Advanced Engineering Letters Vol.1, No.2, 35-39 (2022) e-ISSN: 2812-9709

INCREASING WIND TURBINE EFFICIENCY USING SOFTWARE PACKAGES

UDC: 621.548.4
Original scientific paper https://doi.org/10.46793/adeletters.2022.1.2.1

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Abstract:
Wind energy is a clean source of energy. Wind turbine efficiency is affected by wind speed, Reynolds number, density, humidity, and air temperature, as well as other factors. The conversion of wind kinetic energy into the rotational movement of the wind turbine is performed thanks to the aerodynamic profile of the blade. Due to the large number of factors that affect the efficiency of work, complex mathematical models and software packages, specialized for this purpose, are used to shape the profile of the wind turbine blade. This paper presents the application of software packages for the design of the blade profile depending on the geographical location and meteorological conditions prevailing in the area, to achieve greater efficiency, that is, the production of a larger amount of electricity.

ARTICLE HISTORY
Received: 11.04.2022.
Accepted: 17.06.2022.
Available: 30.06.2022.

KEYWORDS
Wind turbines, wind farms, renewable energy sources, aerodynamics, software engineering

1. INTRODUCTION

Wind energy is a renewable energy source that has been used for centuries to get mechanical energy and, in recent decades, for the production of electricity. Of great interest is the production of clean energy from renewable sources, which, unlike coal, gas, and other fuels, pollute the environment far less [1]. The transition to renewable energy sources such as small hydropower plants, solar power plants, biomass and geothermal energy plants, as well as wind energy, is also encouraged by the fact that the price of initial investment has decreased significantly in the last thirty years, while the prices of oil and natural gas continue to fluctuate regularly [2].

As climate change becomes an increasing problem, the acceptance of wind energy is of great importance. Beginning in the 1970s, the world began to experience an energy crisis due to its over-reliance on fossil fuels. There was a need to find and accept new ways to produce energy. This has led to the acceptance of unconventional energy sources such as hydro, geothermal, wind, and solar energy [3,4]. The transition from fossil fuels to a green economy has led to an increase in renewable energy sources. Wind energy stands out because it is free, clean, inexhaustible, and has lower initial investment costs. From local to global proportions, the effects of wind energy on the environment are often positive, as opposed to the negative effects associated with fossil fuel technologies. These include air pollution, climate change, health risks, high mortality rates, and greenhouse gas emissions. However, all energy sources have an impact on the environment and the economy, including wind energy [5]. One of the disadvantages of building wind farms is their impact on the living world. Research has shown that wind turbines have a detrimental effect on birds and bats, which is why they should be built in areas that are not rich in wildlife [6,7].

The global installed capacity of wind farms is 837 GW, as of 2022, and continues to grow [8]. Offshore wind energy is currently one of the most important sources of renewable energy worldwide, and it is expected that the installed power will increase very quickly in the short term [9]. The cost of producing a wind turbine blade is 15% to 20% of the total cost of producing a wind turbine. The costs of blade design represent a small amount of total production costs, i.e., initial investment. The profit coming from a better constructive model, as

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well as the use of composite materials and better fabrication techniques, shows the necessity of applying numerical modelling, and optimization. When designing a wind turbine, the goal is to achieve the highest possible power in certain atmospheric conditions. From an engineering point of view, it depends on the shape of the wind turbine blade [10].

Thanks to the aerodynamic profile of the wind turbine blade, the kinetic energy of the wind is converted into the rotational movement of the wind turbine. Due to such a blade profile and the difference in wind speeds in front of and behind the blades, there is a difference in pressure resulting in buoyancy. The projection of the buoyancy force on the plane of rotation generates torque. Since the blade performs a rotational movement, the wind speed (V) as well as the circumferential speed (Vt) are authoritative of the forces acting. Starting from the axis of rotation towards the periphery, the relative speed increases, and its angle of attack in relation to the axis of rotation decreases. Thus, the wind turbine blades are twisted along the axial axis [11].

Due to the great importance of the blade profile in the efficiency of the wind turbine, this paper shows how, by applying software packages, we come to a better profile calculation.

2. MATERIALS AND METHODS

The aim of the study was to select the best blade profile for a given model of wind turbine under the meteorological conditions prevailing in a particular geographical location. By using software packages, we will achieve greater efficiency in electricity production.

Due to the large number of factors that affect the efficiency of the wind turbine, complex mathematical models are used for shaping, while calculations are also performed on physical models in wind tunnels. The problem with wind energy is that air is a fluid with low density, which is why it is necessary to build large and expensive devices for laboratory testing [12].

Electricity produced from wind energy varies from hour to hour, daily and seasonally. Therefore, the calculations are performed so that the wind turbine corresponds to the geographical location and the average meteorological conditions that prevail at that location. In this paper, the software packages RetScreen, Qblade, and xFoil were used to achieve the best possible choice of wind turbine blade profile, which achieves significantly higher efficiency in electricity production.

2.1 Parameters for the blade model calculation

For the purposes of the research, the initial parameters used in the calculation were the average wind speed, the average annual temperature, and the atmospheric pressure at the selected geographical location. The location chosen for this calculation is in Denmark, a place on the sea called Thyboron, because of its good meteorological conditions for wind farms. Denmark is well-known for its innovative energy sector and wind turbine technology [13].

Denmark is surrounded by the sea and has great potential for wind farms. Wind energy and windmill technology have deep roots in the history of Denmark and have been popular among the people in the past [14]. The Danish energy system is very interconnected and flexible, with a large amount of energy obtained from renewable sources. As much as 43.2% of the produced energy was obtained from wind farms [15]. Wind farms have become the primary energy system in Denmark [16]. Moving turbines away from urban areas reduces the need for protection from visual and audible negative effects, which also reduces design costs [17].

The exact meteorological parameters, obtained from the RetScreen software for the selected location, are shown in Table 1.

Table 1. Average annual temperature, wind speed, and atmospheric pressure

Parameters	Measured values
Wind speed measured at a height of 10 m	6,8 m/s
Average annual temperature	10 ^{o}C
Atmospheric pressure	101 kPa

For the needs of research, we chose a wind turbine manufactured by Siemens, model AN BONUS 600/44MK IV, with a power of 600 kW. The pillar of the wind turbine is 40 m high, while the diameter of the rotor we are examining is 44 m. Other data for the selected wind turbine was collected from the database of the RetScreen software package. For further analysis, we need a pillar consisting of two parts of 15 and 20 m, with a diameter of 3 m at the base and 1.1831 m at the top. The diameter at the flange connection is 2,545 m. The height at the place of the flange connection is 15 m, and the number of screws is 50 pieces.

2.2 The most favorable wind speed for the selected wind turbine

Based on the selected parameters, using the Retscreen software package, we come to the result that the selected wind turbine has a positive growth of energy production at wind speeds up to 15 m/s, which is shown in Figure 1, where after that speed, the production efficiency decreases, but even with that decrease, it satisfies the need for the desired energy production.

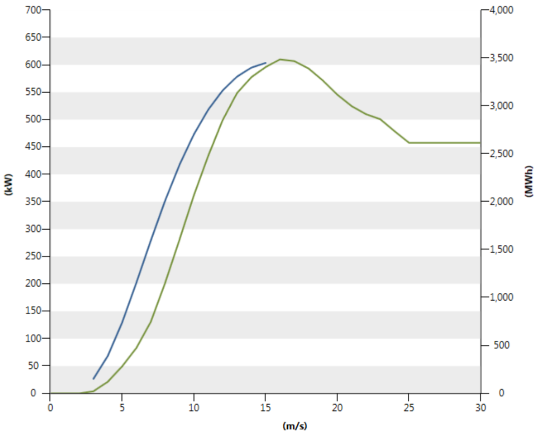


Fig. 1. The curve of the power and energy, depending on the different wind speeds

Also, the graph shows the power output when the wind speed changes. At lower speeds, from 0 to 5 m/s, the wind turbine does not produce energy. The output power increases exponentially to a speed of 15 m/s. At that speed, it has a power of 610 kW. This is the optimal wind speed for the selected wind turbine.

The Retscreen can also be used to calculate the cost of building a wind turbine or wind farm.

3. RESULTS AND DISCUSSION

3.1 Calculation of the blade profile

The QBlade software package determines the blade profile in accordance with the selected model and the desired production needs. The blade profile is presented in Figure 2.

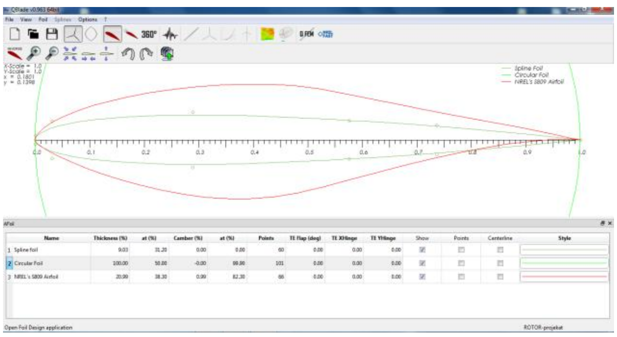


Fig. 2. Blade profile

One of the parameters that affects the efficiency of the wind turbine is the Reynolds number. The Reynolds number is a dimensionless quantity and a key parameter of viscous fluid flow. This number defines the boundary between laminar and turbulent flow. Figure 3, using the xFoil software package, shows the change in buoyancy coefficient (Cl) in relation to the resistance coefficient (Cd) for three Reynolds numbers (350,000 Re- green line, 500,000 Re- black line, 675,000 Re- dark blue line).

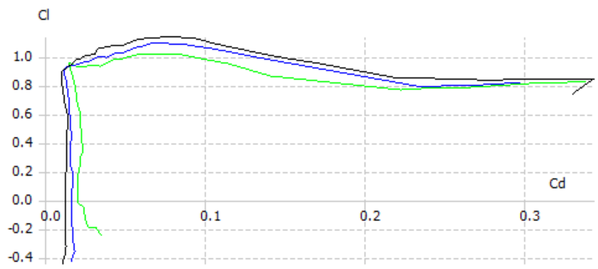


Fig. 3. The curve of the buoyancy coefficient depending on the resistance coefficient

The buoyancy coefficient rises with the increase in the angle of attack. According to the obtained results, shown in Figure 4, for three Reynolds numbers (350,000 Re - green line, 500,000 Re - black line, 675,000 Re - dark blue line) we see that the buoyancy coefficient is the largest for the angle of attack (α) of 17^{o}, then decreases.

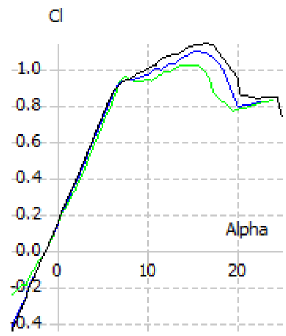


Fig. 4. The curve of the buoyancy coefficient depending on the angle of attack

The coefficient of the pitching moment decreases to the value of the angle (α) of 7^{o}, after which it increases and reaches the maximum value for the angle of attack (α) of 13^{o}, after which it begins to decrease. The coefficient of pitching moment in relation to the angle of attack is shown in Figure 5.

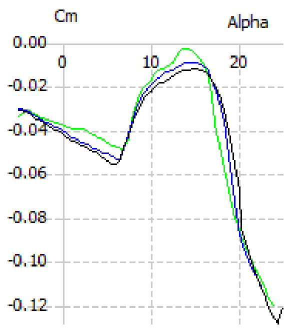


Fig. 5. The curve of the coefficient of pitching moment depending on the angle of attack

Lift-to-drag ratio (ratio of aerodynamic buoyancy and drag forces) in relation to the angle of attack shown in Figure 6 reaches the largest value for:

1. The angle of attack α = 7^{o}, the lift-to-drag ratio (ratio C_l and C_d) is 85, for Reynolds number 675,000;
2. The angle of attack α = 9^{o}, the lift-to-drag ratio (ratio C_l and C_d) is 60, for Reynolds number 350,000.

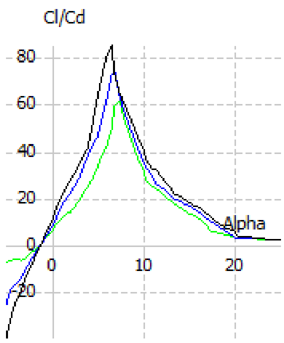
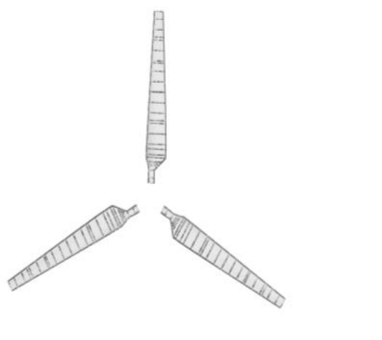


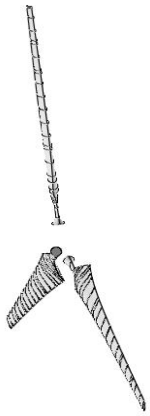
Fig. 6. The curve of the L/D ratio depending on the angle of attack

3.2 Wind turbin aeroprofile

Using the QBlade software package, based on the previous data, the appearance of the blade was defined, which is shown in Figure 7a and 7b.



a)



b)

Fig. 7. Wind turbine airfoil

4. CONCLUSION

Wind is an inexhaustible ecological source of energy and a very important resource in electricity production. It is a renewable and unlimited energy source. It does not pollute the environment, and its global potential far exceeds its needs. With the development of industry and technology, the need for electricity increases.

This trend of increasing electricity consumption is accompanied by increasing air pollution, which results in global warming. The increase in electricity consumption should be followed by the development of renewable sources of energy, as well as the tools that are needed for their construction.

The application of software packages in the design of the blade profile leads to better wind turbine performance and a better choice of wind turbine for the selected location based on the meteorological conditions that prevail there.

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