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Design and Establishment of a Small Wind Turbine

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Abstract

In the last century, with the increase in the human population, rapid industrialization, and the rapid increase in the use of electrical-electronic devices, the need for energy has increased rapidly. Wind turbines are highly preferred as renewable energy because they do not cause environmental pollution. In this study, the design and establishment of a small wind turbine with a power of 1.5 kW and its installation in the appropriate place are in Sakarya University of Applied Sciences, Faculty of Technology, Sakarya, Turkey. The whole procedure is explained in detail. In addition, a Static analysis was made on the wind turbine pole using the Ansys program. Three blades are used in the wind turbine. Analysis of wind turbine blades is done with the Ansys program. The equivalent Stress (Von-Mises) method was chosen for the total deformation of the wind turbine blades. This study will be a reference for those who will install this type of small wind turbine.

Keywords: Small wind turbine, static analysis, horizontal axis, wind energy

1. Introduction

In our world, energy consumption has been increasing rapidly in the last century with the rapid increase in the human population and the increase in industrialization with technological developments. In addition, as people's social welfare increased, energy-consuming electric vehicles increased rapidly and as a result, their energy needs grew more and more. The earth's atmosphere is rapidly polluted. This increase increases the greenhouse gas effect in the atmosphere and causes flooding and drought in some regions with the decrease in precipitation and causes problems in the production of the food chain. The necessity of meeting the energy need and making this energy production without polluting our atmosphere has emerged. The only way to meet this need in the best way is to use renewable energy sources such as sun, wind, and snow. One of the best ways is to install wind turbines in windy areas, in some places it causes excess precipitation, and as a result of climate changes, renewable energy has been given great importance in recent years to reduce the increasing environmental pollution and to obtain a continuous energy source. Wind turbines are highly preferred as renewable energy because they do not cause environmental pollution.

The usage of wind energy is essential for lowering greenhouse gas emissions. Since the 19th century, scientific research has dramatically improved the performance, size, and design of wind machines. Today, nations frequently deploy three-bladed horizontal axis wind turbines to generate energy. Following this quick and dynamic development, Europe's installed wind power capacity increased by 27% between 2018 and 2019 [1].

Today, wind power forms the most rapidly advancing renewable energy resource with an annual growth rate of about 30 %. Within the last 20 years, the size of wind turbines has increased from a rotor diameter of about 30 m to 150 m, corresponding to an increase in power by a factor of more than 25 [2].

In contrast to bigger utility-scale turbines, micro-scale/small wind turbines typically have hub heights under 30 m and produce power at a rate of 300 W to 10 kW at their rated wind speed. Due to their size, these wind turbines have far greater flexibility in terms of prices, maintenance, and siting and can produce wind energy in locations that are much less suitable for direct delivery to the grid system. The current centralized electricity generation and delivery system will most likely give way to a more

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distributed and locally generated electricity and delivery system in the future as a result of climate change. Modest sustainable electricity generators, like small wind turbines, will probably play a bigger part in the future system structure [3].

The literature contains studies on small wind turbines. The authors use data from the North American Regional Reanalysis to illustrate how a small wind turbine operates and to make predictions about its potential power output and historical trend over Ontario over the past 33 years. They evaluated the performance of a 1 kW Bergey Excel wind turbine at the Canadian Kortright Centre for Conservation test site, which was already in place [3]. Bourhis Chang et al. explained the design method could be improved by adding loss and deflection models. Their study reveals that the performance of micro-scale wind turbines is highly affected by the tip losses due to the finite span of the blades. In addition, they suggest the design of diffusers or shrouded turbines could help to decrease these losses by increasing the active part of a blade. Their experimental investigations suggested an effect of the Reynolds number on the performance of micro-scale runners [4]. Yücel and Özder presented the design and efficiency of a 5 kW gearbox-less wind turbine controlled by yaw and yaw drivers and found that the turbine had an average efficiency of 28% with comparing to a professional design of 30-35% [5].

The small-scale wind turbine is defined as a wind-powered electric generator with a rated capacity of less than 50 kW, generally intended to supply electricity for residential use and/or small farms. The generation power and carbon savings of a small wind turbine and a utility-scale wind turbine are shown in Figure 1. The small wind turbine, which produces 2.5 kWh of electricity, saves approximately 3.3 MWh/year of energy and 1.4 tons of CO_2 carbon per year. It shows how carbon saving improves the atmosphere's health.

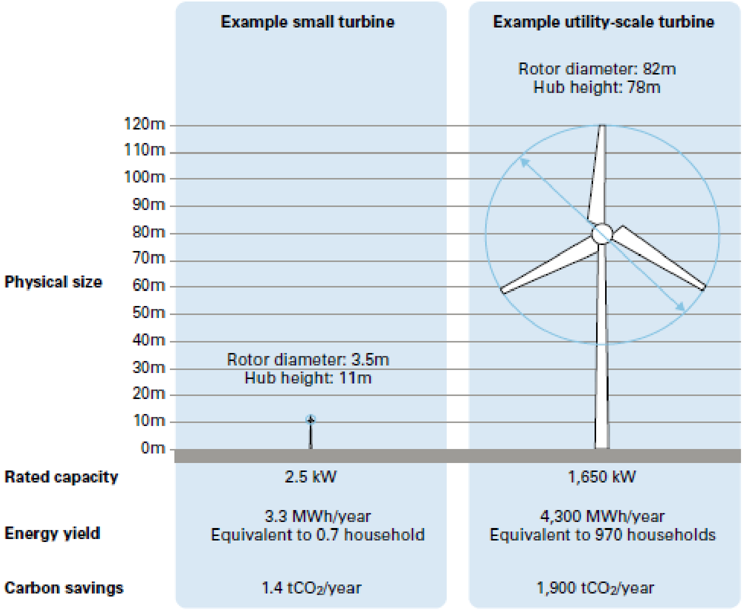

Figure 1. Generation and carbon savings of a small wind turbine and a utility-scale wind turbine [6]

Some researchers investigated the nonlinear dynamic response of wind turbine blades [7], the dynamic modeling and simulation [8], the aerodynamic developments on small horizontal axis wind turbine blades [9], the rotor design method for a small propeller-type wind turbine[10], the power oscillation damping supported by wind power [11], the performance enhancement of a small-scale wind turbine featuring morphed trailing edge [12], the energy and economic performance of small wind energy systems under different climatic conditions of South Africa [13].

2. Basic concept and calculation of wind turbine power

The wind power resource, the accessibility of the wind turbine by roads and other infrastructure, the reliability of the electrical transmission system, the investment costs, the energy prices, the profitability, the available subsidies, the property rights, the land ownership, the land structure, the ecological and environmental aspects are all essential and decisive aspects of planning and locating wind turbine. The visibility of the turbines and the assessment of their aesthetic impact are key social issues in most cases. Visibility and visual impact assessments mostly deal with the following variables: Evaluating the visibility and visual impact of wind turbines are generally associated with the following factors [14].

- Number of turbines,
- Size/height or hub height of turbines,
- Distance to the wind turbines, or proximity of residential and recreational activities,
- Arrangement of wind turbines, visibility of wind turbines from different points of view,
- The total area of the farm,
- The density of turbines,
- Traveling time or road length is affected by the view of wind turbines,
- Coloring of turbines,
- Change of the background attributes,
- Houses or areas affected by the view of wind turbines,
- Distribution of population affected by the view of wind turbines,
- Number of wind power plants,
- Rotor swept area,
- Number of turns in the silhouette
- Contrast,
- Lightness,
- Climate,
- Movement - moving or stationary blades,
- Observers height,
- Weather, or atmospheric conditions,
- Open view of the turbines,
- Forest cover,
- Built environment.

Figure 2 shows a typical horizontal-axis wind turbine. When the wind speed rises over the cut-in velocity in a wind turbine, the wind turbine begins to revolve and generate electrical energy.

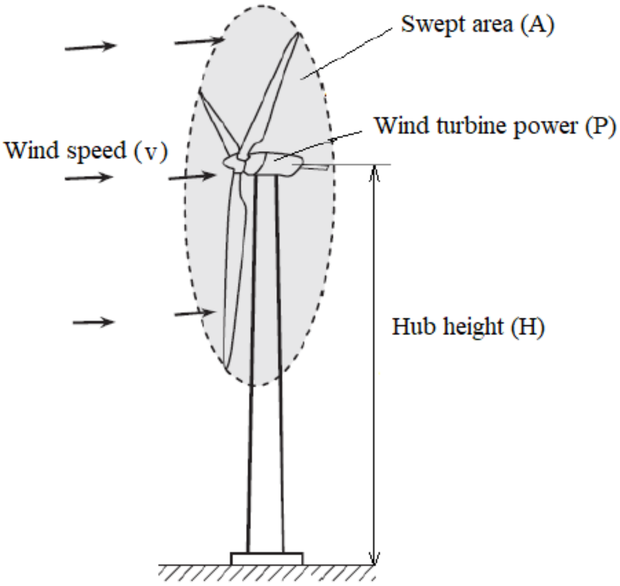

Figure 2. A typical horizontal-axis wind turbine.

Power output from the wind turbine (P) and turbine power coefficient (Cp) can be usually defined respectively.

$$P = 0.5\rho v^3 A C_p \qquad (1)$$

where P is the wind turbine (W), ρ is the atmospheric air density (kg/m^3), v is the wind speed (m/s), A is the blade swept area (m^2) and Cp is the efficiency of a wind turbine.

The efficiency of a wind turbine, Cp, can be calculated as follow;

$$C_p = 4a(1-a)^2 \qquad (2)$$

where a is the flow induction factor.

The swept area of rotor blades can be calculated as follow;

$$A = \pi[(L+r)^2] - r^2 = \pi L(L+2r) \qquad (3)$$

where L is the length of rotor blades (m) and r is the radius of the hub (m).

Since it is recognized that the wind does not remain constant throughout time, statistics are required. A family of two-parameter functions is utilized in its most basic form [2]:

$$P(v;A,k):=\frac{k}{A}\left(\frac{V}{A}\right)^{k-1}exp\left(\frac{V}{A}\right)^{k} \qquad (3)$$

where v is connected with the annual averaged mean velocity, A is the blade swept area, k is the shape factor with values between 1 and 4, and v is a commonly used probability distribution attributed to Weibull that is the distribution with k = 2 is called a Rayleigh distribution. For most practical applications:

$$\bar{v}=\int_0^{\infty}P(v;A,k)vdv\approx A\left(0.568+\frac{0.434}{k}\right)^{1/k}$$

The Weibull distributions with the shape factors are shown in Figure 3.

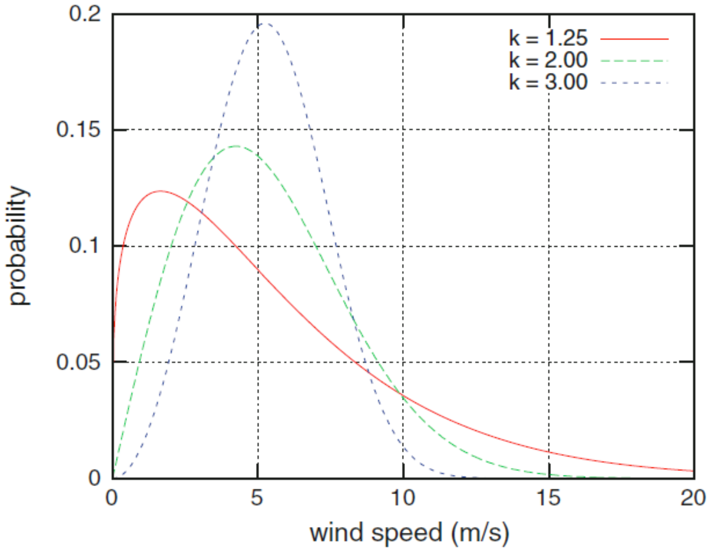

Figure 3. Weibull distributions [2]

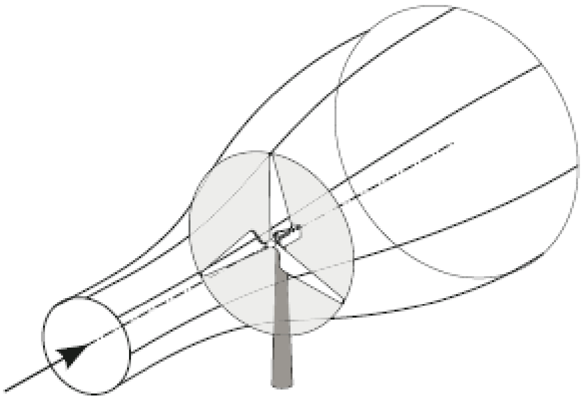

Figure 4. Wind turbine with slip stream

The temporally and spatially constant wind may have velocity v perpendicular to the area as shown in Figure 4 [2].

3. Established small wind turbine

The small wind turbine was established at Sakarya University of Applied Sciences, Faculty of

Technology in Sakarya-Turkey. The wind turbine has a 1.5 kW power capacity and the NACA N11 type airfoil. The Hub height of the wind turbine is 6 meters. The wind turbine has a maximum of 23439 of the Reynolds number and 1.4207E-5 of kinematic viscosity for a maximum velocity of 33.3 m/s at 10 °C.

3.1 Design of wind turbine steel pole

The suitability and robustness of the steel pole, having a 6-meter height, designed for a 1.5 kW small wind turbine were checked. The steel pole has 6 meters in height. Deformations, stresses, buckling, and safety factor of the designed steel pole were investigated. As a result of this examination, the critical load coefficient was obtained and it was examined how much displacement occurred due to buckling. In the buckling analysis, the weight of the wind turbine body part, the forces arising from the wind, and the sum of the mast's weight were evaluated as input forces.

These are the results of the flow analysis performed by applying a wind speed of 30 m/s. As a result of the analysis, the highest velocity was found to be 39.67 m/s and the highest pressure was 103409.51 Pa. The result of pressure and velocity distribution as a result of flow analysis in the steel pole of the wind turbine is shown in Figure 5.

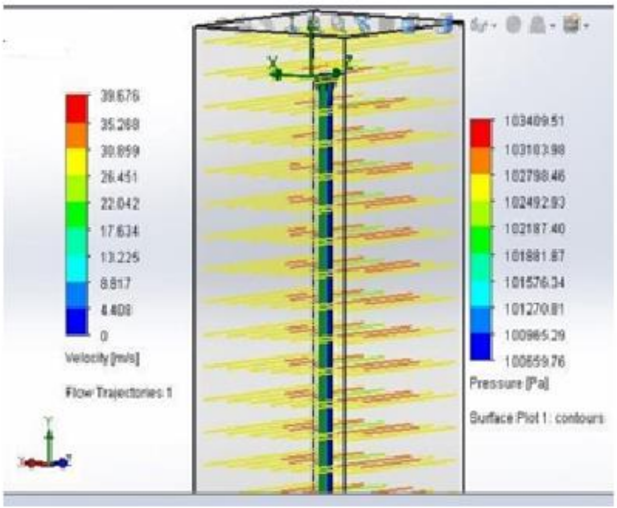

Figure 5. Pressure and velocity distribution in the steel pole of wind turbine

3.2 Design of wind turbine blades

The wind turbine blade modeling was done on the computer using the Solidworks program. Wind turbine blades were produced by choosing the N 11 type from the airfoil models determined by the National Advisory Committee for Aeronautics (NACA). Before the flow analysis is performed, the air volume in which the wind turbine blade is located is modeled. This modeling is shown in the Figure 6. The wind turbine blade in the form of an airfoil model is placed at the G point. When the G point is taken as a criterion, the modeling parameters are measured as shown in Figure 6.

The air volume modeled in the Autocad program is imported into the Ansys Workbench CFX flow analysis program. Figure 7 shows the air volume that has been meshed.

Considering the weather data for the average of the past few years taken from the archive of the entry wind speed meteorology directorate, the maximum value of 33.3 speed in the Esentepe region, Sakarya-Turkey, region has been accepted. The aim here is to obtain the maximum pressure at this maximum wind speed value. The flow of the wind in the modeled air volume is given in Figure 8.

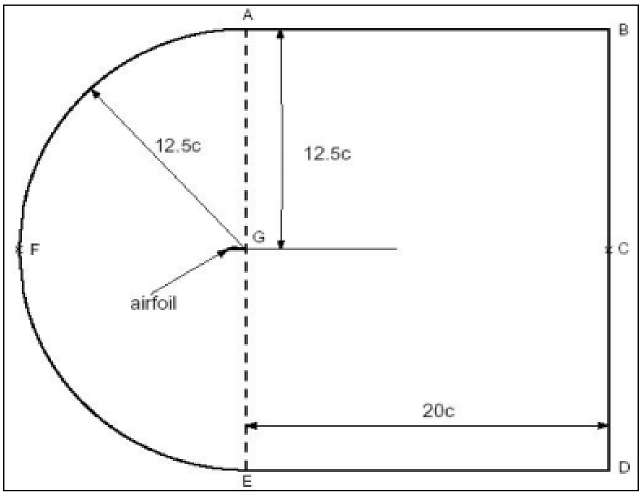

Figure 6. Air volume modeling criterion

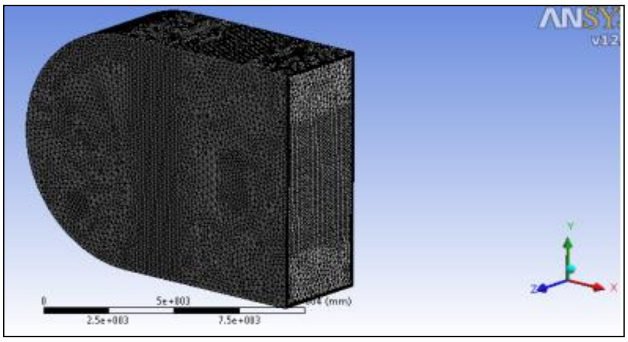

Figure 7. Meshed air volume in the Ansys workbench CFX

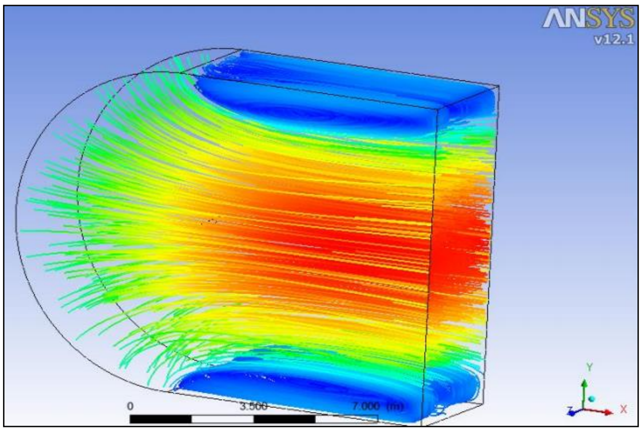

Figure 8. The flow of wind in the modeled air volume

The maximum pressure created by the wind on the wing was found. This value can be easily read from the program as 3.61 MPa. Figure 9 below shows this pressure value and the pressure distribution for the windward direction of the blade.

The Equivalent Stress (Von-Mises) method was chosen for the total deformation of the wind turbine blades. The total amount of deformation was determined as a maximum of 86.32 mm and the maximum stress is 380.28 MPa. The numerical analysis is done by the Ansys program and the result of the analysis is shown in Figure 10. As can be seen in the analysis, the greatest deformation occurs at the wing tip, as can be predicted. The other parts of the blades have very lower deformations compared to the tip of the blade of the wind turbine.

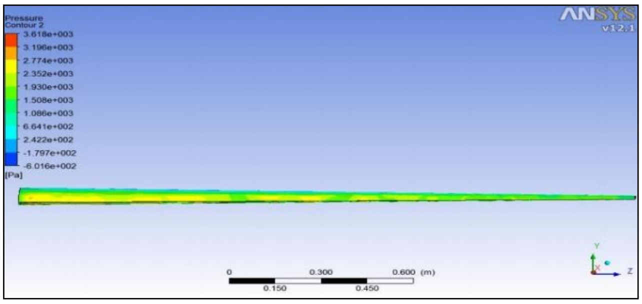

Figure 9. Pressure value and the pressure distribution for the windward direction of the blade.

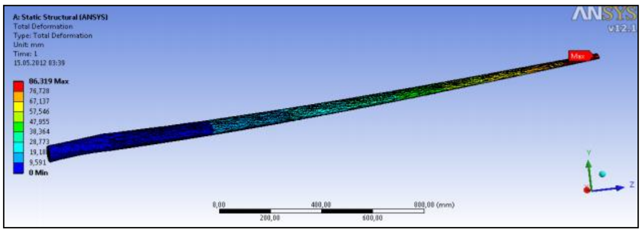

Figure 10. Maximum pressure in the blade section for the wind direction

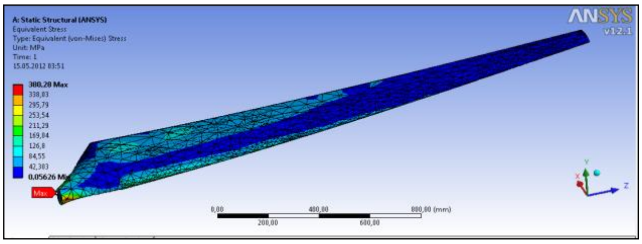

Figure 11. Maximum stress on the wind turbine blades

The maximum stress on the wind turbine blades was found to be 380.28 MPa as shown in Figure 11. As seen in Figure 11, the maximum stress is at the connection point of the wind turbine blade with the rotor.

The three blades of the wind turbine are shown in Figure 12. The blade materials are the monolith laminate layer; a) Shell resin is Epoxy, b) Shear mesh reinforcement is glass fiber and the sandwich laminate layer; c) Main Beam Reinforcement is Uniaxial Glass Fiber, d) Joints are structural adhesive, e) Core Material is Balsa wood and the surface; d) Primer e) Topcoat is polyurethane paint.

Figure 12. Picture of the three blades of the wind turbine

3.3 Design of wind turbine stator and rotor

The copper coils wound by the machine are placed on the template. Properly placed coils are glued to each other and fixed. Before the coils are placed in the mold, fiberglass is placed on the top and bottom. Polyester resin is poured into the mold. 2 rotor discs are cut on the lathe. A total of 24 Neodymium magnets, 12 on each disc, are placed on the discs using a template and adhered. A mold was created with masking tape and a polyester cast was made. There are 12 Neodymium magnets attached to one of the rotor discs as shown in Figure 13.

After the rotor and stator assembly are completed, the state of the hub is shown in Figure 14. The picture after the small wind turbine with a power of 1.5 kW, whose parts have been completed, is placed in the designated place as shown in Figure 15.

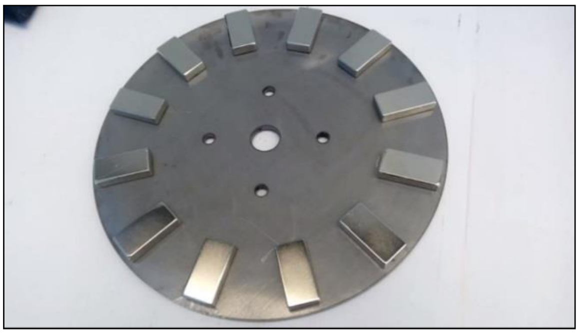
Figure 13. Picture of 12 Neodymium magnets attached to the rotor disc


Figure 14. Picture of the hub of the small wind turbine


Figure 15. Picture of the small wind turbine

4. Conclusions

The small wind turbine, having 1.5 kW power capacity and 6 meters of hub height, was established at Sakarya University of Applied Sciences, Faculty of Technology in Sakarya-Turkey. All procedure was explained in detail. The first step of the procedure was done design the wind turbine pole having steel material. Static analysis was made on the wind turbine pole using the Ansys program and the highest speed was found to be 39.67 m/s and the highest pressure was 103409 Pa on the wind turbine pole. The second step was done design and analyze wind turbine blades. Three blades were used in the wind turbine. Analysis of the wind turbine blades is made by the Ansys program. The Equivalent Stress (Von-Mises) method was chosen for the total deformation of the wind turbine blades. The total amount of deformation was determined as a maximum of 86.32 mm and the maximum stress is 380.28 MPa.

The third step was designing the rotor and the stator. A total of 24 Neodymium magnets, 12 on each disc, are placed on the discs using a template and adhered. As a result, it shows the way for those who will make small wind turbines in the future.

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