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Design of micro-scale wind power plant with vertical axis wind turbine darrieus type-H

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Abstract

In Medan Belawan District, Medan City, Indonesia, where average wind speeds are higher than in other districts, this proposal intends to build and simulate straight-blade wind turbines for use in micro-scale wind power plants as an alternative energy source. Given that the average annual wind speed in Medan Belawan District, Medan City, is 2.5 m/s, a wind turbine of the Darrieus rotor type-H, which is appropriate for regions with low wind speeds and fluctuating wind directions, can be developed. According to the design results, the turbine's height is 2.8 meters, and its diameter is 3.36 meters. Two Computational Fluid Dynamics (CFD) simulations of the turbine design were performed. In our conclusion, using SolidWorks software, the first generated a torque of 45.28 Nm, an average electrical power of 134.78 Watts, and a mechanical power of 168.48 Watts. The second generated an average mechanical power of 175.77 Watts, an average electrical power of 140.61 Watts, and a torque of 47.25 Nm using Ansys Fluent software.

Keywords: Micro-scale power plant, Vertical axis wind turbine Darrieus.

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1. Introduction

The Indonesian government has made a policy to secure energy availability in Indonesia, along with the increasing population and the need for energy in the economic industry. One of the policies implemented was issuing Government Regulation No. 79 of 2014 concerning the National Energy Policy, which regulates the management of renewable energy [1-4]. Along with population growth and the progress of Indonesia's industry, the need for energy has also increased. Indonesia has relied on fossil fuels (petroleum, natural gas, and coal) for years to meet its energy needs. The country's dependence on fossil fuels has resulted in problems concerning environmental pollution and energy security. Therefore, a 2050 net zero emission scenario was created to transition from fossil-based energy to clean, renewable energy that does not cause greenhouse gas effects and is also available in large quantities. To achieve this net zero emission scenario, renewable energy, especially wind and water, has begun to be developed. Wind is an abundant renewable energy source, and its use does not cause air pollution, which can lead to the greenhouse effect. One of the uses of wind energy is a wind turbine coupled with a generator, which converts the wind's kinetic energy into electrical energy. Medan City is located at coordinates 3° 27' – 3° 47' North Latitude and 98° 35'–98° 44' East Longitude. Medan City is the fourth most densely populated city in Indonesia. With the dense population of Medan City, almost everyone uses electrical equipment for their daily activities. Medan City has 21 sub-districts, one of which is on the coast, namely Medan Belawan Sub-district, which has a higher wind speed than other sub-districts. The temperature in this city averages around 27 degrees Celsius throughout the year, with the highest average wind speed being 3.34 m/s [5, 6].

Referring to previous research on the aerodynamic analysis of blades in small-scale vertical axis wind turbines (VAWT) using analytical techniques and CFD methods, the blade design parameters and dimensions were taken to produce the required power output. Analytical models were developed to evaluate the aerodynamic forces, such as lift and drag on the blade surface. These forces, which are very helpful for evaluating the structural integrity of the VAWT blade, were then found to be in good agreement with the CFD results simulated using the software [7]. Previous research employed analytical and numerical modeling methods to determine blade design parameters, such as solidity, aspect ratio, and pressure coefficient, targeting a power output of 1 kW. The blade design was then analyzed under extreme wind conditions, where the maximum values of deflection and bending stress were determined at the peak values of aerodynamic and centrifugal forces. The design was meticulously optimized to achieve structural strength, specifically reducing deflection and bending stress. This resulted in a blade design with high strength and lower material consumption, contributing to the cost-effectiveness of the wind turbine rotor assembly, which covers more than 50% of the total cost of the wind turbine. The study successfully produced a turgo turbine with a radius of 60 mm, generating 477.7 watts of power with an efficiency of 85.97% [8]. Previous research further used the turbulence model k—ωSST to simulate the turbulence flow regime and the CFD method. This study involves highway traffic conditions to harvest energy from moving vehicles to produce a wind turbine. It is concluded that the three-blade Darrieus wind turbine is very efficient and easy to affect when vehicles are moving [9].

Based on previous studies and the problems that have been explained, the author made a Darrieus turbine design type-H, where this turbine is made of three-blade aluminum and formed according to the airfoil profile so that it is more efficient and capable of producing maximum power for a micro-scale wind power plant using the Computational Fluid Dynamics (CFD) method and the development of a solid blade model. The design utilizes SolidWorks simulation and ANSYS Fluent software to obtain the turbine's torque and large mechanical and electrical power capacity.

The paper is organized as follows: the methodology is presented in Section 2, including the initial values of turbine parameters and the wind turbine design flowchart for a micro-scale wind power plant. The results in Section 3 discuss various topics starting from the initial conditions, the basics of wind turbine selection, turbine power calculation, Darrieus VAWT turbine design Type-H, turbine blade design, Darrieus Type-H VAWT turbine support mast design, flow simulation of the Darrieus Type-H VAWT turbine, designing the computational domain of a Darrieus Type-H VAWT turbine, SolidWorks simulation of the Darrieus Type-H VAWT turbine, ANSYS Fluent simulation of the VAWT Darrieus turbine Type-H, and simulation output power results. Finally, conclusions are drawn in Section 4.

2. Methodology

After obtaining the average wind speed value in Medan City, Medan Belawan District, North Sumatra, verification is needed to determine the optimum number of blades and the type of turbine blades designed. A wind turbine with three blades produces a higher rotational speed and tip speed ratio than a wind turbine with two and four blades [10, 11]. Furthermore, the type of blade selected is the NACA-0012 Airfoil, whose aerodynamic characteristics have been determined using the airfoil property synthesizer code [12-15]. This profile is one of the thinnest available (12% of Chord). Compared to the NACA-0015 (15% thickness of Chord), the rotational ability is increased with a thinner airfoil [16-18]. The next turbine parameters are based on manual calculations based on the average wind speed at the research site, as in Table 1.

Table 1.
Initial values of turbine parameters.

Parameter	Symbol	Calculation Value
Wind velocity	V_{in}	2.5 m/s
Turbine Height	H	2.8 m
Turbine Diameter	D	2.4 m
Chord	C	0.3 m
Number of Blades	N	3
Tip Speed Ratio	TSR	2.5
Turbine Leg/Pole Height	H_L	5.2 m

After manual calculations and designing a wind turbine according to the parameters, it is necessary to simulate the turbine on the software to get valid results. Then, the flow diagram of the Darrieus Type-H VAWT turbine design for a micro-scale wind power plant [19-21] is shown in Figure 1.

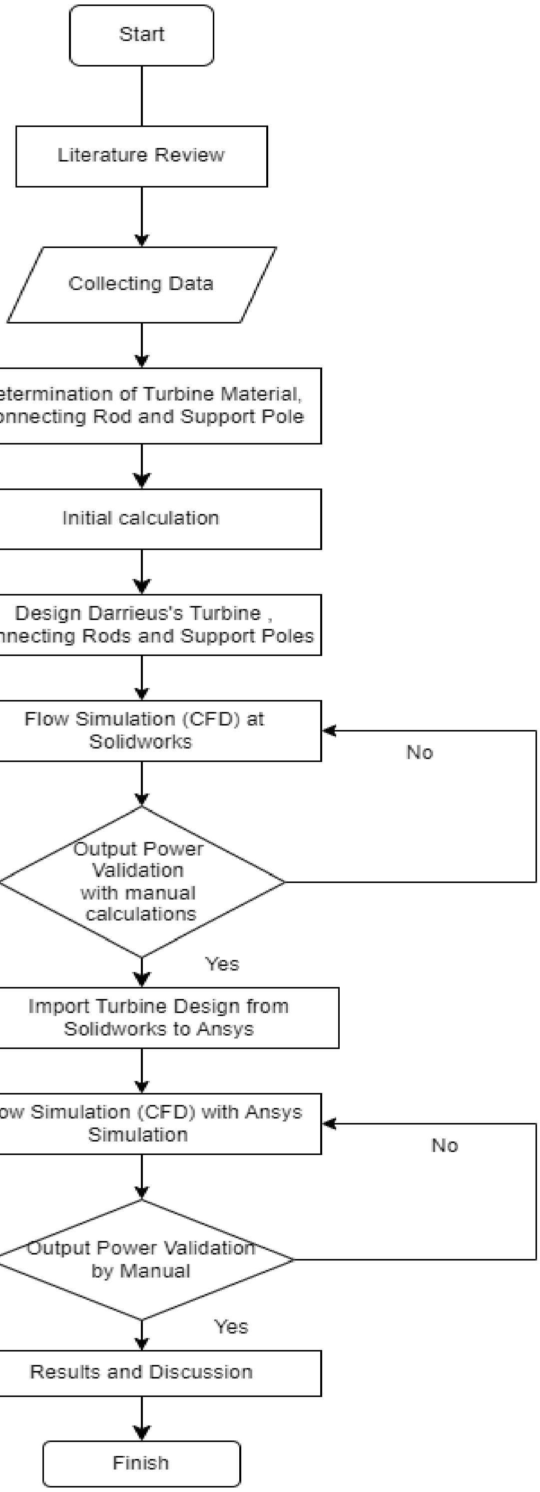

Figure 1.
Wind turbine design flowchart for micro-scale wind power plant.

3. Results

3.1. Initial Condition

After collecting average wind speed data through the Meteorology, Climatology, and Geophysics Agency station, daily wind speed data was obtained in Medan Belawan District, Medan City, North Sumatra Province, Indonesia, in 2023 [5, 22-24] as shown in Table 2. Based on Table 2, the average wind speed data frequently observed in Medan Belawan District, Medan City, is grouped and calculated. Therefore, the average wind speed in this area is set at 2.5 m/s.

Table 2.
Average wind speed data in Medan city in 2023.

Date	Wind speed in 2023 (m/s)											
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agu	Sep	Oct	Nov	Des
1	3	2	1	1	2	2	2	2	1	2	3	3
2	2	2	3	2	3	2	2	2	3	3	2	1
3	2	2	2	1	2	2	2	4	1	2	2	2
4	2	3	2	4	3	3	2	2	1	2	2	2
5	2	1	2	2	1	2	2	2	3	2	2	2
6	3	2	3	1	3	2	2	2	2	2	1	1
7	2	2	2	2	2	2	2	2	2	2	1	2
8	2	2	1	2	3	2	2	2	1	2	2	1
9	2	1	1	2	2	2	1	2	2	2	1	2
10	3	3	2	2	3	2	2	2	4	1	2	1
11	1	1	2	1	2	2	2	3	2	2	4	3
12	2	2	1	2	4	2	2	2	3	2	2	2
13	2	2	2	2	2	2	2	2	3	2	2	2
14	2	3	2	2	1	3	1	2	1	2	1	2
15	4	2	3	2	2	2	2	4	2	1	1	2
16	2	2	3	2	2	2	2	2	3	1	2	3
17	2	2	2	4	2	2	3	3	2	1	2	2
18	2	2	4	2	1	1	2	2	2	2	2	2
19	2	3	2	2	2	3	3	2	2	2	2	1
20	2	2	2	2	2	2	3	2	1	1	4	1
21	3	2	2	2	2	2	3	3	1	2	2	3
22	2	2	2	1	1	1	3	3	1	1	2	2
23	2	2	1	3	2	2	2	2	1	3	2	2
24	1	2	2	1	2	4	3	1	1	1	1	3
25	3	2	2	3	2	2	2	2	2	2	2	2
26	2	2	4	1	2	1	2	3	2	2	4	2
27	2	2	1	2	2	2	2	2	2	2	2	1
28	2	2	2	3	2	4	2	4	3	2	2	3
29	3	-	2	1	2	2	5	2	2	1	1	2
30	2	-	2	1	2	2	2	2	2	2	2	1
31	1	-	3	-	2	-	2	2	-	1	-	2

3.1.1. Basics of wind turbine selection

There are two types of wind turbines, the HAWT type [25-27] and the VAWT type [28-31] which are distinguished based on the turbine shaft and rotor. The wind turbine chosen is the VAWT wind turbine, which, based on literature studies, is more efficient in areas with wind directions that are not in one direction, such as in densely populated areas and buildings. So that the wind coming from all directions can be utilized with the VAWT turbine, the VAWT-type turbine used is the Darrieus H-type turbine, which has a simple construction and is arranged like the letter H, so it is suitable for micro-scale generators. It can withstand the strength of the incoming wind.

3.1.2. Turbine power calculation

The wind turbine design produced an output power of 200 watts at a wind speed of 2.5 m/s. This power is relatively small on a micro scale but is still useful for households that require small amounts of power. Our calculations indicate that the turbine will produce a minimum power of 100 W at a wind speed of 2 m/s. We've also determined the optimum turbine height and diameter to ensure stability and maximum power output. For instance, the comparison between the turbine rotor's diameter and height for stability, known as D/H, is 1.2.

$$A_{swept} = \pi \times D \times H \quad (1)$$

$$= \pi \times 1.2 \times H^2$$

$$P = 0.5 \times A_{swept} \times \rho_{air} \times v^3 \quad (2)$$

$$100 = 0.5 \times 1.225 \times \pi \times 1.2 \times H^2 \times 2^3$$

$$100 = H^2 \times 18.4632$$

$$H = 0.5 \left(\frac{100}{18.4632}\right)$$

$$H = 2.8\, m$$

Then, the rotor blade diameter can be calculated by

$$D = 1.2\, H \quad (3)$$

$D = 1.2 \times 2.8$

$D = 3.4$ m

After obtaining the height and diameter of the blade, the next step is to calculate the swept area of the blade by

$$A_{swept} = \pi \times D \times H \quad (4)$$

$A_{swept} = 22/7 \times 3.4 \times 2.8$

$A_{swept} = 29.92\ m^2$

Based on the average wind speed data in Medan City, the average wind speed is 2.5 m/s, so the maximum power that can be extracted at this wind speed is

$$P_w = 0.5 \times A_{swept} \times \rho_{udara} \times v^3 \quad (5)$$

$P_w = 0.5 \times 1.225 \times 29.92 \times 2.5^3$

$P_w = 286.34$ W

Next, determine the Tip Speed Ratio (TSR) of the H Darrieus turbine rotor, where the TSR can be determined in advance without a calculation process because the turbine rotation number parameter is not yet known. The amount of TSR on the Darrieus wind turbine that can be selected ranges from 2 to 5. For the design of this wind turbine, the TSR value is determined to be 2.5. Then, the number of turbine rotations can be calculated by.

$$\omega = \frac{TSR \times V_{in}}{R} \quad (6)$$

$\omega = \frac{2.5 \times 2.5}{1.68}$

$\omega = 3.72$ rad/s

Then, to calculate the efficiency of the wind turbine, enter the turbine TSR value using the following formula

$$\eta_\omega = 0.399 + 0.055\,\lambda \quad (7)$$

$\eta_\omega = 0.399 + 0.055 \times 6$

$\eta_\omega = 0.729$

$\eta_\omega = 72.9\ \%$

Once the efficiency of the wind turbine is obtained, the power on the turbine shaft can be calculated based on this efficiency

$$P_{poros} = P_w \times \eta_\omega \quad (8)$$

$P_{poros} = 286.34 \times 72.9\ \%$

$P_{poros} = 208.74$ W

The efficiency of the PMSG generator (η) is 80%, so the electrical power produced by the generator can be calculated by

$$P_{elektris} = P_{poros} \times \eta_{generator} \quad (9)$$

$P_{elektris} = 208.74 \times 80\ \%$

$P_{elektris} = 166.99$ W

Then, the turbine's electrical power is obtained at 166.99 W. Furthermore, the rotor solidity, or the ratio of the blade area to the blade path area, greatly affects the torque experienced by the turbine. The higher the turbine solidity, the greater the torque produced by the turbine, and consequently, the higher the turbine's output power. A good solidity value for a vertical wind turbine is 0.4. After determining the solidity value, the next step is to calculate the Chord Blade using the formula.

$$\sigma = \frac{n \times C}{D} \quad (10)$$

$0.4 = \frac{3 \times C}{3.36}$

$C = 0.44$ m

3.2. Darrieus VAWT Turbine Design Type-H

3.2.1. Turbine Blade Design

The wind turbine design begins by determining the blade type. The blade chosen is the NACA-0012 airfoil type, with a length of 2.8 m and a width of 0.448 m. Furthermore, a stick is also made, which is used to strengthen the blade, connect it to the turbine shaft, and adjust the blade pitch angle. After obtaining the desired design image, the design is drawn using SolidWorks software in three dimensions. The 3D design results in SolidWorks show the details and dimensions of the CAD design of the airfoil shown in Figure 2.

Figure 2.
Design of 3D Airfoil NACA-0012.

The most important thing for turbine performance is choosing a blade material that is lightweight, corrosion-resistant, and inexpensive. In this case, aluminum is chosen because it is not only lightweight but also recyclable, making it safe for the environment. Figure 3 shows a connecting rod, one of the design's important components. The spacer material must be strong, light, and corrosion-resistant. Three recommended materials for this purpose are steel, aluminum, and carbon. Stainless steel is the most expensive, while carbon tends to rust due to water and humidity. Based on the data, neither material is suitable for operation, so aluminum was chosen for the blade connecting rod.

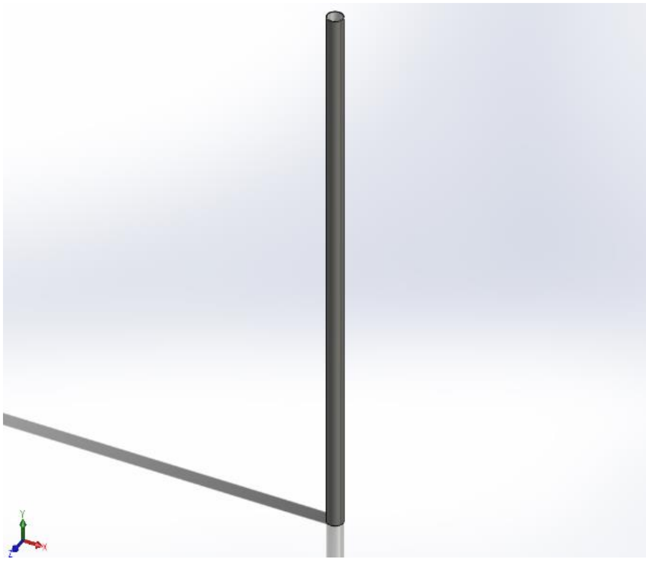

Figure 3.
Blade connecting stick design.

3.2.2. Darrieus Type-H VAWT Turbine Support Mast Design

Although not discussed, the turbine support leg or pole needs to be designed. The standard height of the support pole used for this turbine follows the standard in Medan Belawan District, Medan City, which is a minimum of 5 meters, while the designed and calculated shear stress pole is 5.2 meters high. Steel or iron is chosen as the material for the support pole, which has resistance to the pressure caused by the turbine when it rotates. The shape of the turbine leg is depicted in Figure 4. After all the parts have been designed, the next step is to assemble them to create a sturdy design that can be used in simulations later. The results of the assembly part design for the Darrieus Type-H VAWT wind turbine are shown in Figure 5.

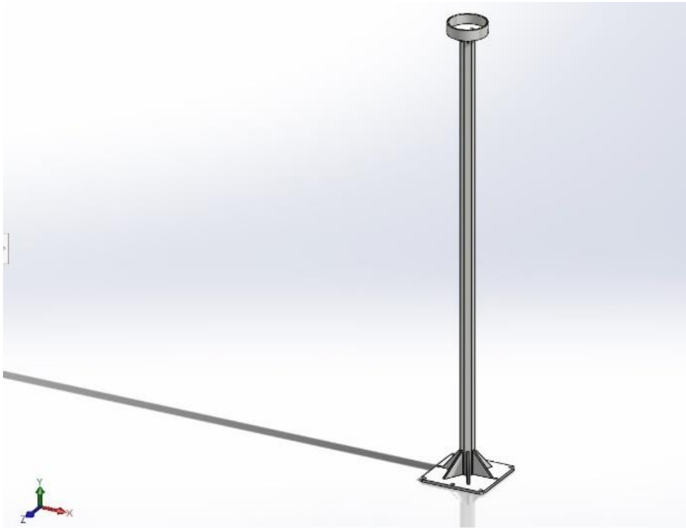

Figure 4.
Design of turbine support pole/leg.

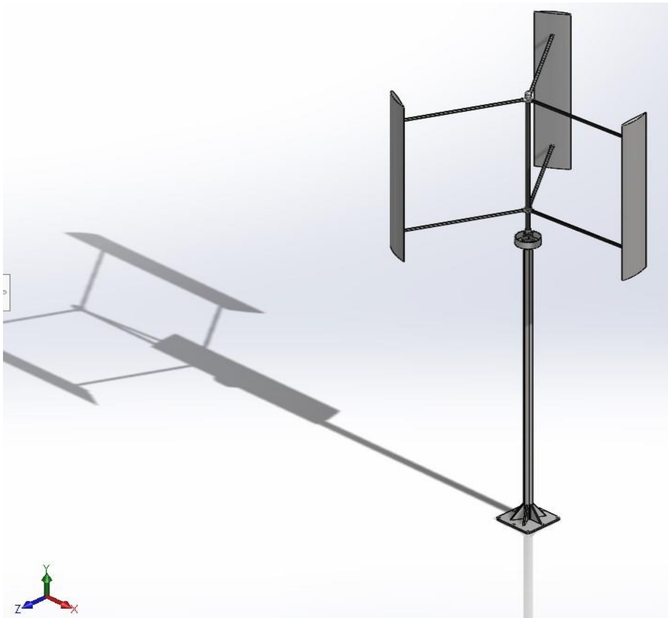

Figure 5.
Design of turbine support pole/leg.

3.3. Flow simulation of Darrieus Type-H VAWT turbine

3.3.1. Designing the computational domain of a Darrieus Type-H VAWT turbine

After the VAWT wind turbine design is completed, the next step is to carry out a flow simulation using Computational Fluid Dynamics (CFD). This process begins by designing its domain. The CFD domain of the turbine is a part of the space where the CFD simulation solution is calculated. The computational domain must be discretized into a computational grid (mesh) to solve the discretized fluid flow equations. CFD simulation of the flow around a geometric object, referred to as 'geometry', is necessary for external aerodynamics. Therefore, the computational domain is a volume with sufficient dimensions around the desired geometry. Meanwhile, in internal flow, the computational domain is determined by the boundaries of the geometry itself, and the space inside the geometry is discretized. The size of the domain and mesh used to adjust the range for the flow simulation, which will require space to accommodate the incoming wind and provide room for the turbine to rotate and for the wind to flow over the turbine blades. Tables 3 and 4 show the design size of the computational domain and the turbine mesh designed in SolidWorks.

Table 3.
Turbine computational domain size.

X min	-6.727 m
X max	3.805 m
Y min	0.066 m
Y max	2.994 m
Z min	-2.799 m
Z max	2.799 m
X size	10.532 m
Y size	2.929 m
Z size	5.597 m

Table 4.
Mesh dimensions.

Number of cells in X	26
Number of cells in Y	10
Number of cells in Z	14

After designing the mesh, the next step is to set the air conditions that will be used in the simulation, where the air pressure is 0.101325 MPa and the air temperature is 20.05 °C. The wind speed that rotates the turbine is set at 2.50 m/s (in the X direction) in the simulation goals. One of the key technologies in SOLIDWORKS Flow Simulation is a concept in the software called Goals. Goals in SOLIDWORKS Flow Simulation have three purposes:

- Defining Design Objectives and/or other important criteria
- Used for Convergence Control
- Complete the calculation

There are two Goals used in this simulation: Global Goals and Surface Goals. Global Goals are physical parameters that are calculated throughout the Computational Domain, namely a box that includes the entire volume of fluid and/or temperature where the solution is solved. The Global Goals settings used are as in Tables 5 and 6.

Table 5.
Average Speed.

Type	**Global Goal**
Goal type	Velocity
Calculate	Average value
Coordinate system	Global coordinate system
Criteria	1.00 m/s
Use in convergence	On

Table 6.
Average turbulence intensity.

Type	**Global Goal**
Goal type	Turbulence Length
Calculate	Average value
Coordinate system	Global coordinate system
Criteria	1.000 m
Use in convergence	On

Next, Surface Goals are parameters on the selected surface. Often, one of the inlet or outlet boundary conditions is selected to be used as the surface for this type of target. Surface targets are very useful for obtaining pressure drops so that they can request min, average, max, or mass values on the surface. The Surface Goals settings used are in Tables 7, 8, and 9. Finally, the design and mesh setting are imported to perform the simulation; the mesh setting used in the turbine design is shown in Figure 6.

Table 7.
Average turbulence intensity.

Type	**Surface Goal**
Goal type	Total Pressure
Calculate	Maximum value
Faces	*Blade*
Coordinate system	Global coordinate system
Criteria	1.000000e-06 MPa
Use in convergence	On

Table 8.
Average turbulence intensity.

Type	Surface Goal
Goal type	Torque (Y)
Faces	Turbine
Coordinate system	Global coordinate system
Criteria	1.000 N*m
Use in convergence	On

Table 9.
Average turbulence intensity.

Type	Surface Goal
Goal type	*Force*
Faces	*Blade*
Coordinate system	Global coordinate system
Criteria	1.000 N
Use in convergence	On

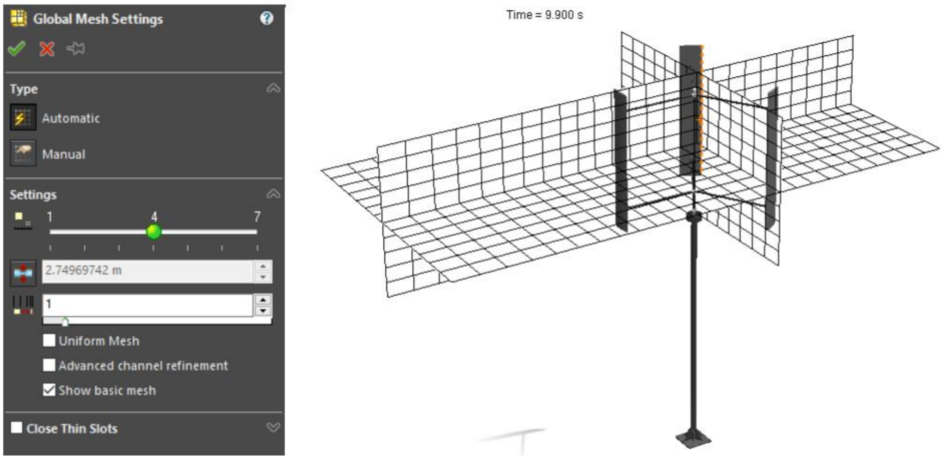

Figure 6.
Design of turbine support pole/leg.

3.3.2. Solidworks simulation of Darrieus Type-H VAWT turbine

After the Domain and Mesh are designed, the flow simulation can be done with Solidworks software. The simulation results obtained from the Flow Simulation of the Darrieus Type-H VAWT turbine are shown in Figure 7. In Figure 7, 120 initial iterations of Solidworks software are shown to determine the average simulation results for turbine rotational speed, turbine force, maximum total pressure, turbulence, and turbine torque. The graph is not yet stable, so the overall simulation results cannot be determined. Only the average turbine speed stabilized at the 61st iteration.

Next, the final simulation results shown present the overall simulation results where the graph is stable, and the iteration point has been determined as in Figure 8. In Figure 8, the simulation shows the results of the final 100 iterations of 1000 iterations carried out to determine the average or stability of the graph so that the respective values for turbine rotational speed, turbine force, maximum total pressure, turbulence, and turbine torque can be determined.

After the simulation is carried out, the flow simulation results can be seen in the progress description. Still, the results are in a graph that makes it easier to read the flow simulation values for each parameter whose results you want to know, as in Figure 9. In Figure 9, the graph shows the average speed experienced by the turbine immediately after the wind rotates it. The wind speed of 2.5 m/s will rotate the turbine, and the turbine will rotate at a nominal speed (Vn) of 2.119 m/s at the 61st iteration. The average speed of the turbine can be seen in the graph, ranging from 2.11 to 2.15 m/s.

Next, Figure 10 shows the simulation result graph for the average turbulence experienced by the turbine during Flow Simulation. From the graph, it can be seen that the turbulence experienced by the turbine has not changed drastically when the simulation reaches the 201st iteration of 0.0282 m, after which the turbine turbulence is small and the airflow around the turbine is regular.

Next, in Figure 11, the graph shows the total maximum pressure experienced by the turbine. The pressure does not change drastically from the 750th iteration to the 1000th iteration, where the total maximum pressure experienced by the turbine is no more than the value of the 963rd iteration, which is 0.101615 Mpa. The greater the total pressure experienced by the turbine, the smaller the turbine RPM, thus affecting the power produced by the turbine to rotate the generator.

Figure 12 shows the graph showing the results of the simulation of the aerodynamic force experienced by the turbine when rotating, which is 59.89 N at the 998th iteration. This aerodynamic force drives the turbine, both in terms of lift and drag.

Next, in Figure 13, the graph shows the highest turbine torque, 83.06 Nm, at the 21st iteration and the average, 45.28 Nm, at the 966th iteration. The selected torque is the average torque because the calculated power is the average power generated by the wind turbine.

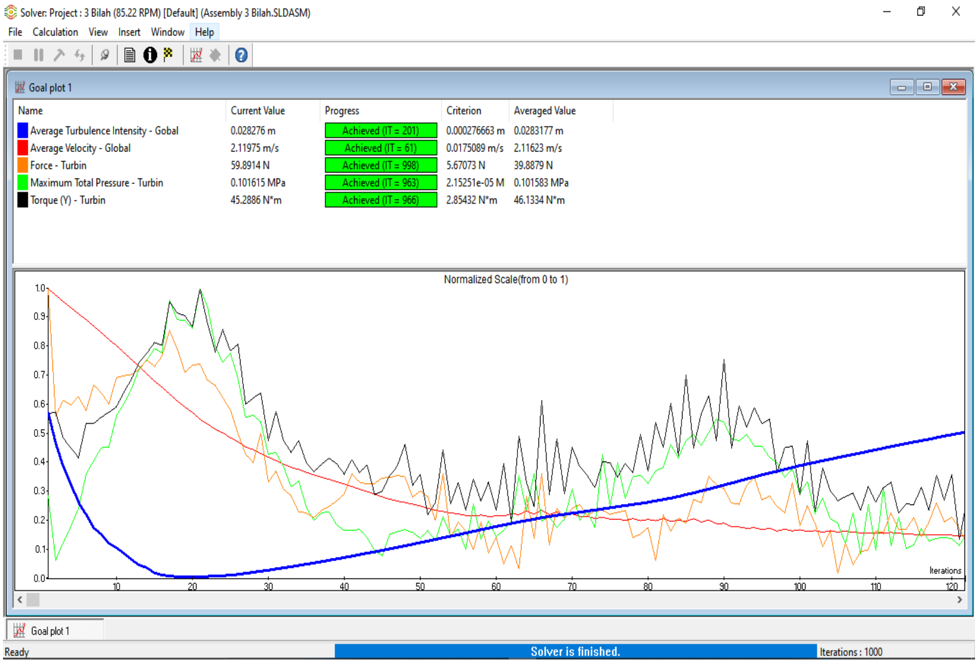

Figure 7.
Flow simulation results of the Darrieus VAWT turbine Type-H 120 in the initial iteration.

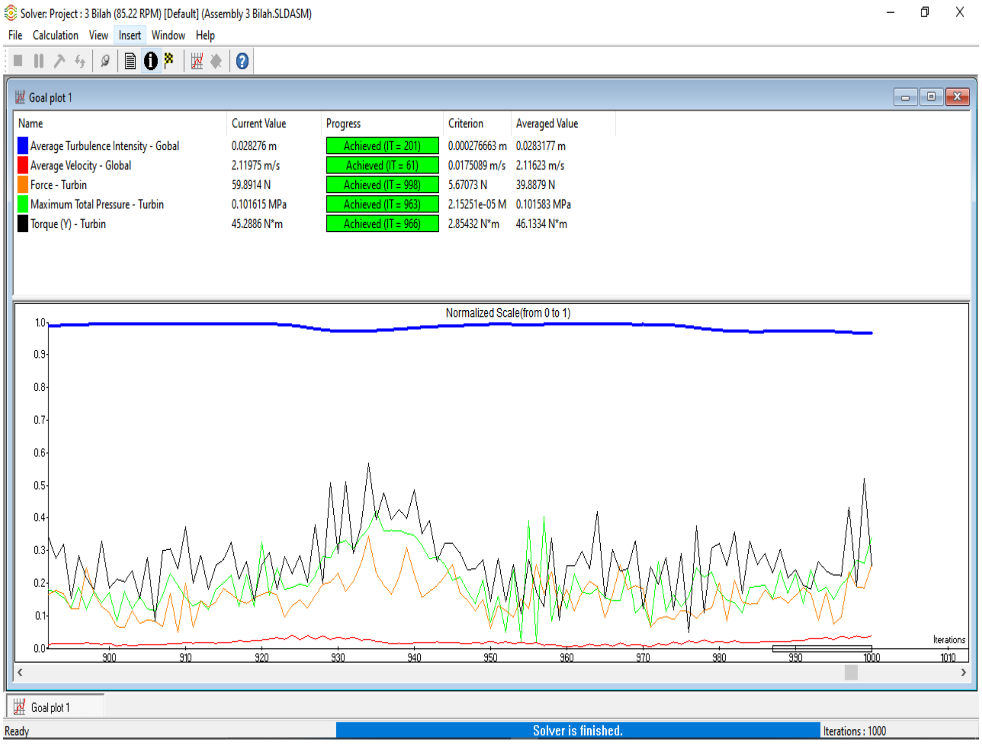

Figure 8.
Flow simulation results of the Darrieus VAWT turbine Type-H 100 in the final iteration.

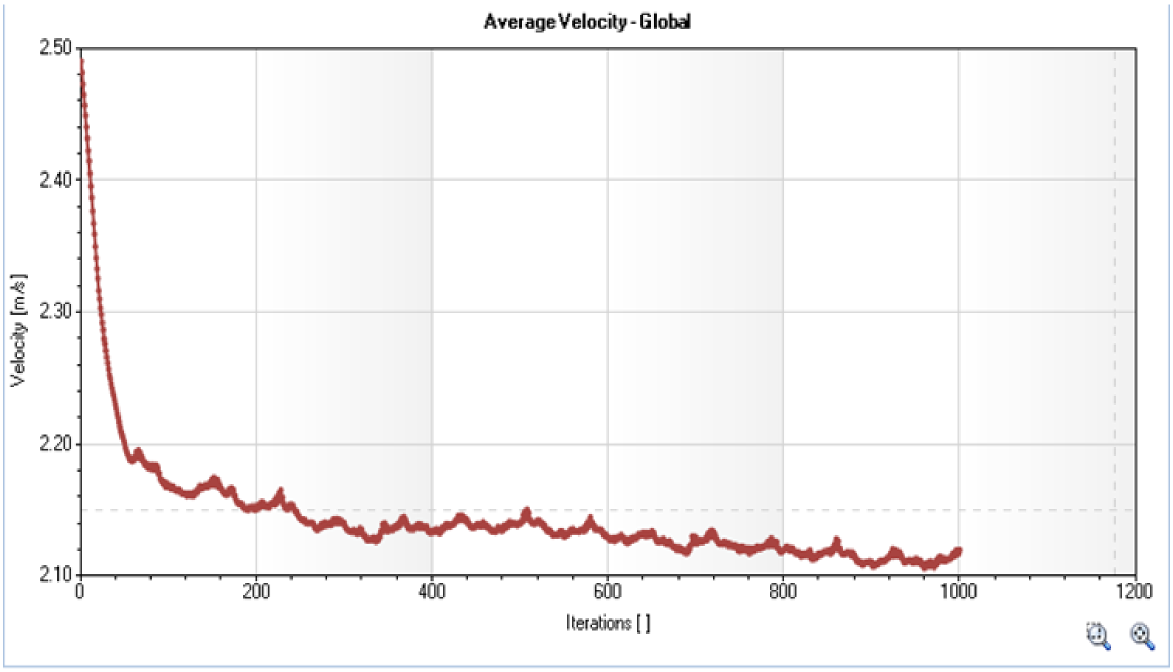

Figure 9.
Average Speed Simulation Result Graph.

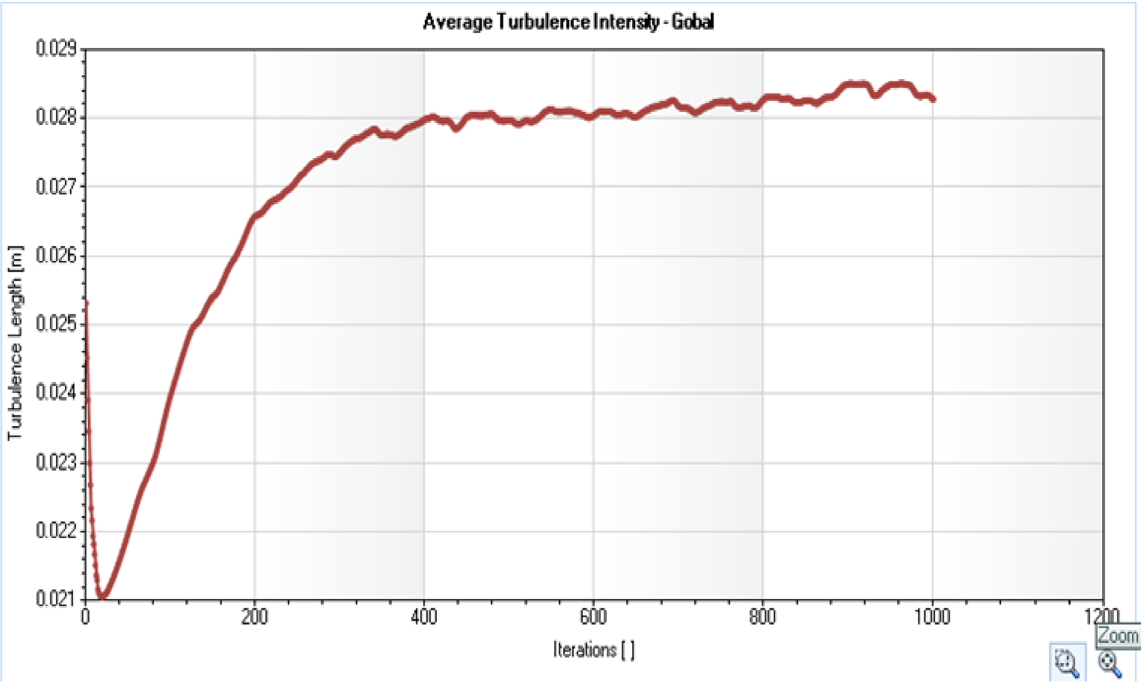

Figure 10.
Average turbulence intensity simulation result graph.

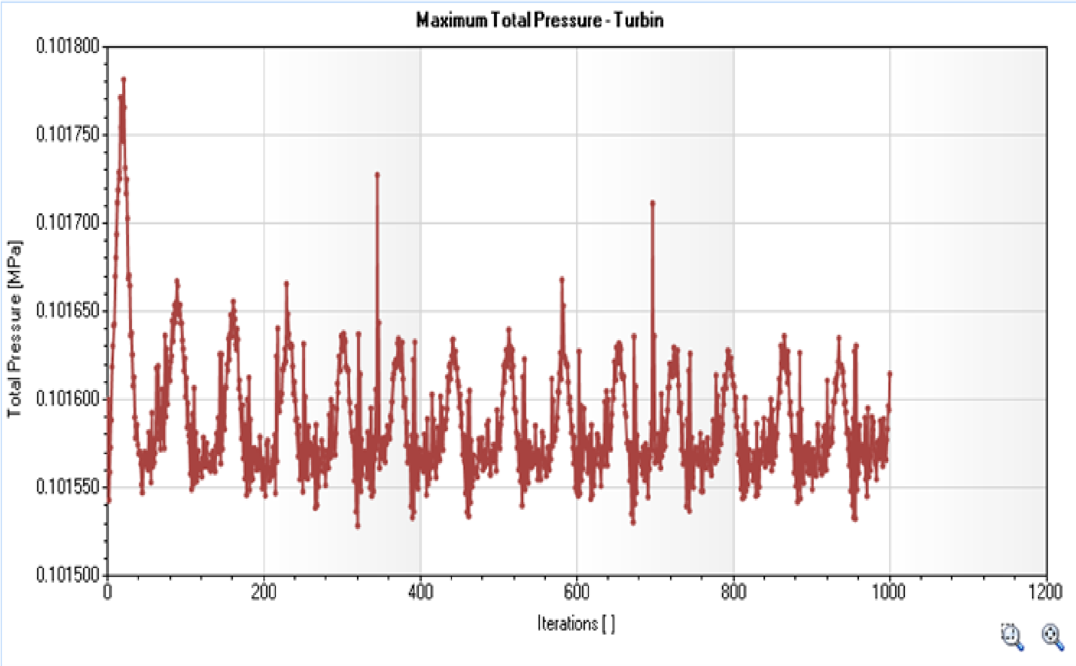

Figure 11.
Simulation results of the total maximum turbine pressure.

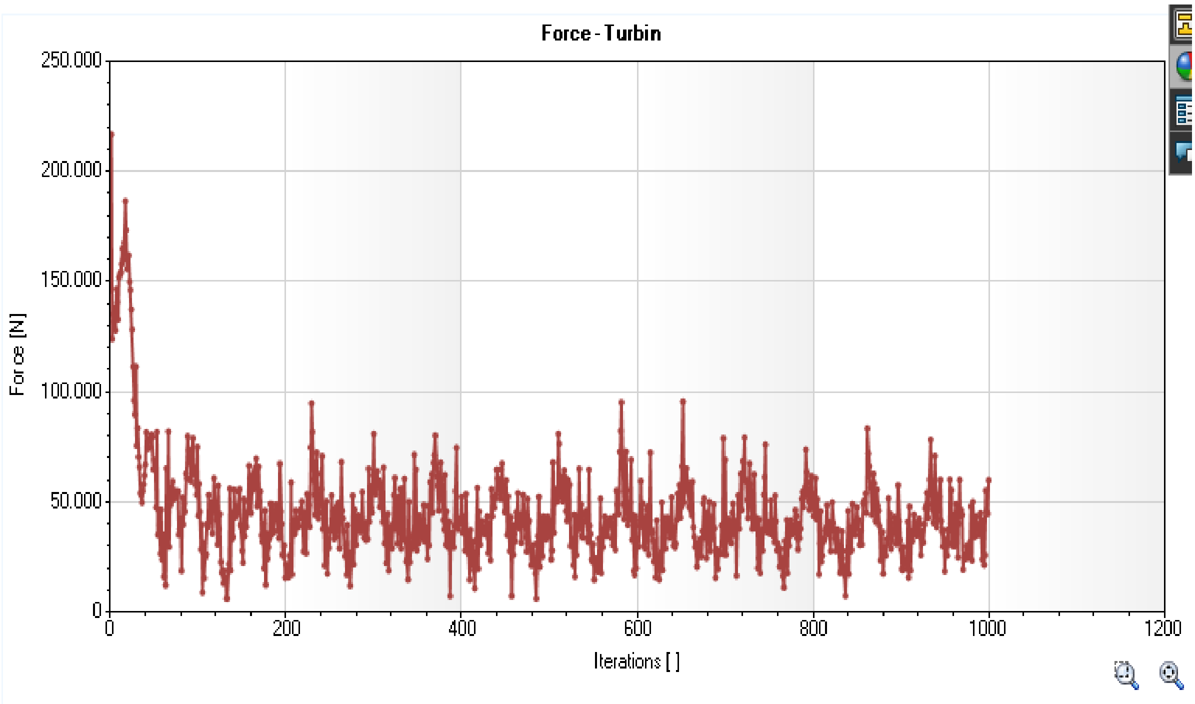

Figure 12.
Turbine force simulation result graph.

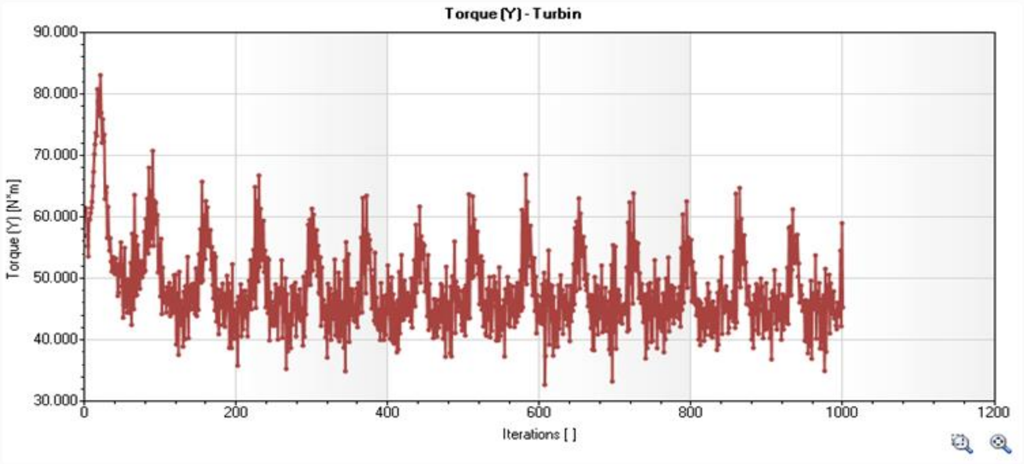

Figure 13.
Turbine torque simulation result graph.

3.3.3. *ANSYS Fluent Simulation of VAWT Darrieus Turbine Type-H*

After Flow Simulation is done with Solidworks software, it needs to be verified with Flow Simulation with Ansys Workbench software, where this software is specifically for Flow Simulation. In Ansys Workbench, it is also necessary to design the domain and mesh used for flow simulation so that the design from Solidworks can be directly simulated. The following are the Domain and Mesh models for the Darrieus Type-H VAWT Turbine simulation in Figures 14 and 15.

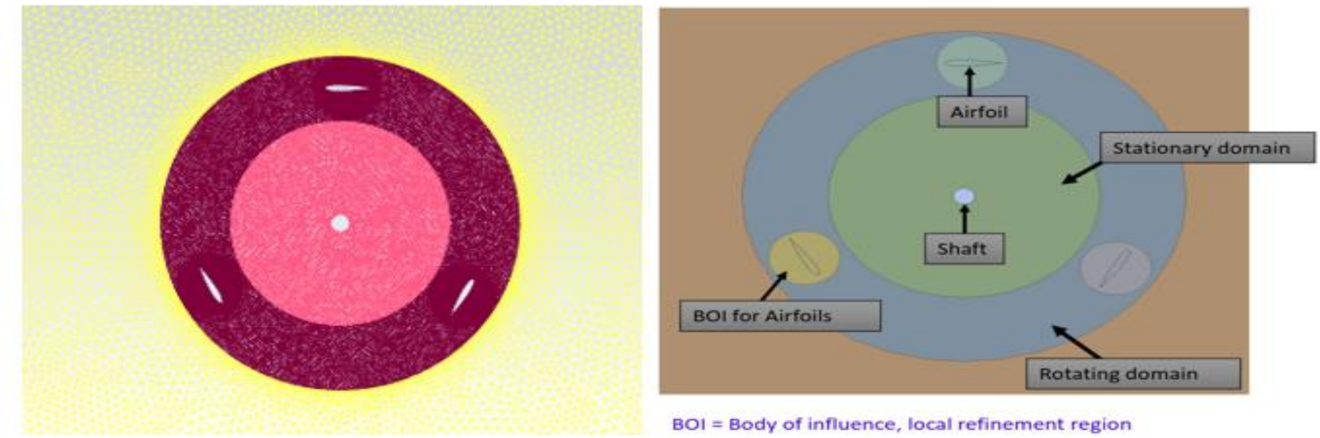

Figure 14.
Design of turbine domain model.

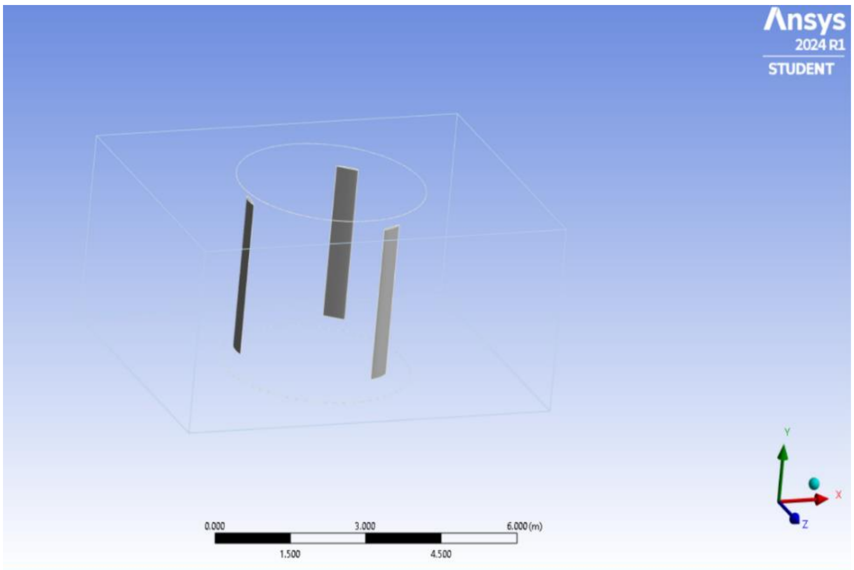

Figure 15.
Design of the simulation mesh model.

It can be seen in Figures 14 and 15 that the design only creates a blade model without a connecting stick and shaft because it reduces the computer load during simulation with Ansys Software. Reducing the stick and shaft will not affect the simulation results if with the stick and shaft because the stick and shaft are inside the turbine or Blade, and both are small in size. A simulation can be carried out after designing the Domain and Mesh models for turbine simulation. The simulation results obtained from the Flow Simulation of the Darrieus Type-H VAWT turbine with Ansys Workbench Software are seen in Figure 16.

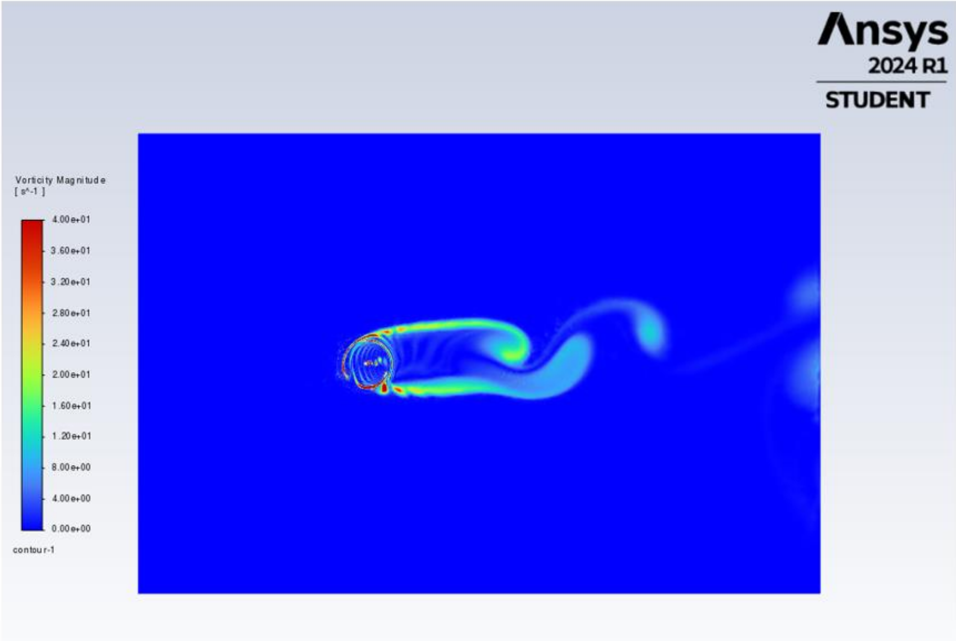

Figure 16.
Flow simulation results in the form of vortex shedding.

In Figure 16, vortex shedding is a form of wind flow in which the wind blows across a part of the turbine/blade structure. The vortex is shed alternately from one side of the blade to the other side of the blade, and alternating low-pressure zones are generated on the downwind side of the structure, causing fluctuating forces acting at right angles to the wind direction. Furthermore, the flow simulation result data was also obtained using Ansys Workbench.

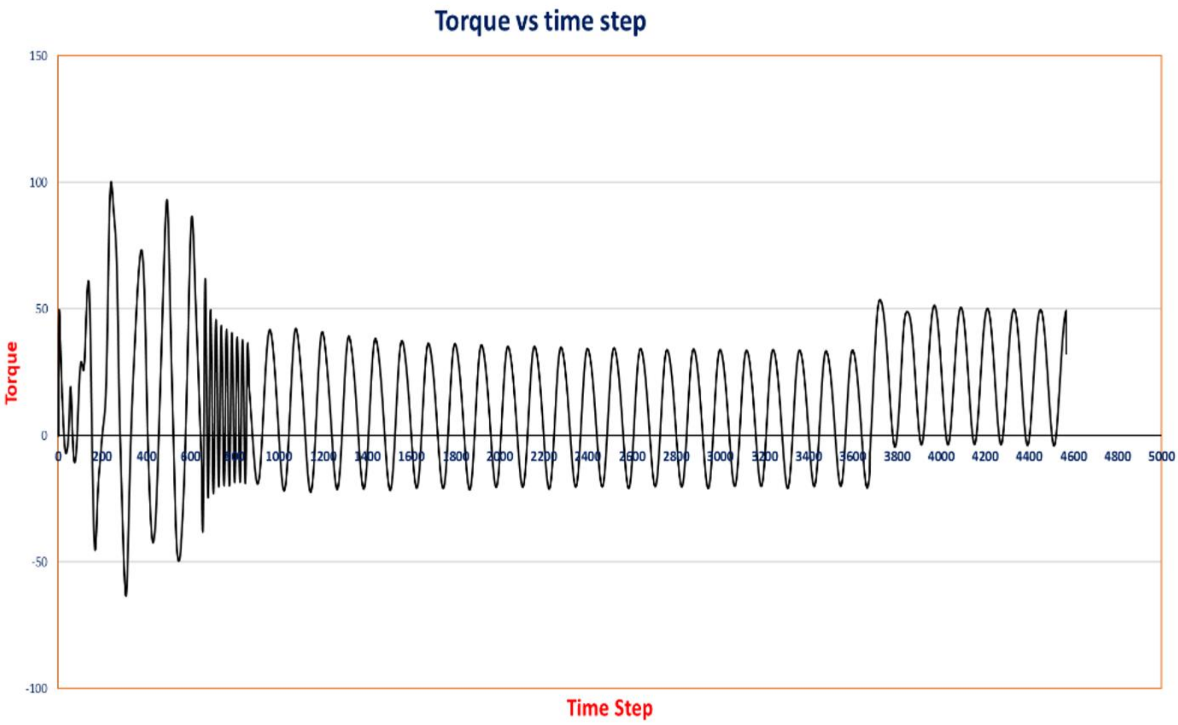

Figure 17.
Torque versus time graph.

Figure 17 shows that the graph is initially irregular or called Initial Transient, which means the beginning of the change where parameters such as pressure, speed, and others begin to affect the turbine torque. This initial transient is part of the overall response time used to form the simulation results. The next wave, which is very dense, like the straight lines in the graph above, is a response to cover the time spent previously in the initial transient. Then, after the response time is covered, the wave will be sinusoidal and soon show a solution wave converted to torque, as in Figure 18.

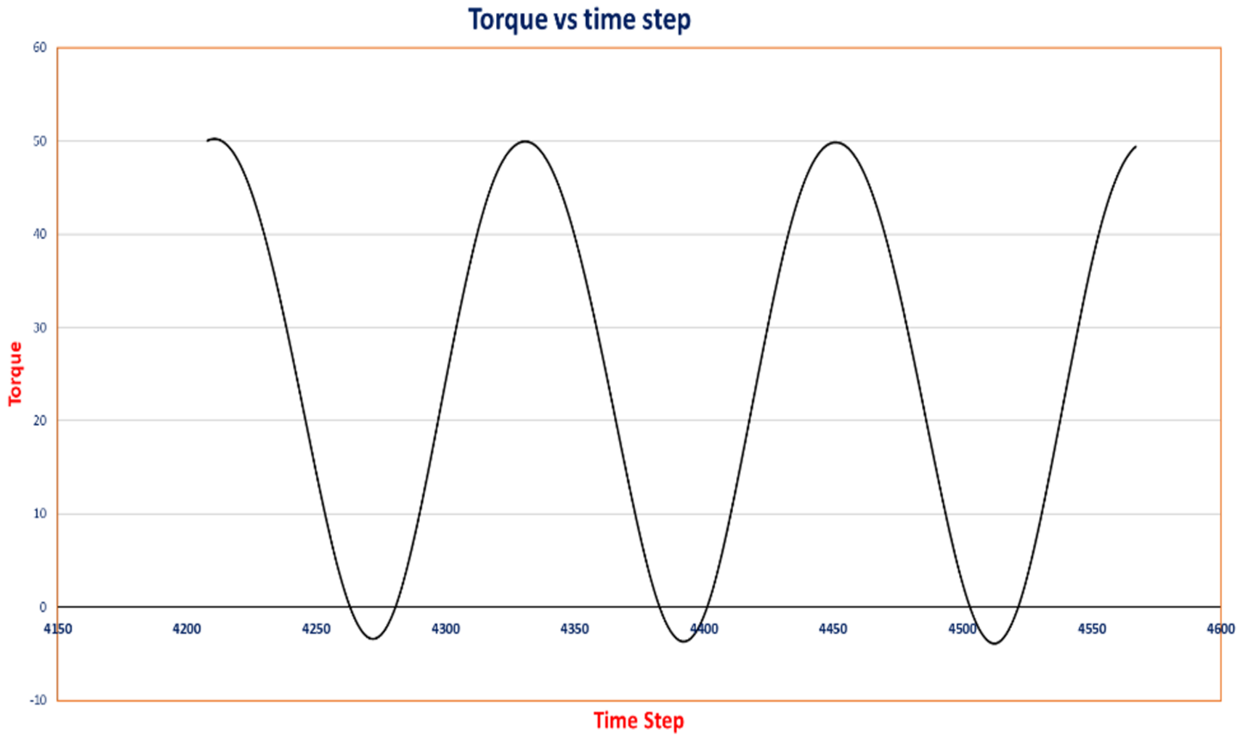

Figure 18.
Torque per cycle graph.

Figure 18 shows the torque graph per cycle, which means that each cycle has a torque value. The torque value is obtained by exporting the simulation data to Excel, and after calculating the average, the torque is 47,251 Nm.

3.3.3. Simulation Output Power Results

After obtaining the torque and angular velocity from the SolidWorks software simulation, the mechanical power and electrical power from the simulation results can be calculated using the following method:

$$\text{Torque} = 45.289 \text{ Nm}$$
$$\omega = 3.72 \text{ rad/s}$$
$$P_{\text{Mechanic}} = \text{Torsi} \times \omega \quad (11)$$
$$P_{\text{Mechanic}} = 45.289 \text{ Nm} \times 3.72 \frac{\text{rad}}{\text{s}}$$
$$P_{\text{Mechanic}} = 168.48 \text{ Watt}$$

The output power of the Flow Simulation results obtained in the SolidWorks software is 168.48 watts. Therefore, the power coefficient (Cp) of the turbine is.

$$C_p = \frac{168.48 \text{ Watts}}{286.34 \text{ Watts}} = 0.58$$

The power coefficient (Cp) obtained by the Darrieus Type-H VAWT turbine is still in the range of 0.2 to 0.6, so the simulation results are declared valid. Meanwhile, the generator's electrical power is:

$$P_{\text{electrical}} = P_{\text{Mechanic}} \times \eta_{\text{generator}} \quad (12)$$
$$P_{\text{electrical}} = 168.48 \text{ Watt} \times 80\%$$
$$P_{\text{electrical}} = 134.78 \text{ Watt}$$

In the simulation with SolidWorks software, the generator's electrical power is 134.78 Watts, and the turbine's mechanical power is 168.48 Watts, with a turbine power coefficient (Cp) of 0.58. Then, for the simulation using ANSYS Fluent software for the torque value per cycle, which is 32,551 Nm, the actual power or average power can be calculated by multiplying the torque by the number of cycles, where the cycle value is taken from its angular velocity, so that the turbine power from the ANSYS software simulation can be calculated by:

$\text{Torque} = 47.251\ \text{Nm}$
$\omega = 3.72\ \text{rad/s}$
$P_{\text{Mechanic}} = \text{Torsi} \times \omega$
$P_{\text{Mechanic}} = 47.251\ \text{Nm} \times 3.72\ \text{rad/s}$
$P_{\text{Mechanic}} = 175.77\ \text{Watt}$

The mechanical power of the flow simulation results obtained using the Ansys Workbench software is 175.77 Watts. The power coefficient (Cp) of the turbine is.

$C_p = \frac{175.77\ \text{Watt}}{286.34\ \text{Watt}} = 0.61$
$P_{\text{electrical}} = P_{\text{Mechanic}} \times \eta_{\text{generator}}$
$P_{\text{electrical}} = 175.77\ \text{Watt} \times 80\%$
$P_{\text{electrical}} = 140.61\ \text{Watt}$

So, in the simulation with ANSYS Fluent software, the generator electrical power is obtained as much as 140.61 Watts, and the turbine mechanical power is 175.77 Watts with a turbine power coefficient (Cp) of 0.61. Next, it is necessary to calculate the maximum and minimum power the turbine produces using the maximum torque of each software used. The maximum-minimum torque of each simulation is as in Table 10.

Table 10.
Simulation results of minimum-maximum torque.

Software / Torsi	Solid works	ANSYS Fluent
Torsi Maximum	83.06 Nm	116.87 Nm
Torsi Minimum	32.70 Nm	24.91 Nm

The minimum-maximum mechanical power of SolidWorks software simulation:
$P_{\text{maks}} = 83.06\ \text{Nm} \times 3.72 \frac{\text{rad}}{\text{s}} = 308.98\ \text{Watt}$
$P_{\text{min}} = 32.70\ \text{Nm} \times 3.72 \frac{\text{rad}}{\text{s}} = 121.64\ \text{Watt}$

The minimum-maximum mechanical power of ANSYS Fluent Software simulation:
$P_{\text{maks}} = 116.87\ \text{Nm} \times 3.72 \frac{\text{rad}}{\text{s}} = 434.74\ \text{Watt}$
$P_{\text{min}} = 24.91\ \text{Nm} \times 3.72 \frac{\text{rad}}{\text{s}} = 92.66\ \text{Watt}$

Table 11 represents the results of the validation of the calculations and simulations that have been successfully carried out.

Table 11.
Simulation results of minimum-maximum torque.

Software / Power	SolidWorks	ANSYS Fluent
Maximum Power	308.98 watts	434.74 watts
Average Power	168.48 watts	175.77 watts
Minimum Power	121.64 watts	92.66 watts

Next, calculate the generator's electrical power converted from the previously calculated mechanical power.

The minimum-maximum mechanical power of SolidWorks software simulation:
$P_{\text{maks}} = 308.98\ \text{Watt} \times 80\% = 247.18\ \text{Watt}$
$P_{\text{min}} = 121.64\ \text{Watt} \times 80\% = 97.31\ \text{Watt}$

The minimum-maximum mechanical power of ANSYS Fluent Software simulation:
$P_{\text{maks}} = 434.74 \times 80\% = 347.79\ \text{Watt}$
$P_{\text{min}} = 92.66\ \text{Watt} \times 80\% = 74.12\ \text{Watt}$

Table 12 represents the results of successfully validating the calculations and simulations.

Table 12.
Simulation results of minimum-maximum electrical power.

Software / Power	SolidWorks	ANSYS Fluent
Maximum Power	247.18 watts	347.79 watts

Average Power	134.78 watts	140.61 watts
Minimum Power	97.31 watts	74.12 watts

In Table 11 and Table 12, the maximum and minimum mechanical power and electrical power in each simulation software show significant differences between the software, which is due to variations in software capabilities. SolidWorks software is generally used for simple design and analysis, while ANSYS Fluent is designed for complex and accurate analysis. This is evidenced in Table 10; ANSYS Fluent is able to calculate lower and higher torque than SolidWorks. However, apart from the maximum and minimum torque, as well as the mechanical and electrical power of the two software, the torque, mechanical power, and electrical power are ultimately close to each other.

4. Conclusion

The design of a micro-scale wind power plant with a Vertical Axis Wind Turbine (Darrieus type-H) has been successfully developed using SolidWorks software, where the turbine has three blades made of the NACA-0012 airfoil model aluminum. The turbine diameter is 3.36 m, and the turbine height is 2.8 m. The connecting rod and shaft are also made of aluminum, but the leg or support pole is made of steel to ensure it is sturdy enough to hold the turbine, connecting rod, and generator. Based on the results of Flow Simulation with SolidWorks software from the design of the Darrieus Type-H VAWT wind turbine that has been created, the results obtained for the average incoming wind speed of 2.5 m/s show that the turbine rotates at an average speed of 2.12 m/s. The maximum total pressure experienced by the turbine is 0.101615 MPa, the torque generated is 45,289 Nm, the average turbulence intensity is 0.028 m, and the force obtained by the turbine is 59,891 N. Furthermore, based on Flow Simulation in SolidWorks, the torque obtained from the turbine is 45,289 Nm, and the angular velocity is 3.72 m/s. The mechanical power obtained by the turbine is 158.48 Watts, with a turbine power coefficient (Cp) of 0.58, and the generator's electrical power is 134.78 Watts. Additionally, for the results of Flow Simulation with ANSYS Fluent software from the design of the Darrieus Type-H VAWT wind turbine that has been created, the results for the torque are 47,251 Nm, and the angular speed of the turbine is 3.72 m/s. The mechanical power obtained by the turbine is 175.77 Watts, with a turbine power coefficient (Cp) of 0.61, and the generator's electrical power is 140.61 Watts. Finally, based on the design results and Flow Simulation for the Darrieus type-H VAWT turbine made according to the wind speed and air pressure in Medan Belawan District, Medan City, the design power of the Darrieus VAWT turbine is aligned with the target output power, where the highest electrical power produced by the turbine reaches 347.79 Watts, with the highest average electrical power of 140.71 Watts, making it applicable in Medan Belawan District, Medan City, North Sumatra Province, Indonesia.

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