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Structural analysis of wind blades with and withoutpower control

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Abstract –*The blade is the principal element in the wind rotor mechanism. the efficiency of the wind turbine depends on the optimal geometry of this element, as well as its structural configuration. This work presents a contribution to wind blade structural design. the blade structure was evaluated without the control power operating case and with the power control case. In this case, an 80KW horizontal axis wind turbine design was proposed. the process begins with design and aerodynamicanalysis based on blade element momentum theory by using Qblade software to determine the blade geometry. The blade structure was defined by the NuMad package, it is composed of two parts. the shell part is four layers of composite materials and the rib part has a sandwich panel shape. The evolution of structure was done by the Co-Blade package. The results show a decreasing in displacement decreased to 64% at the tip of the blades which leads to the stress at the leading and trailing edge being negligible. That proves the importance of a control power system in the protection of the blade structure and turbine generator in the operating case under high wind velocity and ensures the stability of the power output value.*

Keywords: Blade, wind rotor, aerodynamic, structure, composite material.

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I. Introduction

Electricity is an irreplaceable and indispensable source of human comfort in modern life. The global demand for this energy is increasing year by year, but due to the recent methods of energy conversion used to have a significant pollution problem. Which presents a huge challenge and promotes scientific research to improve and optimize current conversion techniques to decrease the amount of pollution, or to find an alternative source of energy. As a new trend, renewable energy sources (solar, wind, geothermal, etc.) present a serious solution. These depend on the availability of these resources and how these renewable energies are converted into electricity. Currently, wind energy has an attractive and growing interest in this field. In which the wind kinetic energy is converted to mechanical energy to finally converted to electrical energy. This conversion uses a wind rotor, which takes the form of a turbine and consists of blades.

The structure of wind turbine blades is a crucial aspect of their design and performance. Researchers aim to improve the efficiency and durability of blades by optimizing their shape, size, material properties, and aerodynamics. This research helps to make wind energy more cost-effective and reliable, which is important for its growth as a sustainable source of energy [1, 5].

The effectiveness of this solution depends on the development of wind turbine construction technology and its performance, including the design of the performance of wind blades. To define the optimal blade shape and structure, several works have been done. G.P. A study of reducing blade mass. It combined two phases. The first is the bend-twisting coupling method. It aims to reduce the loads in the operational state. In this case, the plies of composite material over the caps of the spar beam are rotated. The second phase is the flap-edge coupling method. It aims to reduce the vibration due to stall induction at parked operation state by caps displacement in the opposite direction. The evaluation of material reducing amount has been done by the structural simulation to define the optimal blade mass with acceptable loads resistance. The results show an 8.3% of mass reduction with 5.8% of plies rotation and 3% of caps displacement in opposite direction [6]. Tried to optimize the blade of a 50MW wind turbine to reduce the total cost. An aero-structural optimization method has been used based on Monte Carlo simulation. It focused on the spar caps of the blade root region. The method proposed the airfoil thickener and thinner of 10%. In addition, the cord took greater and smaller by 10% compared to the initial design. The results show an up to 25% weight loss and a 30% cost reduction. Study proposed a new design for the wind blade [7].. This design consists of two parts based on the variation of aerodynamic and structural parameters from the root to the tip case and the opposite case. The blade body is a combination of three blades. This new design is proposed and applied for NREL 5MW to obtain optimal structural compliance. Where the deflection is less than 5m and the strain is less than 0.5%. The structural simulation shows that the new design has a 7.2% low mass compared to the original blade. Another hand, 3.31m of maximum deflection was registered and 0.39% of the stain [8]. One method focused on reducing blade mass by using topology optimization. This method is applied for determining the optimal internal structural compliance. Based on their results, the finite element model was created to study the influence of distinguishing characteristic parameters on blade performance. The results of the application of a 1.5MW wind turbine show that the method defines a new blade structure with a 3% lower mass compared to the initial blade. (BEMT) and computational fluid dynamics (CFD) simulations. The BEMT is a simple and efficient method to analyze the aerodynamic performance of wind turbines, but it has limitations in predicting the performance under complex flow conditions [9].

CFD simulations can provide a more accurate prediction of the aerodynamic performance, but they are computationally expensive and time-consuming. In addition, the structural performance of wind turbines is determined by the design of the blade and its material properties. Factors such as blade weight, stiffness, and natural frequency play an important role in determining the structural performance. Therefore, an optimal design of wind turbine blades requires a trade-off between aerodynamic and structural performance. Effective modeling and simulation tools can help to optimize the design of wind turbine blades, improve their performance, and reduce costs [10, 11].

This work presents a contribution to blade structural design. In which the blade structure efficiency was evaluated for two cases. The first is the wind turbine operates without a power system and the second is with a power control system.

II. Material and method

II.1. Aerodynamic analysis

The performance of wind turbines depends on the blade's aerodynamic and structural performance. The aerodynamic performance is related to several parameters such as the geometry parameter like a chord, twist angle, speed ratio, and section profile. The environmental parameters as mean wind speed and topology of the site. the analyses of the aerodynamic performance of wind turbines are based on blade element momentum theory. where the thrust force and the torque created by the aerodynamic wind effect are presented by:

$$dT = dF_N = \frac{1}{2}\rho BCW^2(C_L cos\varphi + C_D sin\varphi)dr \quad (1)$$

$$dQ = B.r.dF_T = \frac{1}{2}\rho BCrW^2(C_L sin\varphi - C_D cos\varphi)dr \quad (2)$$

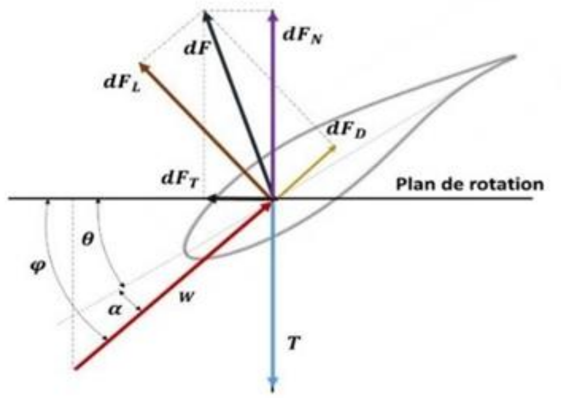


Figure 1. Flow effect on blade section [5].

Where CL and CD are the lift and drag coefficients respectively., r is the radial position, and B is the blade number. ρ is the air density. C is the chord length, φ is the flow angle (fig.1) and W is relative velocity, the chord, the flow angle, and the relative velocity are defined respectively by [10, 11]:

$$C_r = \frac{16\pi R}{9BC_L\lambda\sqrt{(\lambda\frac{r}{R})^2+\frac{4}{9}}} \tag{3}$$

$$tan\,\varphi = \frac{(1-a)}{(1-a')\lambda_r} \tag{4}$$

$$W = \sqrt{V_1^2(1-a)^2 + r^2\Omega^2(1+a')^2} \tag{5}$$

V_1 is the wind speed, Ω is rotor rotation speed, r is element position and a and a' are the axial and radial induction factors defined respectively by [10, 11]:

$$a = \frac{\sigma C_n}{(4sin^2\varphi+\sigma C_N)} \tag{4}$$

$$a' = \frac{\sigma C_t}{(4sin\varphi cos\varphi-\sigma C_T)} \tag{5}$$

σ presents section solidity defined by [5, 6]:

$$\sigma = \frac{BC}{2\pi r}$$

C_N et C_T is the coefficient of normal and tangential force respectively, they are determined as follows [10, 11]:

$$C_N = C_l cos\varphi + C_d sin\varphi \tag{7}$$

$$C_T = C_l sin\varphi - C_d cos\varphi \tag{8}$$

The total efficiency is determined by [5, 6]:

$$C_P = \frac{8}{\lambda^2}\int_0^\lambda a'(1-a)\lambda_r^3 d\lambda_r$$

λr is the local speed ratio, it equals [5, 6]:

$$\lambda_r = \frac{\lambda\, r}{R}$$

II.2. Design and methodology of analysis

To reach the goals, an 80KW wind turbine has been proposed to be installed in the Adrar region, where the mean wind speed is 6.8m/s [7]. The rotor is combined by three 8.5m blades designed for the value of tip speed ratio equal to 6 with profile section type NACA 4415. which have an attack angle of 4.75deg for high drag to lift at 1E6 of Reynolds number [8]. The section is a profile distribution with the variation of the chord and the twist angle as shown in Table 1. Table 2 presents the blade structure contains a shell and two internal ribs.

It shows also the internal rib has the shape of a sandwich panel.it is located inside the shell of the blade to ensure the junction between the upper and the lower shell skin, thus increasing the rigidity of the blade. The two ribs are attached at the 30% and 70% positions chord length in each section. The shell is proposed to be made of four composite layers, and the ribs are sandwich panel structure with three layers, each layer mechanical properties presented in Table 3.

Table1. Chord and twist distribution.

Section	1	2	3	4	5	6	7	8	9	10	11	12
Chord (m)	0.4	0.4	0.55	0.9	1.03	0.79	0.64	0.53	0.46	0.4	0.36	0.32
Twist (deg)	0	0	0	20.7	12.85	8.63	6.02	4.26	2.99	2.03	1.28	0.68
Profile	........Circle......../......NACA4415........											

Table 2. Positioning of the ribs.

Section	1	2	3	4	5	6	7	8	9	10	11	12
30%	0.12	0.12	0.165	0.27	0.309	0.237	0.192	0.159	0.138	0.12	0.108	0.096
70%	0.28	0.28	0.385	0.63	0.721	0.553	0.448	0.371	0.322	0.28	0.252	0.224

Table 3. Mechanical properties

Proprieties	Mat	DblBias	Unit	Balsa
E_1 (GPa)	7.58	11.1	45.8	0.12
E_2 (GPa)	7.58	11.1	10.1	0.12
G_{12} (GPa)	4.00	6.89	6.89	0.02
η_{12}	0.30	0.39	0.30	0.30
ρ (Kg /m^3)	1690	1660	1990	230

To evaluate the proposed design, an investigation method has been proposed, where the aerodynamic analysis is done by using Qblade software.

QBlade is a software tool for the aerodynamic design and analysis of wind turbine blades. It is commonly used for simulation and optimization of wind turbine blades to help improve the efficiency and performance of wind turbines. The software calculates and predicts the loads, performance, and operating behavior of wind turbine blades under various conditions. It provides valuable information for the aerodynamic design of wind turbine blades, allowing engineers to make informed decisions regarding blade geometry, airfoil selection, and other important design parameters [12, 13].

II.3. Modeling procedure

In this work, a procedure based on the design and optimisation of the architecture of the neural network is advanced as described in Figure 2.

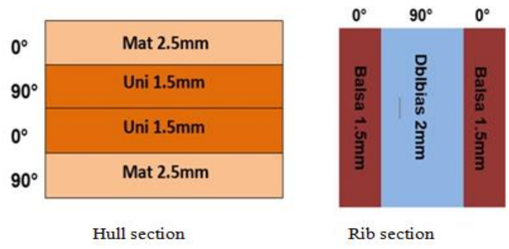


Figure 2. Material configuration.

The blade structure shown in Figure 3 is designed by the NuMad package. The structural analysis is done by using the Co-Blade package [14-17].

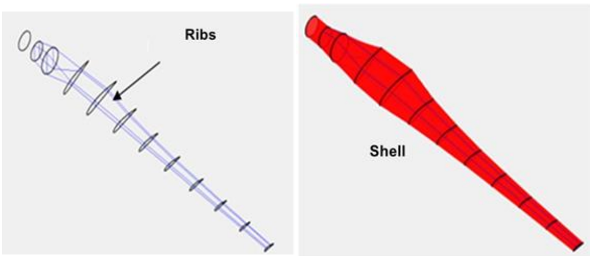


Figure 3. Blade structure (NuMad).

III. Results and analysis

The aerodynamic analysis using the Qblade software resulted in the load distribution. Figure 4 shows the variation of the tangential force, while Figure 5 shows the variation of the normal force. The impact of this load system on the proposed blade structure was evaluated by studying the variations in stress distribution of forces and torques in both the control and non-control cases.

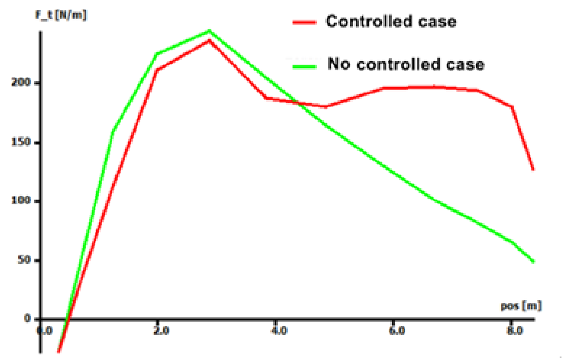


Figure 4.Variation of the tangential force (Ft).

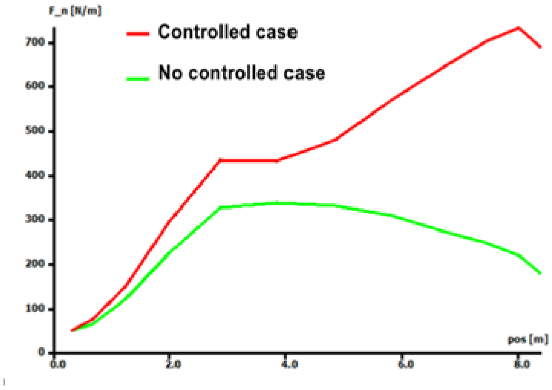
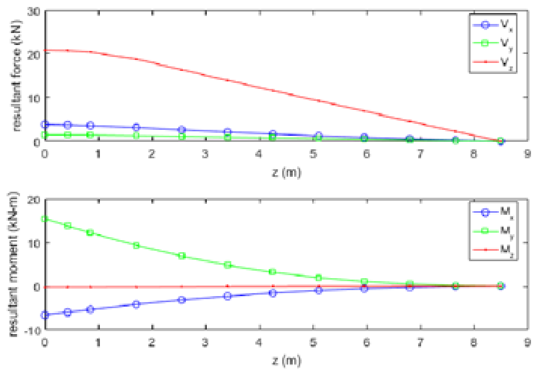


Figure 5. Variation of normal force (Fn).

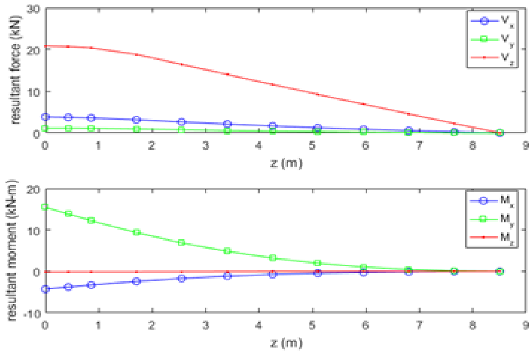
In the general case, if a wind turbine operates without a control system, the increase in wind speed leads to an increase in power collected by the wind rotor and its torque. However, the generator has a limited torque capacity, so it cannot handle increases in torque beyond its nominal torque. This leads to high pressure on the blades, causing them to experience cyclic and variable loads. A wind speed of 15m/s is considered a critical case for blade structural evaluation.

Figure 6 shows the distribution of forces (in kN) in the controlled case as a function of the length Z (in m). It displays also the distribution of the resultant moment (in kN-m) as a function of the length Z (in m). The figure deals with the distribution of the force and the resultant of the moment in the two cases (controlled and uncontrolled).

- In the uncontrolled case, the blades rotate with a maximum centrifugal force of 21kN at the root level of the blades and decrease towards the blade tip. The normal force is 3kN and the tangential force is 1kN. There is a normal torque of -7 kN.m and a tangential torque of 16 kN.m.
- In the control case, the centrifugal force, Vz, Vy, and My are the same as the uncontrolled case but the normal torque is -4kN.m instead of -7kN.m.

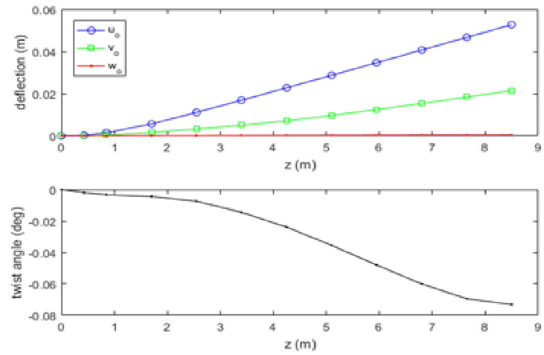


Uncontrolled case



Controlled case

Figure 6. Distribution of forces and resultant moment

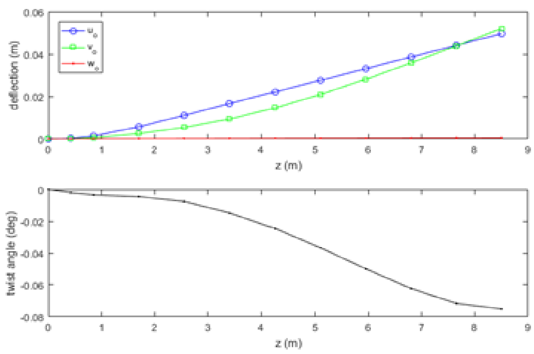


Controlled case

Figure 7. Displacements and rotation of section

Figure 7 shows the displacements and rotation of the section as a function of the length Z (m) in the two cases (controlled and uncontrolled).

- In the uncontrolled case, the variations of the loads put the blades under constraints causing displacements of the blade sections, with the maximum at the tips of the blades with a maximum value of 0.05m in both normal and tangential directions. The constraints also result in small rotations of the blade sections with a maximum value of 0.07 degrees at the end of the blades.
- In the controlled case, the decrease in normal torque leads to a decrease in normal displacement, with a maximum value of 0.018m at the end of the blade. The reduction in displacement directly affects the constraints.

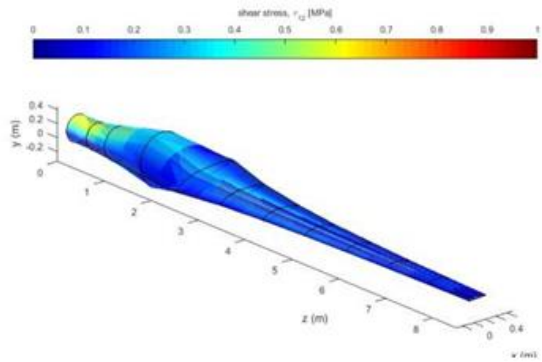


Uncontrolled case

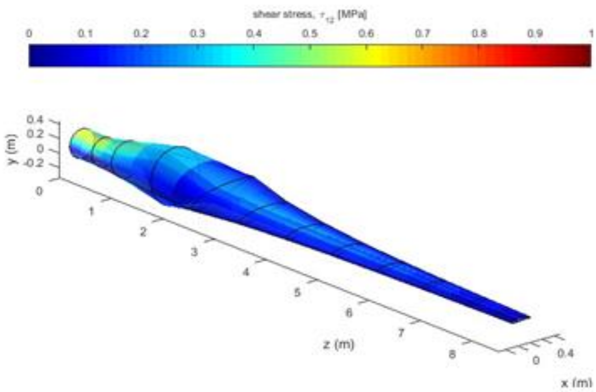
Figure 8 displays the distribution of shear stress (in the uncontrolled case and in controlled case) in a screw view along the length Z (in m).

In the uncontrolled case, the cyclical movements create normal and transverse stresses in the layers of material. The maximum shear stress is at the root level with a value of 0.65MP, and the minimum shear stress is at the leading and trailing edges with a value of 0.2MP.

In the controlled case, the maximum shear stress at the blade roots remains the same as the uncontrolled case, but there is no stress at the leading and trailing edges.



Uncontrolled case.



Controlled case

Figure 8. Shear stress distribution

Figure 9 depicts the failure criteria with respect to the length Z (in m). The results of evaluating the failure criteria suggest that the blade structure configuration is secure and meets the necessary safety standards.

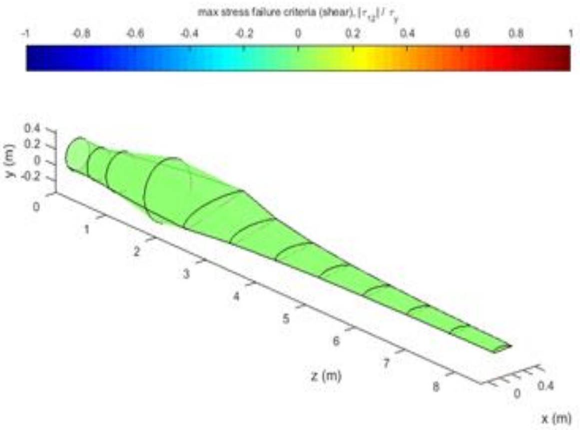


Figure 9. Failure Criteria.

IV. Conclusion

The focus of this work is to contribute to the development of a composite material wind turbine blade. A horizontal axis wind turbine model capable of producing 80kw was studied, with a blade length of 8.5m and a NACA4415 profile. A structural performance study was conducted to validate the blade structure, considering material and thickness. The blade is estimated to be made of composite material with two different configurations: one for the blade shell with four composite plies of different angles (0°/90°/0°/90°), and the second for the internal rib with three composite plies of angular configuration (0°/90°/0°).

The structural behavior of the wind turbine was studied under a wind speed of 15m/s for two cases: one without power control and the other with power control. The results of the structural evaluation show that in the case of no power control, the blades experience high fluctuation in loads, which affects the blade structure layers. However, when using the power control system, the loads decrease, leading to a decrease in displacement to 64% at the tip of the blade. This reduction in displacement results in a decrease in section deviation and negligible stress at the leading and trailing edges, ensuring a long working life for the blade and generator, and providing increased output power.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

References

[1] W. Wang, J. Yang, J. Dai, A.Chen, EEMD-based videogrammetry and vibration analysis method for rotating wind power blades, Measurement, Vol 207, 2023, pp. 112423, https://doi.org/10.1016/j.measurement.2022.112423.

[2] S. Jayswal, A. Bhattu, Structural and modal analysis of small wind turbine blade using three different materials, Materials Today: Proceedings, Vol. 72, Part 3, 2023, pp. 1347-1352, https://doi.org/10.1016/j.matpr.2022.09.329

[3] M. Khazaee, P. Derian, A. Mouraud, A comprehensive study on Structural Health Monitoring (SHM) of wind turbine blades by instrumenting tower using machine learning methods, Renewable Energy, Vol. 199, 2022, pp.1568-1579, https://doi.org/10.1016/j.renene.2022.09.032

[4] H.A. Porto, C.A. Fortulan, A.J.V. Porto, Power performance of starting-improved and multi-bladed horizontal-axis small wind turbines, Sustainable Energy Technologies and Assessments, Vol. 53, Part A, 2022, pp. 102341, https://doi.org/10.1016/j.seta.2022.102341

[5] Z. Chuang, C. Li, Shewen Liu, X. Li, Z. Li, L. Zhou, Numerical analysis of blade icing influence on the dynamic response of an integrated offshore wind turbine, Ocean Engineering, Vol. 257, 2022, pp. 111593, https://doi.org/10.1016/j.oceaneng.2022.111593

[6] G. P. Serafeim, D. I. Manolas, V. A. Riziotis, P. K. Chaviaropoulos, D. A. Saravanos," Optimized blade mass reduction of a 10MW- scale wind turbine via combined application of passive control techniques based on flap-edge and bend-twist coupling effects", Journal of Wind Engineering and Industrial Aerodynamics, Vol 225,2022, https://doi.org/10.1016/j.jweia.2022.105002.

[7] S., Yao, M. Chetan, D. T. Griffith, E. Mendoza, A. S., M. S. Selig, D. Martin, S. Kianbakht, K. Johnson, E. Loth, "Aero-structural design and optimization of 50 MW wind turbine with over 250-m blades", Wind Engineering, vol 46, 2022, pp. 273–295. https://doi.org/10.1177/0309524X211027355.

[8] Ranjeet A. & Robert A. Chin (2022) Structural design and analysis of a redesigned wind turbine blade, International Journal of Ambient Energy, 43:1, 1895-1901, DOI: 10.1080/01430750.2020.1723688.

[9] Jie Zhu, Xin Cai, Dongfang Ma, Jialiang Zhang, Xiaohui Ni, Improved structural design of wind turbine blade based

on topology and size optimization, International Journal of Low-Carbon Technologies, Vol.17, 2022, pp. 69–79, https://doi.org/10.1093/ijlct/ctab087.

[10] Debbache M, Hazmoune M, Derfouf S, Ciupageanu D-A, Lazaroiu G. Wind Blade Twist Correction for Enhanced Annual Energy Production of Wind Turbines. Sustainability. 2021, vol. 13, n°.12, pp. :6931. https://doi.org/10.3390/su1312693.

[11] T. Burton, N. Jenkins, D. Sharpe, EA Bossanyi, Wind energy handbook, 2ed, 2012.

[12] H. Daaou Nedjari, S. Kheder Haddouche, A. Balehouane, O. Guerri, Optimal windy sites in Algeria: Potential and perspectives, Energy, Volume 147, 2018, pp. 1240-1255, https://doi.org/10.1016/j.energy.2017.12.046.

[13] M. Alaskari, A. Oday, M. H. Majeed, Analysis of Wind Turbine Using QBlade Software, Materials Science and Engineering, vol 518, 2019, pp. 032020, Doi 10.1088/1757-899X/518/3/032020

[14] http://airfoiltools.com/airfoil/details?airfoil=naca4415-il (View 2022).

[15] https://www.q-blade.org/ (View 2022).

[16] https://numad.readthedocs.io/en/latest/ (View 2022).

[17] https://code.google.com/archive/p/co-blade/ (View 2022).