Geometric Modeling and Contribution to the choice of a Blade profile for a Wind Turbine

JOUILEL Naima, RADOUANI Mohammed, EL FAHIME Benaissa
Laboratory of mechanic, mechatronic and command
Moulay Ismail University - ENSAM Meknès, Morocco
naima.jouilel@gmail.com ; m.radouani@ensam-umi.ac.ma ; b.elfahime@ensam-umi.ac.ma

Abstract— **The work involves a sensitive part of the wind turbine which is the rotor, specifically selecting the appropriate blade profile for a given wind distribution. A geometric modeling is performed based on a combination of the theories of the axial flow and the theory of the blade member. Then, a simulation of the turbine for different profiles was performed to establish the choice of the profile of the blades in an iterative manner to provide aerodynamic performance by introducing data for the wind distribution of the Essaouira region.**

Keywords: geometric modeling, NACA profile, simulation, rotor,blade element momentum

I. INTRODUCTION

The development of renewable energy sources is vital to meet the growing demand for electricity. Having a better use of renewable energy is a challenge that causes continuous development in methods and means used.

Renewable energy in Morocco represented 0.4% of the national energy balance (excluding biomass) and nearly 10% of electricity production in 2007. Renewable energy is supported by strong hydropower sources and the newly installed wind energy parks (147 MW installed and 975 MW under deployment). Morocco plans a $13 billion expansion of wind, solar and hydroelectric power generation capacity and associated infrastructure that should see the country get 42% of its electricity from renewable sources by 2020.

The increase in wind generation remains limited. In fact, the maximum power that can be extracted is 60% (Betz limit) [1]. Several studies have been conducted to develop wind turbines with performance that greatly approximate this limit [2] [3] [4].

The work involves a sensitive part of the wind turbine which is the rotor, specifically selecting the appropriate blade profile for a given wind distribution.

The dimensioning of the rotor of a wind turbine is essentially based on aerodynamic theory to define the parameters affecting its overall performance [5] [6].

A geometric modeling is performed based on a combination of the theories of the axial flow and the theory of the blade member. In fact the theory of single axial flow does not yield results for calculating the geometrical characteristics of the rotor.

A simulation of the turbine for different profiles is performed to establish the choice of the profile of the blades and in an iterative manner to provide aerodynamic performance by introducing data for the wind distribution of the Essaouira region.

The expression of the extracted power is given by the equation:

$$P = 1 / 2.\rho.V_0^3.S.C_P \quad (1)$$

The purpose of this paper is to illustrate the impact of the profile on the transmitted power from the rotor to the multiplier. Cp is the power coefficient whose maximum value is 16/27 (limit BETZ) [1] it depends on the profile of the blades used.

II. AERODYNAMIC THEORIES FOR CALCULATING THE AERODYNAMIC POWER:

A. *Froude Rankine Theorem:*

In Rankine-Froude theory [7], the rotor is considered such an apparatus modifying the kinetic energy of the fluid passing through it. This theory assumes a one-dimensional flow and perfect and incompressible fluid through the rotor. The surface swept by the blades of the rotor is replaced by a disc permeable factor of a pressure discontinuity.

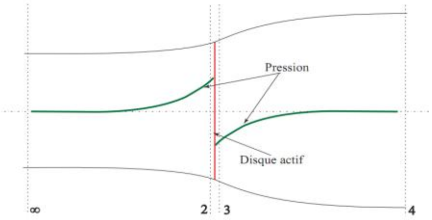

Figure 1: Substitution of the area swept by the rotor blades by a disc permeable

To express the power *P* of the rotor based on the coefficient of induced axial velocity, we use the momentum theory and Bernoulli's equation. With this method it is possible to express the power of the rotor based on the coefficient of induced axial velocity. It is also possible to show that the maximum power extracted by the rotor does not exceed 16/27 of the available power (Betz law) for an induced speed equal to one third of the speed infinity upstream [1].

Xth International Conference on Integrated Design and Production 2015- Tangier Morocco, 2-4 December 2015
X^{ème} conférence internationale : Conception et Production Intégrée 2015 – Tanger Maroc, 2-4 Décembre

B. *Theorem of blade element :*

This theory is based on cutting the blade in installments using cylindrical surfaces and on a study of the flow slice slice [8]. It is assumed that the flow in a ring is independent of the other rings. Consequently, if we get the drag and lift forces for each slice, we can evaluate the integral characteristics of the rotor. For the elemental forces, each slice of the blade is presented as a cylindrical wing subjected to the relative wind created by the speed of at the infinity and by the rotation.

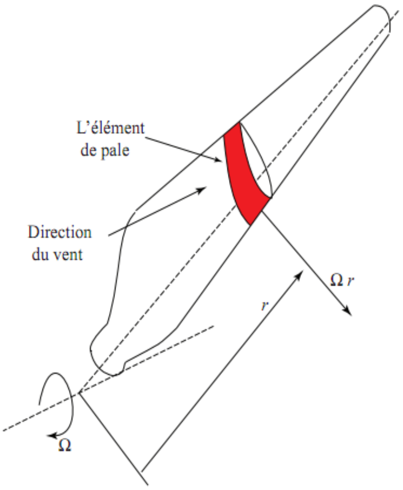

Figure 2: Efforts suffered by a blade member of a wind rotor subjected to wind

C. *Blade Element momentum:*

This approach is based on the theory of the blade element, but the relative velocity profile is corrected by the induced speeds. Here, the axial induced velocity is calculated for each elementary ring by applying the theorem of momentum in the axial direction [9] and [10].

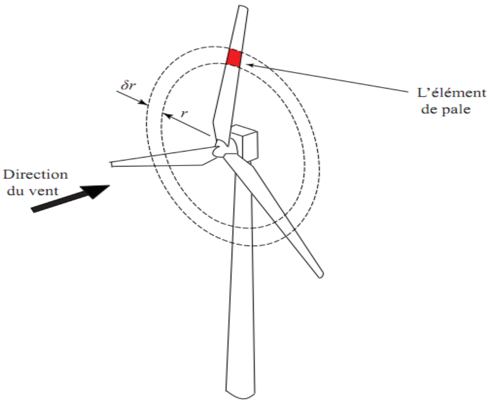

Figure 3: Ring scanned by a blade member

The tangential induced velocity is calculated using the angular momentum theorem. It thus takes account of the velocity field disturbed by the rotor.

Unlike the one dimensional theory of Froude Rankine, induced speeds vary along the blade. By cons, they are averaged in the azimuthal direction. This theory is now improved by using deferent corrections taking into account the finite number of blades.

III. GEOMETRIC MODELING OF ROTOR:

A. *blade parameters:*

The dimensioning of a blade must achieve a compromise between lift and drag: have the maximum lift while taking into consideration the strength to prevent delamination of the blades. That is to maximize the ratio: f = Cz / Cx where Cz is the coefficient of lift and Cx drag coefficient

A rotor is characterized by the number of blade that we take equal to 3. The calculation of the chord along the blade is made according to the following equation:

$$C = 8.\pi.r / BCl.\ (1-\cos\phi) \qquad (2)$$

With:

- Cl is lift coefficient equal to : $2.\pi.\ (\alpha + 0.0726)$
- α is the angle of incidence
- ϕ is the equal flow angle: $\phi = 2/3 \tan{-1} (1 / (\lambda r))$

TABLE I. CHORD ALONG THE BLADE

r/R	*Chord (m)*	*twist angle β*
0,1	1,819342914	21,19293791
0,2	1,602316743	17,46004502
0,3	1,403435087	13,86717051
0,4	1,224910304	10,46572701
0,5	1,067366574	7,289965882
0,6	0,93015656	4,357495645
0,7	0,81177875	1,671986534
0,8	0,710272166	-0,773205503
0,9	0,62352313	-2,991474997
1	0,549469461	-5

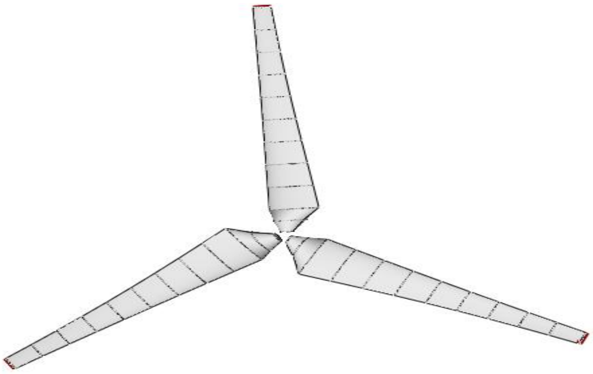

Figure 4: Introduction of geometric parameters of the rotor in Q-Blade

B.Profile choice:

The shape of the blade profiles determines their aerodynamic performance but also their resistance. The compromise between performance and mechanical strength is at the heart of the problem of the definition and optimization of the geometry of the blade. From aerodynamic or hydrodynamic point of view, the more the profile is thin the less it generates resistance to progress. The profile shape is an essential characteristic of a blade and it greatly influences the aerodynamic characteristics and the performance of an air turbine.

In this study we focus on the NACA profiles. Those are the most used in the aerodynamic field. The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.

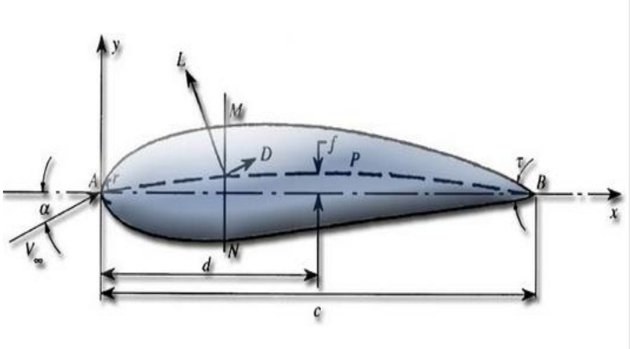

Figure 5: Characteristics of a NACA profile

To illustrate the influence of the choice of the profile on the performance of a horizontal axis wind turbine for a given wind distribution, a simulation was performed for different profiles of the NACA four-digit family:

- NACA 0012
- NACA 2206
- NACA 4306
- NACA 4412

IV. TURBINE SIMULATION

A. Simulation parameters:

The simulation of the turbine first passes by introducing the different parameters including Weibull factors. Based on studies in Morocco, the area that represents a peak wind speed is that of the region of Essaouira. For this reason, we will work with data extracted from this city for geometric modeling and aerodynamics of the turbine [11].

The wind distribution follows a Weibull distribution.
The figure 6 shows the law of the wind in the region of Essaouira at a height of 100m:

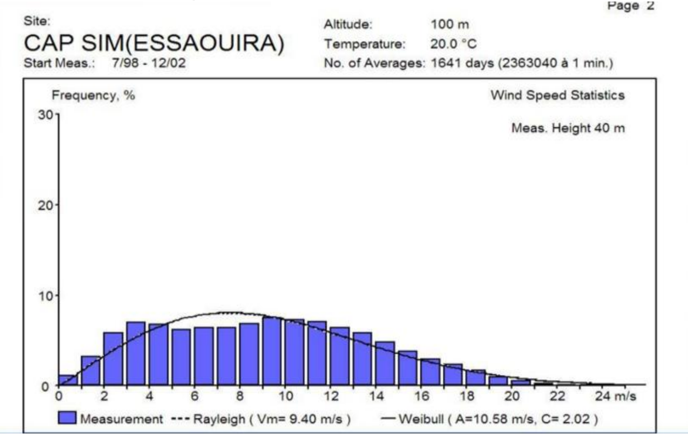

Figure 6: Wind distribution for ESSAOUIRA region

Where:

K Weibull shape factor. It gives the shape of the distribution and has a value between 1 and 3.

C is the Weibull scale factor expressed in m / s. It can express the chronology of a characteristic speed.

In the case of Essaouira

- The form factor: K = 2.01
- The scale factor: C = 9.06 m / s

The BEM model (blad element momentum) is used to test and develop different rotor designs and compare them by introducing small changes. This iterative approach allows the two-dimensional analysis of the blades.

For the simulation, we will based on the range of the wind [1m / s, 22m / s] equivalent to that recorded in the region of Essaouira and this for a wind turbine rotor with a horizontal axis. The simulation results include:

- Cp: power coefficient
- Ct: thrust coefficient
- TSR: Tip Speed Ratio

B. *Résultats*

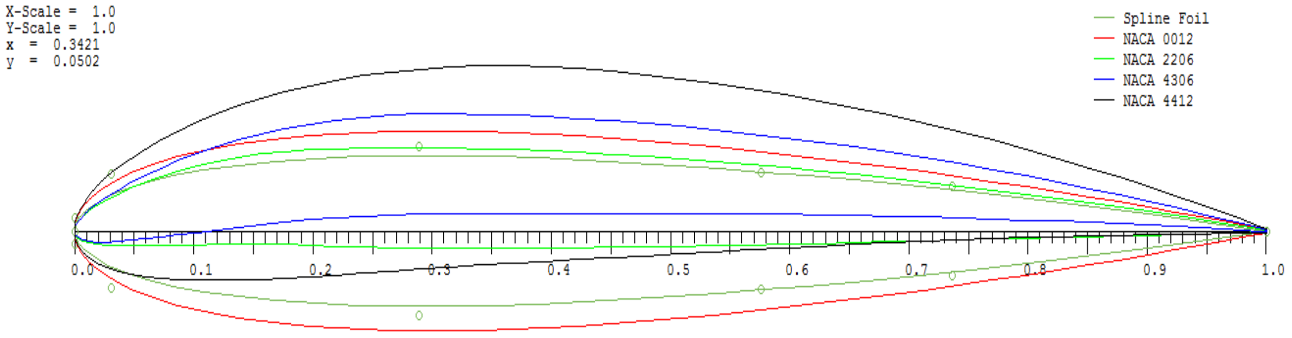

Figure 7: The shape of the four NACA profiles

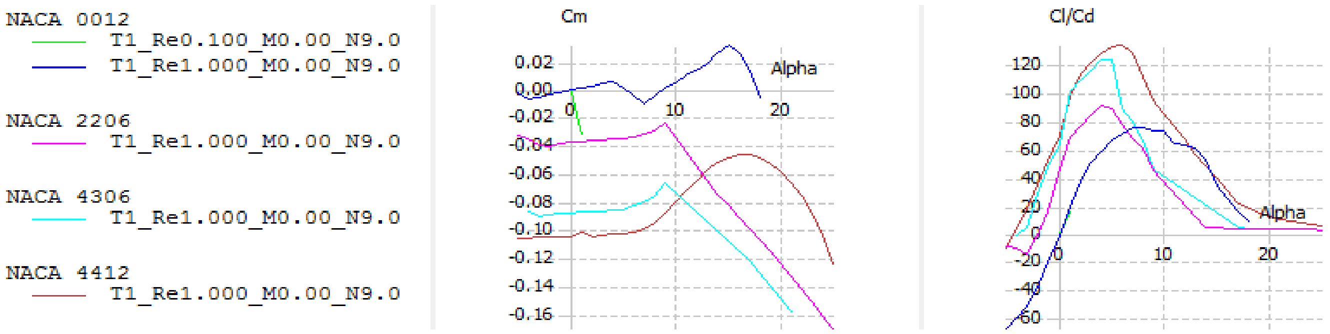

Figure 8: Cm and Cl/Cd evolution

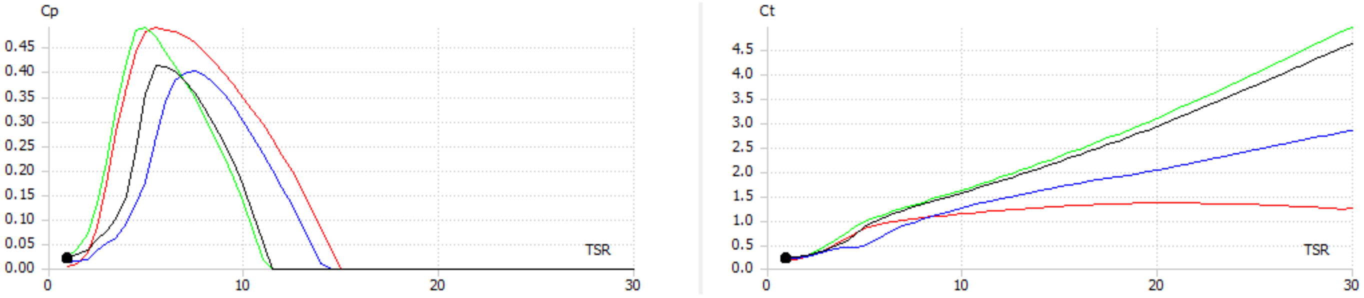

Figure 9: Thrust coefficient evolution

According to the graph of Cp as a function of TSR, the profiles 4306 and 4412 reach maximum values of Cp which implies a maximum value of the power (up to 50% of the kinetic power of the wind) with a difference of 10 % compared to the two other profiles.

From the results found above, we can clearly see the influence of the profile on the overall performance of the wind turbine. The profiles of symmetrical shape such as the NACA 0012 profile has a high confidence level and a poor power factor while non-symmetric profiles such as the NACA 4412 exhibit a high drag coefficient.

CONCLUSION

By introducing the meteorological data of the region of Essaouira for a horizontal axis wind turbine and for different profiles of the NACA four-digit family, the system response totally change from one profile to another. The one giving the maximum drag is the NACA 4412. It should be noted that there is another factor influencing the choice of the profile is that of cost: the manufacture of NACA 00XX profiles is cheaper than the NACA 44XX profiles.

REFERENCES

[1] A. Betz, "Das Maximum der theoretisch möglichen Ausnutzung des Windes durch Windmotoren", Gesamte Turbinenwesen, 17 (1920), pp. 307–309

[2] X. Yang, F. Sotiropoulos, R.J. Conzemius, J.N. Wachtler, M.B. Strong, "Large-eddy simulation of turbulent flow past wind turbines/farms: the Virtual Wind Simulator (VWiS)" Wind Energy (2014), pp. 1–21.

[3] S. Rolland, W. Newton, AJ. Williams, TN. Croft, DT. Gethin, "Simulations technique for the design of a vertical axis wind turbine device with experimental validation", Appl Energy 2013;111:1195–203.

[4] D. Wood, Small wind turbines. "Analysis, Design, and Application". London: Springer-Verlag; 2011.

[5] D. Le Gourières, "Énergie éolienne : Théorie, conception et calcul pratique des installations". Eyrolles, 1982.

[6] V. Nelson, " WIND ENERGY: Renewable Energy and the Environment", CRC Press Taylor & Francis Group, LLC (2014).

[7] T. Burton, N. Jenkins, D. Sharpe, E. Bossanyi, "Wind Energy Handbook". John Wiley and Sons, 2001.

[8] L. Wang, X. Liu, N. Renevier, M. Stables, G.M. Hall, "Nonlinear aeroelastic modelling for wind turbine blades based on blade element momentum theory and geometrically exact beam theory", Energy, Volume 76, November 2014, Pages 487–501.

[9] J. Manwell, J. McGowan, A. Rogers, "Wind energy explained: theory, design and application (2nd ed.)Wiley (2009).

[10] X. Liu, L. Wang, X. Tang, "Optimized linearization of chord and twist angle profiles for fixed-pitch fixed-speed wind turbine blades", Renew Energy, 57 (2013), pp. 111–119.

[11] Metrological data of ESSAOUIRA region, "http://fr.windfinder.com/windstatistics/essaouira_mogador_airport"