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Computer Aided Wind Turbine Design and 1 kW Prototype Manufacturing

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Abstract - Wind energy is one of the alternative energy sources with a great potential in world energy production. The design, simulation and manufacturing stages of the wind turbine are explained throughout this study. After creating the design, the blade and airflow behaviors of the turbine are examined in the simulation environment. Then, the components required for turbine production are manufactured and supplied according to the technical drawing. Finally, the turbine is manufactured and the alternator performance is observed according to the blade rotation speed.

Keywords: *Wind turbine, turbine design, prototype manufacturing, simulation, wind energy*

1. Introduction

The world is increasingly shifting into using renewable energy sources. Especially in recent years, increasing investments in the energy field shows the importance of renewable energy. Wind energy is a type of renewable energy that has become very popular in recent times [1]. Wind, leaving fuel oil behind, was the 5th largest form of power generation capacity in 2007. Moreover, wind left behind nuclear energy as the 4th largest form of power generation capacity in 2013. In 2015, wind surpassed hydro as the 3rd largest form of power generation capacity. Finally, wind surpassed coal as the 2nd largest form of power generation capacity in 2016. Germany was the largest market in new wind power capacity installations with 44% of the total EU installations in 2016. This was followed by Spain, England and France. Turkey (1.4 GW) also broke its record for annual new installations. Wind turbines are the systems which mechanically capture the kinetic energy of the wind in a rotor connected to an electric generator which consist of two or more blades and convert the energy of wind; first into mechanical energy and then into electrical energy [3-4]. Today, the most common wind turbine design is horizontal-axis wind turbines. The rotational axes of such turbines are parallel to the ground. The rotors of these turbines are usually classified according to the direction of the rotor (the wind is from front or the wind is from behind), the blade hub design, the number of blades (usually two or three), the rotor control (pitch or stall), alignment with the wind (free yaw or active yaw) and the gear design [5]. These design-related differences affect the amount of energy the turbine produces. That's why, the amount of investment related to the wind turbine increases every year. The first capital investment in wind energy is used for machinery and supporting infrastructure. Factors that increase the energy such as turbine design, installation and operation of the plant are expensive making wind power an alternative energy source. Mathematical modeling of a wind turbine is necessary to

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understand the behavior of the wind turbine on the process area. The reason for this is that it allows the development of comprehensive control algorithms that will help the wind turbine operate at optimum values. The modeling ensures that the values of the wind turbine performance are controlled [6].

In this article, wind energy systems were studied and computer aided design and prototype construction of a 1 kW wind turbine system were emphasized. Firstly, the turbine design was carried out in a computer environment then a prototype of the wind turbine was fabricated.

2. Computer Aided 1 kW Wind Turbine Design

1 kW wind turbine design was modelled in a single system with two 500 watt alternators, shafts, bearings, gear system and fasteners. In the simulation environment, it is assumed that the wind speed has a constant value (20 m/s). Three-bladed wind turbine design with 2.1-meter rotor diameter and simulation calculations were made. Each turbine component that was designed and simulated by calculations were specially manufactured according to the technical drawings. A double braking system is used for protecting the turbine system from excessive wind speed. The first of these braking systems is the bicycle hydraulic brake disc system. Turbine-mounted braking system allows the turbine to be slowed or stopped at any time when being desired. The second brake system is the charge control device, in which the charge control system automatically brakes the 24-volt alternator when it reaches 29-volt power. The magnetic alternators that provide alternating current output were used for electricity generation. The router that caught the wind was made to constantly turn the turbine in the direction of the wind and a slip ring was added to prevent the circulating of the alternator cables. Finally, the turbine was mounted on the aluminum pipe and the manufacturing phase was completed.

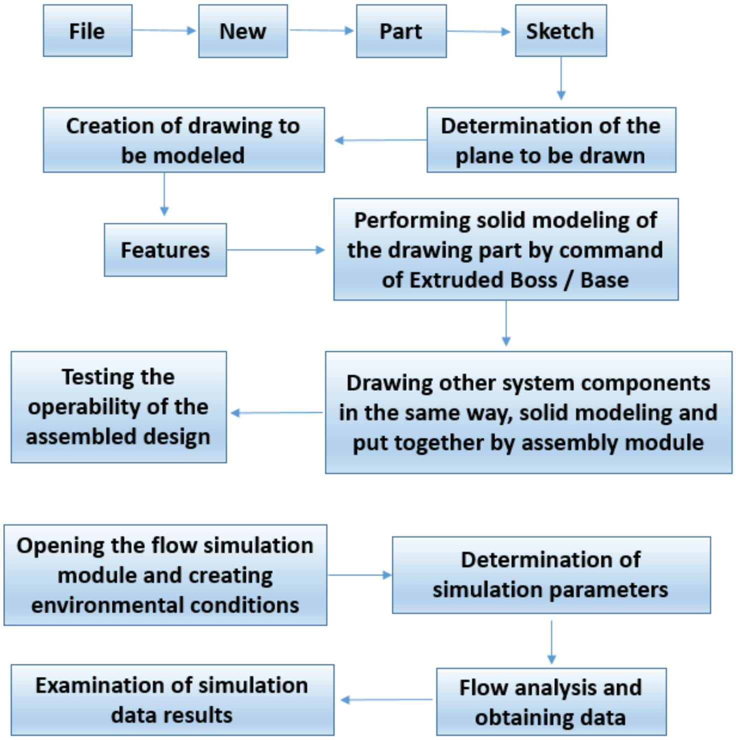
2.1. Using cad program for wind turbine modelling

Computer aided design of a product is the first step taken during product engineering and production, and it is the modeling process of that piece in software. The designed product model can be visualized in a desired perspective. Interaction and compatibility between the parts themselves can be visually examined, thanks to the advantages providing convenience in the production of parts, such as sectional view. The drawing of the turbine components was conducted using the SolidWorks program as a part of the design of the wind turbine. The AH79-100C blade profile was designed according to the UIUC (Department of Aerospace Engineering) for evaluating the design of the airflow-based system [7]. Aerodynamic behaviors of the system were determined by the flow analysis and as a result of this analysis the blade performance evaluation was conducted.

The reasons for using the drawing program to create the model are as follows;

a) Vector-based and measured-3D drawings can be created with this program.
b) Thanks to coordinated work with other programs, the designs can be transferred to other programs, the programs can be examined and the technical data can be obtained on the created models.
c) Separately drawn parts can be combined and assembled with the assembly module, detailed data on many tests such as flow or static and the impact on the drawing can be obtained and motion analysis can be added to the system with animation plug-in [8].

The flow diagram that was used for creating the design is as follows;



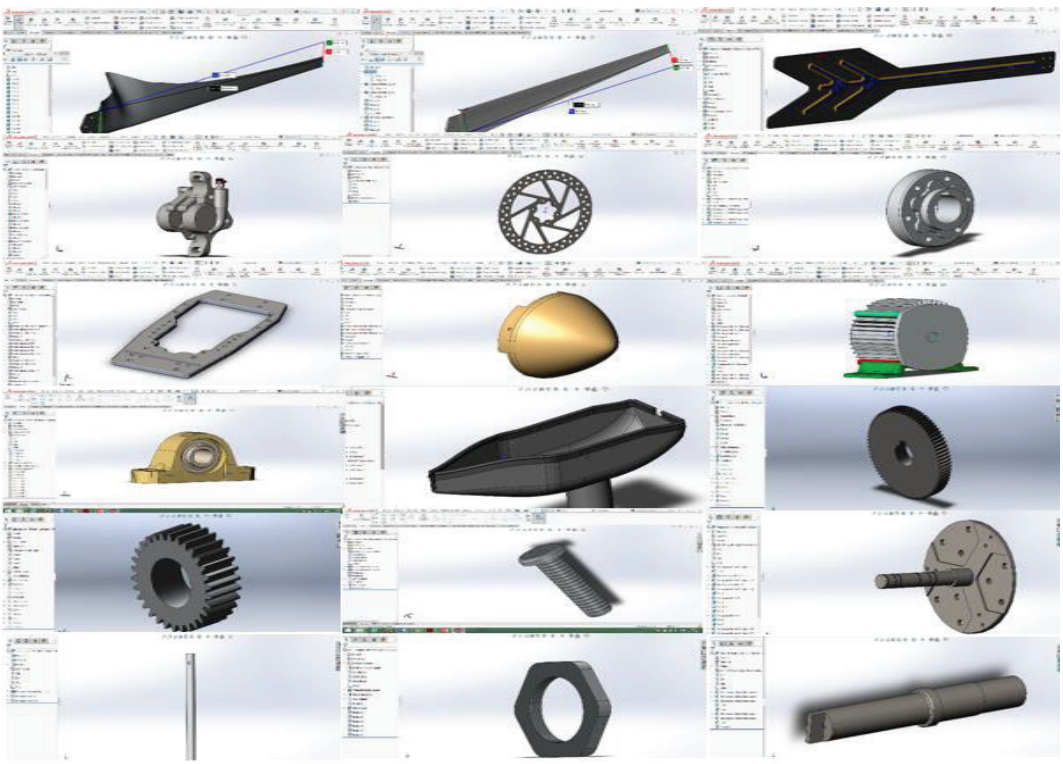


Figure 1. Solid models of wind turbine components

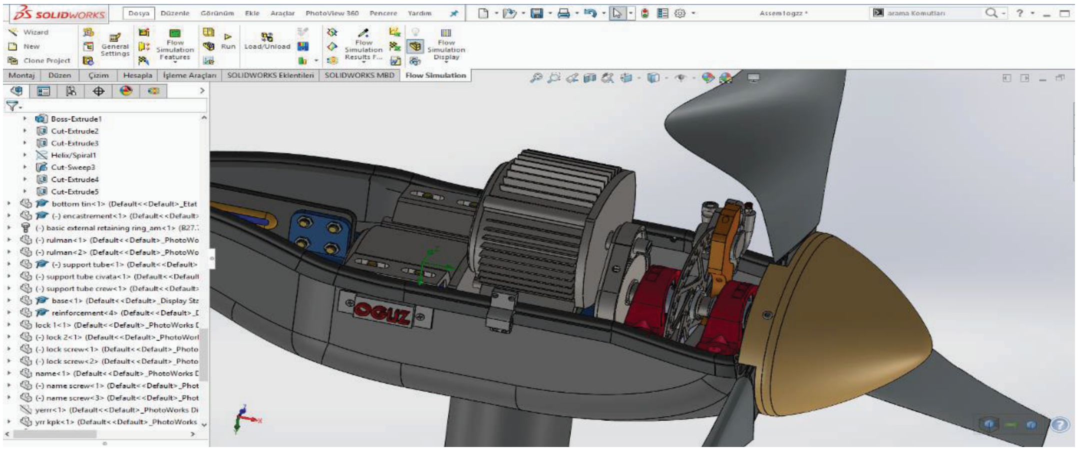


Figure 2. View of the wind turbine after assembly

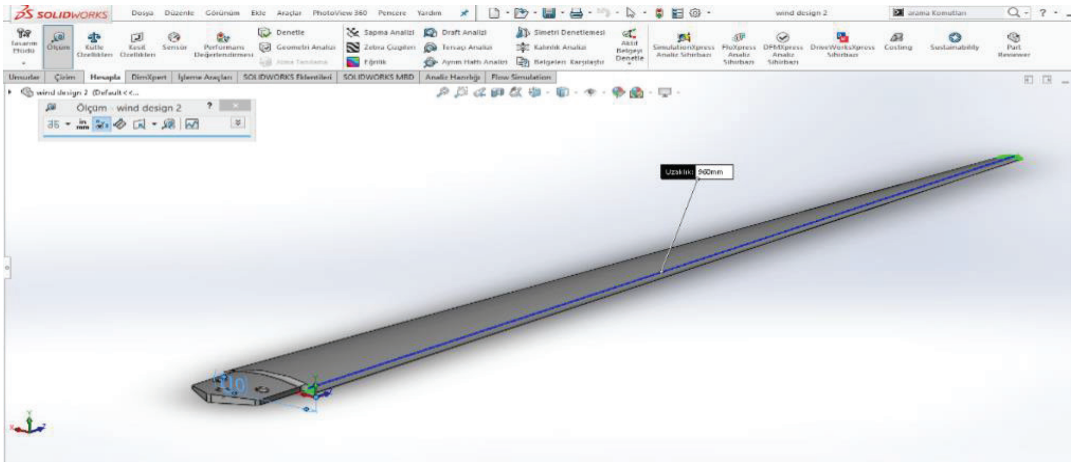
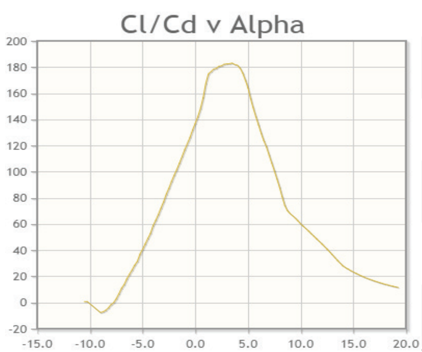


Figure 3. AH79-100C blade profile

The two important criteria to be considered while designing the blade are the aerodynamics and the strength. Aerodynamically, it is important to pay attention to the value of C_L / C_D (lift / drag coefficients) and the value of a^0 (attack angle). For best blade efficiency, the minimum value of the angle of a^0 should be selected, in addition to the maximum value of l/d. The value of C_L/C_D appears to be at the maximum value at $3{,}5^0$ attack angle in the data of AH 79-100C blade profile [7]. The variation of C_L and C_D values according to attack angle and Reynold numbers are given in the figure.



Airfoil	Reynolds #	Ncrit	Max Cl/Cd
ah79100c-il	50,000	9	32.2 at α=11°
ah79100c-il	50,000	5	31.5 at α=10°
ah79100c-il	100,000	9	61.7 at α=8.5°
ah79100c-il	100,000	5	61.5 at α=7°
ah79100c-il	200,000	9	97.6 at α=6.25°
ah79100c-il	200,000	5	97 at α=4.75°
ah79100c-il	500,000	9	147.6 at α=4.5°
ah79100c-il	500,000	5	137.7 at α=3°
ah79100c-il	1,000,000	9	183 at α=3.5°
ah79100c-il	1,000,000	5	161.4 at α=2.75°

Figure 4. Change of C_l/C_d ratio versus attack angle and Reynold numbers

The lift and drag coefficients and the Reynold number are calculated by the following equations;

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A} \quad (1)$$

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \quad (2)$$

$$Re = \frac{UL}{\upsilon} = \frac{\rho UL}{\mu} = \frac{Inertial\ force}{Viscous\ force} \quad (3)$$

v= velocity of the fluid

l= the characteristics length, the chord width of an airfoil.

ρ= the density of the fluid

μ= the dynamic viscosity of the fluid

υ= the kinematic viscosity of the fluid [9].

2.2 Parameters and Simulation Data Results

1. The volume to be used for the air flow simulation was generated.

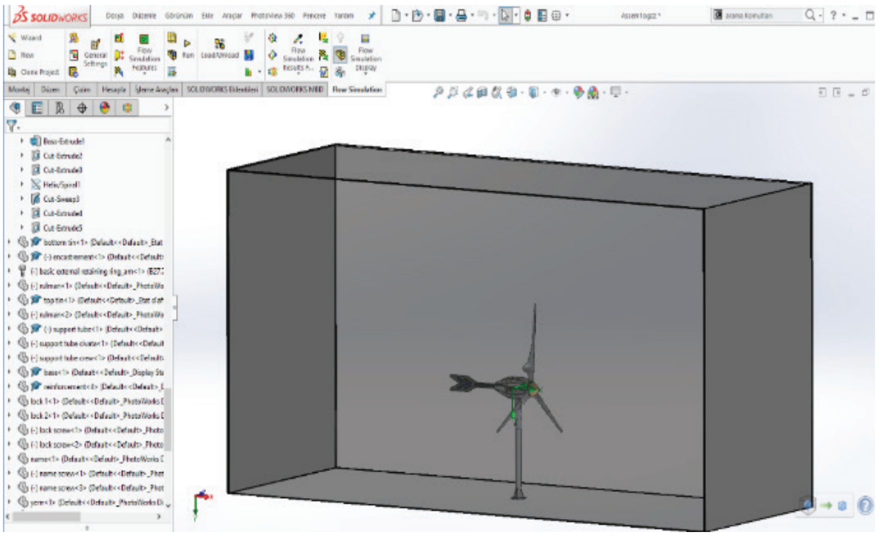


Figure 5. Air volume modeling

2. A new flow simulation project is defined by clicking the project for the flow simulation and then clicking on the wizard. The (current) box is preferred in the configuration box. Each flow simulation project is associated with a SolidWorks configuration.

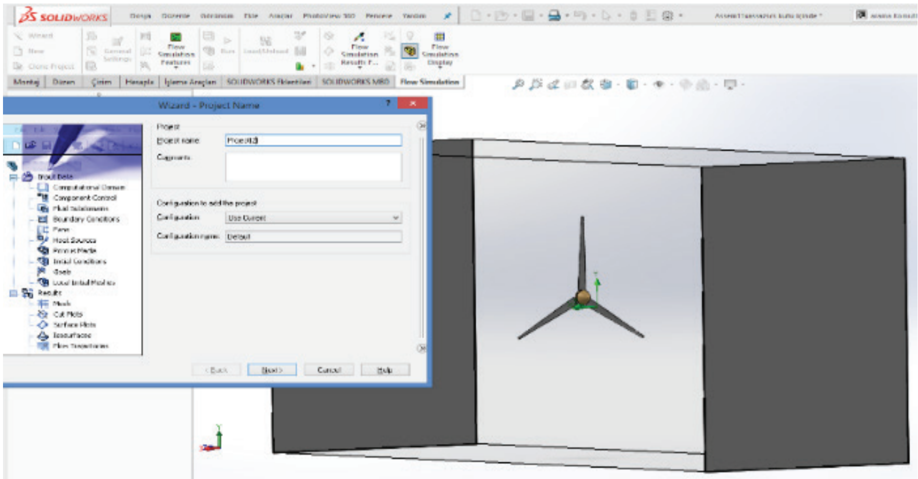


Figure 6. Project description

3. In the unit system box, we can select the desired unit system for both input and output. The International System (SI) was used by default for this project.

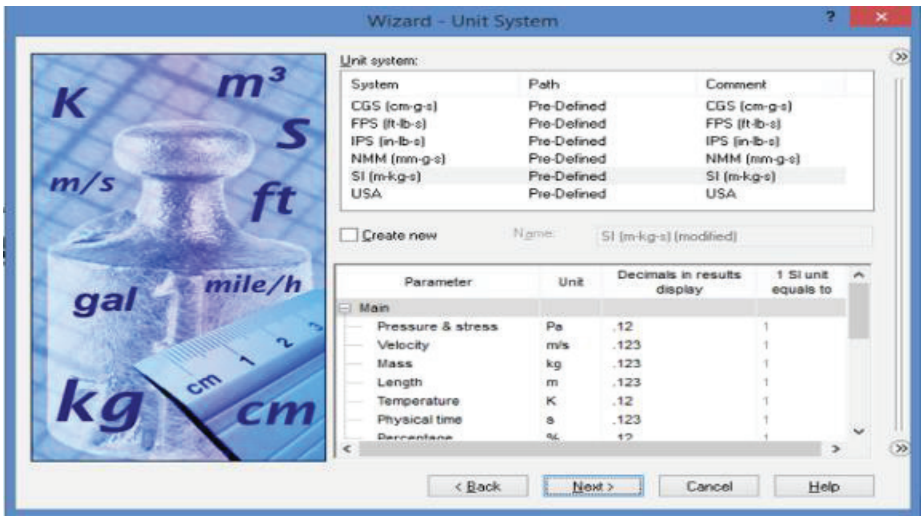


Figure 7. Unit System Identification

4. In the analysis type box, depending on the type of the flow analysis (internal) or (external) can be selected. In this study, the internal type was preferred due to the flow analysis occurıng in a closed volume air. The option to exclude cavities without flow conditions was chosen to ignore the internal gaps that are not included in the internal analysis. The x, y or z reference axis of the general coordinate system is used for determining the data in the form of a table or formula in a cylindrical coordinate system based on this axis. Another important point, that should be taken into account in the analysis, is the type box which is to be specified for the improved physical properties (heat conduction in solids, gravitational effects, time dependent problems, surface radiation from the surface and rotation). It is stated that the rotation command will rotate the turbine blades.

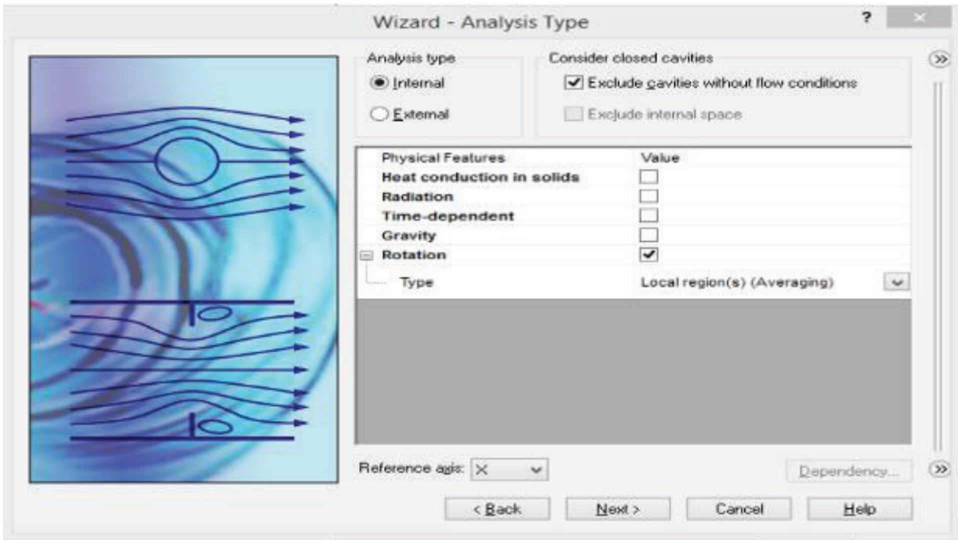


Figure 8. Determination of the type and the shape of the analysis

5. The SolidWorks engineering database contains numerical physical information on a wide variety of gases, liquids, solid materials and radiation surfaces. Air flow was used as a fluid flow in simulation. Laminar and turbulent flow were selected as the flow types in the simulation.

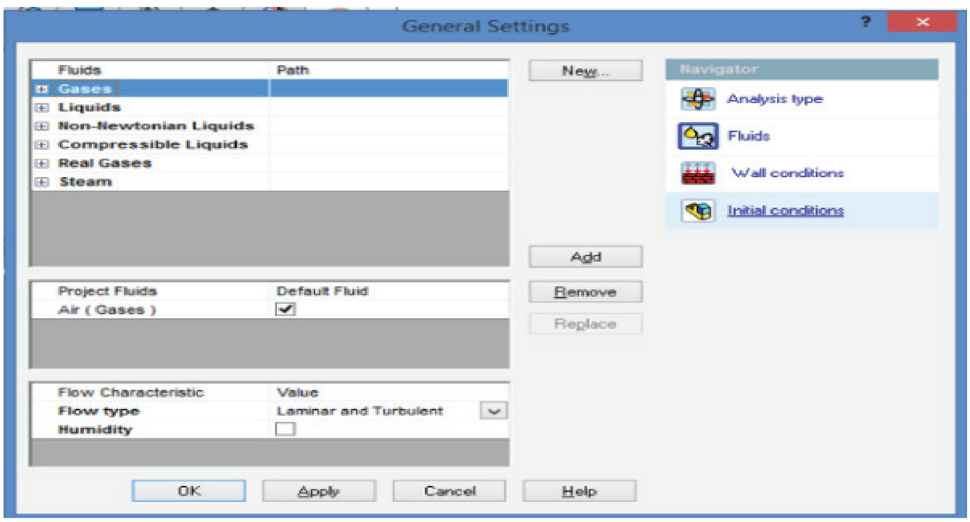


Figure 9. Determination of fluid flow and type

6. The formed air volume walls were chosen as adiabatic walls for examining the interaction on the wind turbine blade of the air flow. The initial condition parameters specify the conditions under the conditions of the starting point of flow. As the initial condition of the thermodynamic parameters, the temperature at 293.2 Kelvin, atmosphere pressure 101325 Pa and air density 1 kg / m^3 are used. The simulation wizard part is completed with the finish button. The next step is to determine the boundary conditions. The boundary conditions are used in internal flow analysis to define fluid properties in model inputs and outputs or model surfaces in external flow analysis. These data specify the computational domain settings, the boundary conditions, and the goals for which we want to calculate values such as pressure, temperature, velocity, and density.

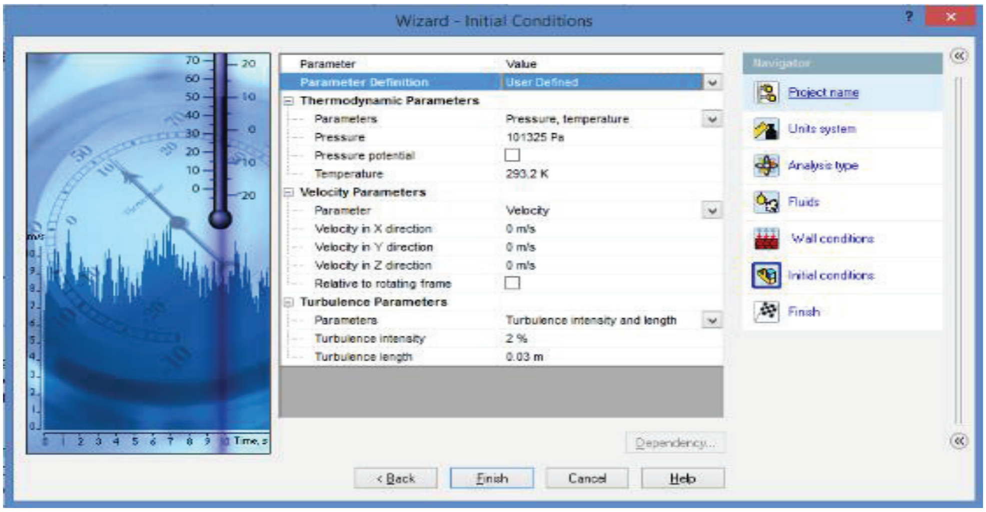


Figure 10. Selection of the atmospheric conditions

7. Firstly, computational domain boundaries determined and the domain shows the area in which analysis calculation is to be performed.

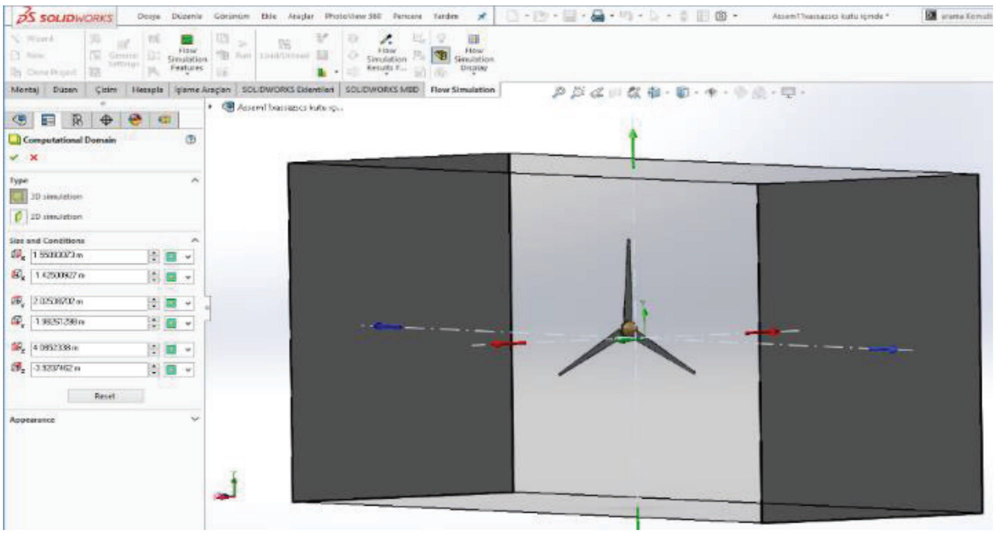


Figure 11. Determination of the calculation area

The next step is to determine the boundary conditions. The boundary conditions are used for defining the fluid properties of the model inputs and outputs in the internal flow analysis or in the model surfaces in the external flow analysis. For the computational domain, it is used for defining 20 m / s air velocity and for the external, the atmospheric pressure was defined. The rotation speed of the rotor 50 rad / s is given from the rotational regions part. In this way, the air flow movements around the rotor region and around the blade design were examined.

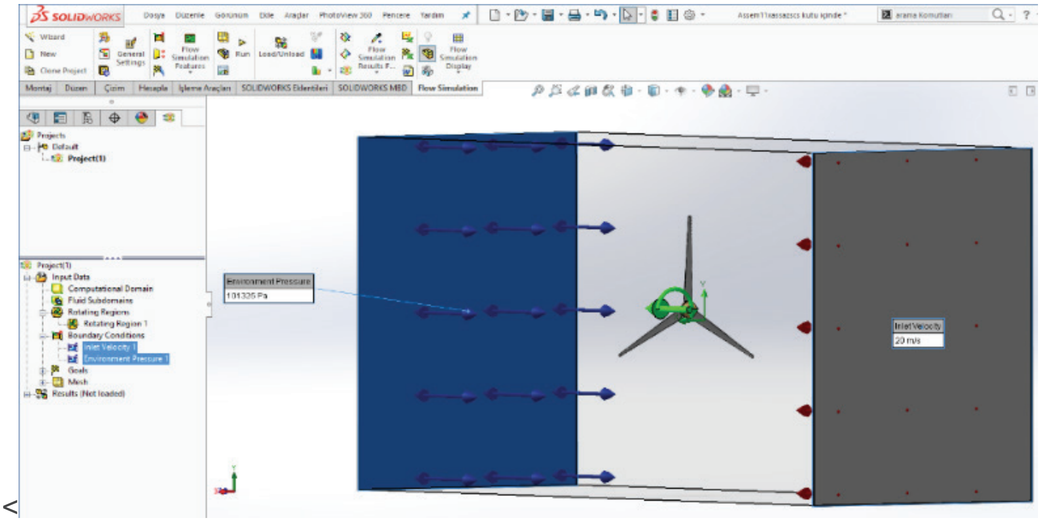


Figure 12. Boundary conditions input

The target parameters calculate the physical parameters within the computational domains. The target parameter to be calculated is determined as an examination of the distribution of the airflow over the blade profile and rotor area.

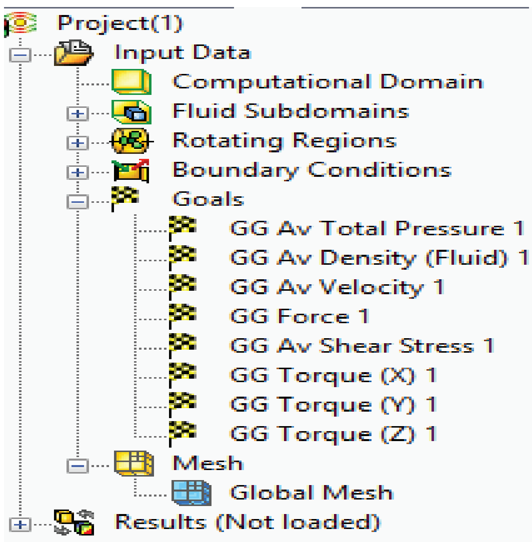


Figure 13. The input data

After entering the project data, the calculation section is started. In addition to initiating the analysis in the solution and result box, the mesh settings can be arranged. However, what is important here is the sufficiency of computer power supplies (CPU time and memory). The control is started and the analysis is started by run command. Analysis was initiated with run command after controlling the power supplies.

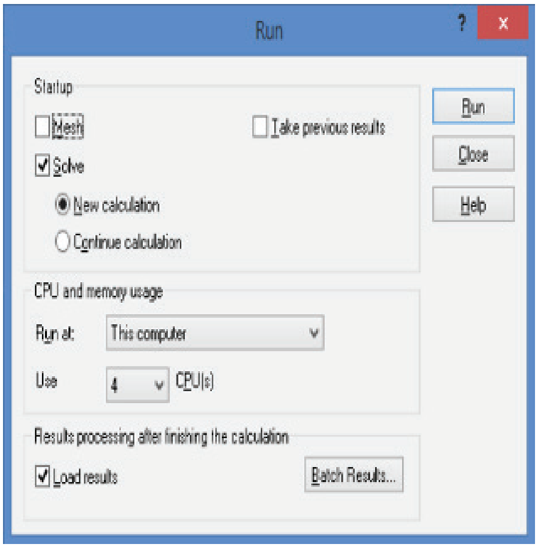


Figure 14. Obtaining solution and result

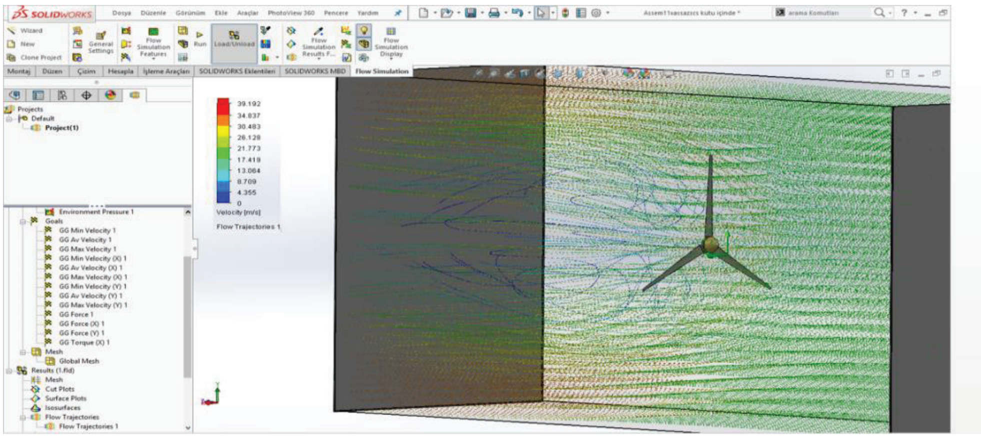


Figure 15. Simulation display

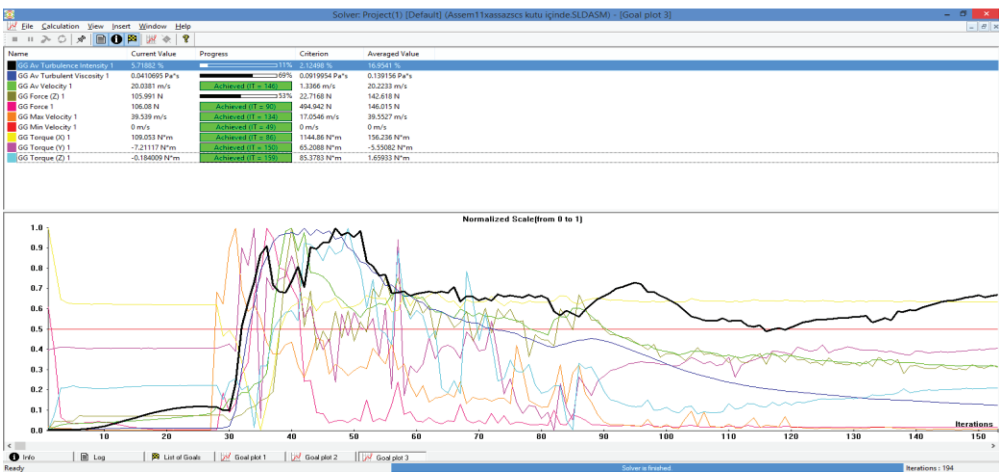


Figure 16. Calculation results for the blade model

3. The Manufacture and the Assembly of the Wind Turbine Components

During the construction phase of the wind turbine which was designed in SolidWorks, it was noted that each part was manufactured at values close to the measurement. Firstly, the parts to be manufactured in the design direction were determined and technical drawings were taken out. During the production phase of the parts, turning and milling machines were used in the production of spindle, support elements, gear and pole. The router was produced with laser cutting machine; the turbine support structure was produced through welding and sawing machines. The blades, bearings, blade connection disc, nose, alternator, charge controller, bicycle hydraulic brake disc system and fittings were provided in private. Following the manufacturing and supplying of the parts, the process progresses to the assembly phase.

3.1. Spur gear design and manufacturing

Gears are an important connecting element in the design, which allow the generator to increase the number of turns per minute and produce more energy at lower revs. The use of gears has negative aspects, such as gaining motion at greater wind speeds due to friction on the system in addition to its positive advantages, such as generating more energy at lower speeds. It has been determined that the alternator has sufficient power output at the rotor inlet revolution of 50 rpm and at the range of 2000-3000 rpm. A 2-stage spur gear design was prepared for achieving a speed range of 2000-3000 rpm and the rotor was provided with sufficient power output at 650-1000 rpm rotation speeds. The following figure shows the gear design in the CAD program and its manufactured state.

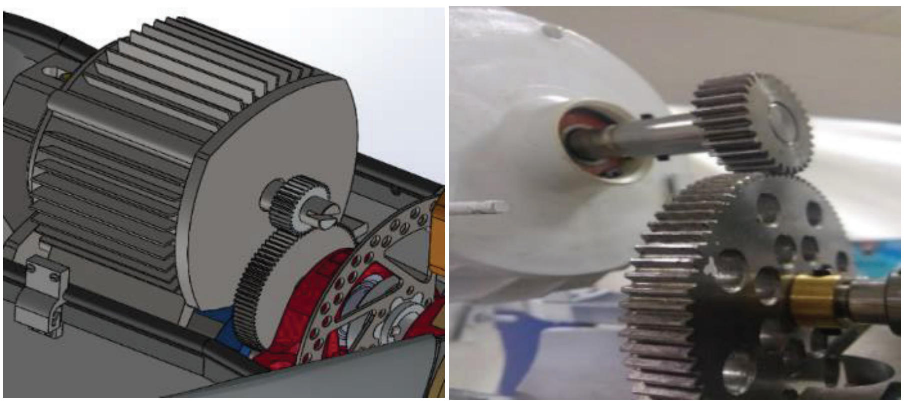


Figure 17. Designed and manufactured spur gear

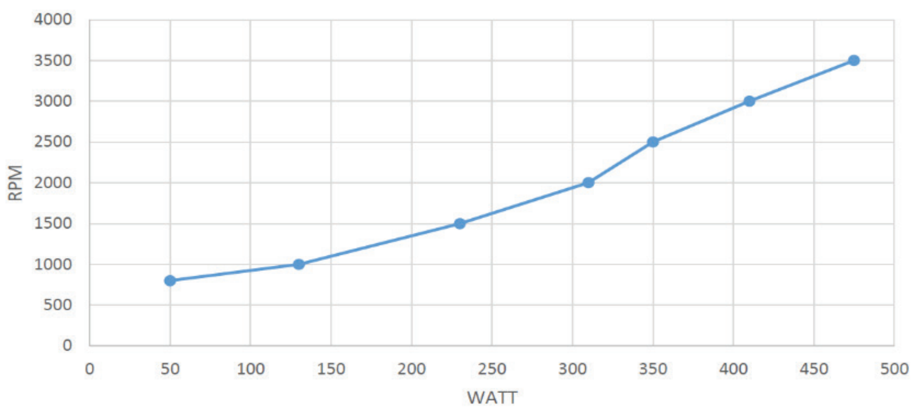


Figure 18. Alternator power output according to the rotation speed

3.2. Router design and manufacturing

The turbine rotor must always be in a perpendicular position to the wind in order to benefit from the power of the wind that drifts in different directions. This routing movement is provided either by an electronic controller which determines the direction of the wind or by a system called router that can turn around 360^0 by bearings routed in the direction. The following figure shows the router in the CAD program and its manufactured state.

Figure 19. Designed and manufactured router

3.3. Support plate and manufacturing

It is the structure that carries the alternator, rotor, connecting elements, gear box, shaft, bearing and brake disk system of the turbine. It is made of 15 mm thick aluminum material. The support plate and its construction are shown below.

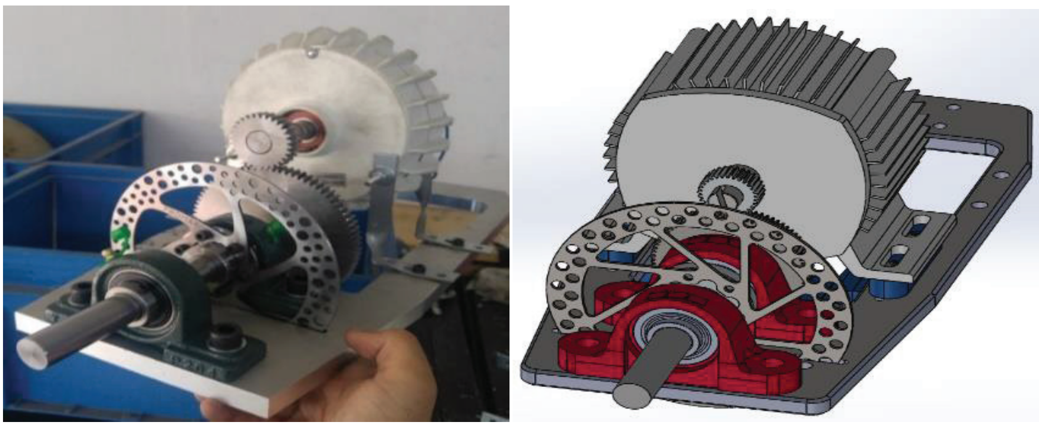


Figure 20. Designed and manufactured plate support element

3.4. Brake control system

<The turbine is controlled at high speeds and kept constant at certain speeds to protect the blades and system components. Double braking system is used in the design. The system can be manually slowed down at any time with the brake disc system on the turbine. The other braking system is the control charger. Alternators will automatically slow the system down when it reaches 29 volts. The following figure shows the brake disc mechanism and control charger.

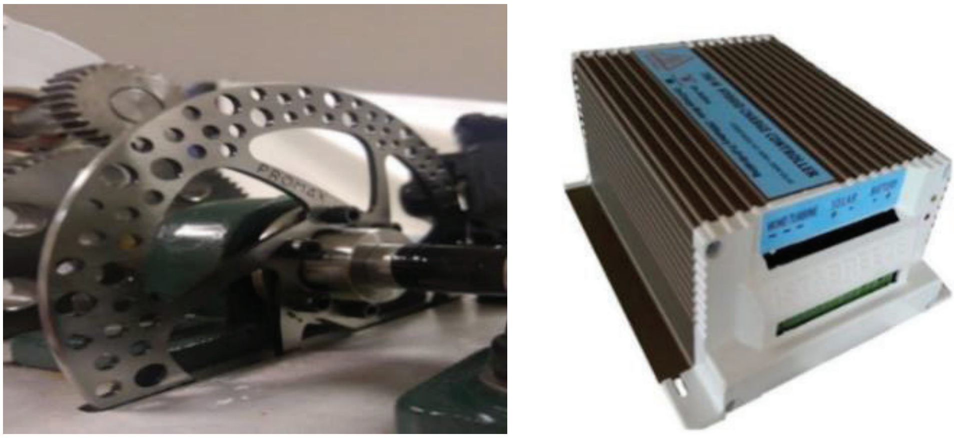


Figure 21. Brake control systems

3.5. The blade and rotor system selection

The components of the wind turbine blades catch the kinetic energy of the wind. In a wind turbine, the material from which the blades are produced must be light, robust with a high corrosion resistance and strength. In this study, composite performance blades that are 103 cm in length and 650 g in weight containing 30% fiber and 70% polypropylene fiber and glass fiber were used. The following figure shows initial appearance of the rotor design and turbine.

Figure 22. Designed and manufactured rotor turbine

3.6. Assembly phase of the turbine design

The assembly of the wind turbine is the most important part in the design process. The manufactured and supplied parts must be combined with great care and calculation. First, the assembly was commenced on the support plate with alternators, bearing, brake disc and the assembly of the shafts, then continued with the assembly of the router. The center of gravity is calculated after the parts on the plate support have been assembled. Following the finding of the center of gravity, the bearing fixture that enables the rotation of the turbine for 360^0 is fixed to the support plate first. Finally, the connection to the turbine pole is provided. A slip ring system was added to prevent the alternator cables from tangling during rotating motion. The final assembly of the turbine is shown below.

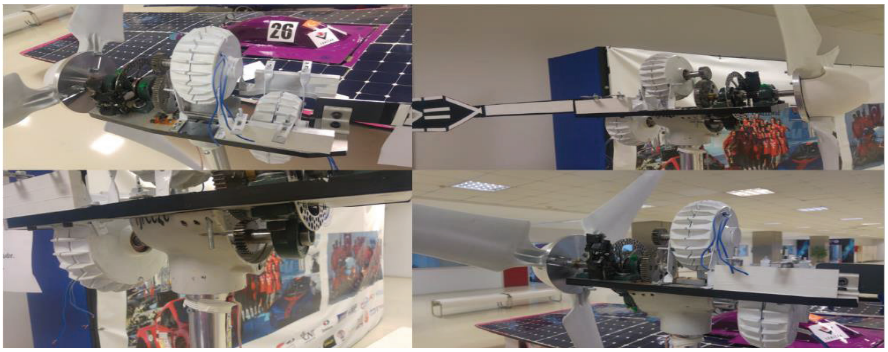


Figure 23. Final assembly of the wind turbine

4. Conclusion

In this study, a wind turbine was both designed and manufactured in 1 kW power. During the design phase, the necessary calculations were conducted, and it has been noted that all the connecting elements are dimensionally compatible with each other. Each part was individually designed and then put in the computer-based assembly phase. AH79-100C was selected as the blade profile according to the UIUC data for evaluating turbine blade performance flow analysis. The blade performance analysis was performed to observe the distribution of the air around the blade as well as the torque and power on the turbine. As a result of the flow analysis, it was observed that the pressure change increased as it got to the front of the rotor and it fell as it passed to the back of the rotor. The velocity of the air rises at high speeds on the blade tips and around the rotor, but it appears to have decreased for it is captured by the rotor, the kinetic energy of the air behind the rotor. A wind turbine prototype was manufactured with the same dimensions following the design and simulation studies. The technical drawings of the parts to be manufactured during the production phase were created and parts were manufactured using turning, milling, laser cutting, spiral cutting, sawing processes. The other materials were supplied in accordance with the system. Bearing was made to prevent the vibration of the shafts that receive the rotor movement during the assembly phase. The grub screws connection element was used for fixating the gears to the shafts. The turbine's operability was observed and tested following the completion of the assembly process. The stages of design, calculations and production are provided above step by step.

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