predicting power of the wind turbine as for the prognostic of the best blade design.

One suggestion for future works is an experiment with a model of NREL S809 profile having the same parameters used in this work for the comparison of the numerical and experimental results.

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