CFD analysis of a hybrid, Darrieus-Savonius, horizontal wind turbine, using static and moving mesh

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Abstract: Changes in the ecological spirit of the world lead to the need for usage of additional ways of obtaining clean energy. With help comes solutions to use wind energy. In the world, there are numerous commonly used, various kinds of wind turbines of different sizes, numbers of generated power and the different place of use. They are increasingly used as household wind turbines to improve the ecology and a marked decrease in household spending. Moreover, it was decided to use an innovative, previously unused connection of two separate types of wind turbines. The approach to turbine positioning is also innovative. Due to the use of its horizontal orientation and purpose to mounting on the roofs of the buildings, to do not exceed the specified size limits in building regulations. It also allows increasing the number of applications of this solution. With the use of Darrieus - Savonius turbine increasing of the range of the wind speeds, which are able to spin a turbine is achieved. In the case of higher efficiency, the Darrieus turbine operates at high wind speeds, while the Savonius turbine at lower wind speeds. Two separate solutions have been coupled with each other by claw clutch, which allows the rotation of only one part or two parts of the turbine depending on the prevailing wind conditions. The CAD model of the turbine was made and then the turbine was subjected to advanced CFD analysis. Initially, analysis of the air course around the turbine was performed, using statistical and analytical data on wind speeds prevailing in Poland, within the areas of single-family houses. The approximate values of the wind flow streams and the torque which ultimately is moving the electric generator were determined. The subsequent CFD analysis was performed using the moving FEM mesh, mapping the actual velocities of the turbine blades. The turbine blades revolved at velocities close to the obtained analytical speed of the shaft and turbine components. Airspeeds were analysed in the case of the shape of the flow of streams. The pressure of the air around the turbine was also analysed, the value of which could be used to add strength analysis using FEM method. The main purpose of the test was to determine the torque acting on the engine. Thanks to this information, it was possible to determine the energy efficiency of the turbine and select the appropriate elements, such as the generator, bearings etc. The obtained information has also had an impact on the final shape of the turbine's executive elements. Thanks to performed analysis, it was possible to obtain proper turbine performance parameters without conducting expensive, real, experiments. In the end, the prototype of this Darrieus – Savonius turbine was manufactured.

1. Introduction
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commonly used, various kinds of wind turbines of different sizes, numbers of generated power and the different place of use. They are increasingly used as household wind turbines to improve the ecology and a marked decrease in household spending. Moreover, it was decided to use an innovative, previously unused connection of two separate types of wind turbines. Due to the use of its horizontal orientation and purpose to mounting on the roofs of the buildings, to do not exceed the specified size limits in building regulations. It also allows increasing the number of applications of this solution. With the use of Darrieus - Savonius turbine increasing of the range of the wind speeds, which are able to spin a turbine is achieved. Two separate solutions have been coupled with each other by claw clutch, which allows the rotation of only one part or two parts of the turbine depending on the prevailing wind conditions. The CAD model of the turbine was made and then the turbine was subjected to advanced CFD analysis. Initially, analysis of the air course around the turbine was performed, using statistical and analytical data on wind speeds prevailing in Poland, within the areas of single-family houses. The subsequent CFD analysis was performed using the moving FEM mesh, mapping the actual velocities of the turbine blades. The turbine blades revolved at velocities close to the obtained analytical speed of the shaft and turbine components. Airspeeds were analysed in the case of the shape of the flow of streams. The pressure of the air around the turbine was also analysed, the main purpose of the test was to determine the torque acting on the alternator. The obtained information has also had an impact on the final shape of the turbine's executive elements. Thanks to performed analysis, it was possible to obtain proper turbine performance parameters without conducting expensive, real, experiments. In the end, the prototype of this Darrieus – Savonius turbine was manufactured, [1-10].

1.1. Principle of the Darrieus turbine
The principle of operation of this type of turbine is relatively simple. As a result of the appropriate shape of the turbine blade profiles and their exposure to wind, a lifting force is created that rotates the rotor with the shaft. Then, through the gears that increases the speed, the generator sets in motion and the production of electricity starts. In general, permanent magnet generators are used in this type of construction [1-6].

1.2. Principle of the Savonius turbine
It is a relatively simple construction that usually has two or three blades. The horizontal cross-section of the Savonius turbine rotor is close to the letter "S". The operation of this turbine is primarily based on the use of wind pressure forces, but also to a small degree of lift. The difference in wind forces on the concave and convex sides of the blades causes the rotor to rotate. The optimal Savonius rotor has only two blades rotated 90 degrees apart from each other. Like most VAWT turbines, Savonius designs are characterized by work at very low wind speeds and constant operation, regardless of the wind direction. Thanks to this, it does not need high masts, which significantly reduces costs. Quiet operation allows installations even on residential buildings. An unquestionable advantage of the Savonius turbine is durability. They can be operated even with wind reaching 60 [m/s]. For comparison, turbines with a horizontal axis of rotation are most often switched off at a speed of around 25 [m/s], [1-3, 6-8].

1.3. Assumptions of the project
The main assumption of the project was to combine two types of turbines. For each other in order to use them at all ranges of wind blowing velocities. In addition, the turbine setting in a horizontal way means that it can be used in households without the need for building permits and other environmental permits. After conducting the modelling of shapes, the aerodynamic analysis was performed [3-5, 7].

2. Aerodynamic analysis
The aim of the aerodynamic analysis was to verify the created geometric 3D models and obtain the turbine shaft torque value in order to select the appropriate power generating system [3-5, 7].
2.1. Process of preparing models for analyses

The CAD model of the hybrid Darrieus-Savonius turbine, figure 1, was used for the need of aerodynamic analysis. This model has been simplified to a form in which elements that have no significant effect on the air flow around the turbine structure had been removed. The prepared geometry was then subjected to perform finite elements (FEM). First step was to prepare the mesh of air flowing around turbine. Second step was to prepare Finite Element Description of bodies of turbine and other influencing zones. After the finite element mesh was created, the model was transferred to the computational environment in which boundary conditions and appropriate air flow parameters were imposed.

![Figure 1. Model of the Darrieus-Savonius turbine.](image1)

Depending on the examined case, the degree of simplification of the model and the manner of conducting the analyses has changed. For the analysis 3d tetrahedral mesh were used, to describe air volume. For description of faces of turbine blades triangle mesh was used. Several types of influencing zones were used. Inflation layers were used, describing appropriate change of values of velocities of air around analysed object. For moving mesh analysis several zones and connections between them were used, to able the move of the object and mesh. Two different turbulent models were used - k - ω and k - ω with SST model, [3-5, 7].

3. Performing Aerodynamic analysis

The first investigations were geometry analysis of the turbine blades. The model has been prepared in a way that only considers their cross-section. So-called 2D analysis. The geometry of the Darrieus turbine blades was prepared, followed by Savonius. After performing static analyses, i.e. for which the turbine blades do not move, the results of air flow and numerical values were read. The analysis parameters were set on appropriate level. The geometrical forms of the turbine blades have been successfully verified. The next step was to reset the simulation with the moving blades of the wind farm. The aim of this study was to verify the methodology of conducting analyses using the so-called "Moving mesh", [3-5, 7].

![Figure 2. The distribution of air velocities around the turbine blades.](image2)
The correct simulation results were obtained. Unfortunately, the obtained numerical results and flow cannot be referenced to the 3D geometry of the turbine, therefore additional tests had to be carried out. Figures 2 and 3 show the results of air flow and air pressure distribution around the geometry of turbine blades. All analyses were carried out considering the air speed occurring in the Śląskie Voivodeship. In figures 2 and 3 you can also observe the speed values. The 6 [m/s] wind velocity was assumed. Figures show declines and increases in speed in the areas near the turbine blades. They result from the shape and rules of movement of such a turbine. The low speed of air is marked in blue, while the high speed in red.

![Figure 3](image3.png)

**Figure 3.** The distribution of air velocities around the turbine blades – vectors.

The next stage was to conduct the simulation considering the 3D models of the turbine. Initially only Darrieus and Savonius turbine were used, separately. The results were obtained, which, according to the assumptions, show that the Darrieus turbine achieves the highest efficiency at high wind speeds, while the Savonius turbine at the lowest. Figure 4 shows the course of the air planes around the Savonius turbine blades. The low values of the air velocity were marked with a low colour, while the bright colours, such as yellow and red, were marked with high air velocities.

![Figure 4](image4.png)

**Figure 4.** Number of streams and their velocity around the turbine blade Savonius.

After analysing the separated elements of the hybrid turbine, static tests were carried out to determine the starting torque of the Darrieus-Savonius hybrid turbine. The result of the flow of streams and their velocity is visible in figure 5. The speeds of the streams are described by different colours. The blue colour speed is close to 0, while the yellow and red speeds are high. By analysing
the streams of the streams, it is also possible to observe whether the turbine's operational principle has been met and whether the air velocities assume the assumed values.

![Velocity Contour 1](image1)

**Figure 5.** Number of streams and their velocity around the hybrid turbine blades.

Figure 6 shows the pressure and velocity distributions in the part of the Darrieus turbine. On the basis of the obtained results, it was possible to select an alternator, which will change the rotation of the rotor into electric current. In figure 6, low air velocities are marked in blue, while the high red ones are marked. Similarly, in the case of the pressure distribution, the vacuum values, the orange colour and the red in the high air pressure are marked with a solid colour.

![Pressure Contour 1](image2)

**Figure 6.** Distribution of velocity fields and the air pressure around the blades of the turbine hybrid. Darrieus part.

For the purposes of the turbine start torque analysis, three wind speeds were used, the parameters of which are reflected in real weather in the Silesian Voivodship. For air velocities of 2, 3 and 5 [m/s]. Torque values 0.8, 1.9 and 7.5 [m/s] were obtained for SST turbulent model. For previously used, traditional k-omega archived results were 0.55, 1.32, 5.4 [m/s].
The obtained torque values were used to select the appropriate generator (alternator). The obtained results of pressure distribution on the surface of the blades can be used to test the strength of the entire system, figure 7.

The next stage of the research was to conduct a 3D analysis with regard to the movement of the turbine elements. A forced wind speed of 6 [m/s] was used. Mass parameters and inertia values of the components of the system were applied. Wind turbine blades were simulated based on the wind speed. This analysis confirmed the correctness of using a hybrid solution. Over time, the turbine speed has been increasing until it reaches a steady state. Figure 8 shows a screenshot of the turbine rotation simulation with visible air stream velocities. The velocities of air around the turbine were changing during rotation of turbine wings.

**Figure 7.** Distribution of air pressure fields around hybrid turbine blades. Savonius part.

**Figure 8.** The course of velocity planes and their velocity around the blades of the hybrid turbine during the analysis of rotational motion of the turbine blades.
4. Conclusions
The obtained results of analyses served to further work on the construction of the entire hybrid turbine system. With the use of aerodynamic analysis, the costs of the process of verification of the created geometric forms have been reduced and accelerated. The principle of operation of the turbine was confirmed, regarding to which it was possible to proceed to the production of individual turbine components and to conduct experiments in stationary conditions. The actual tests will verify the correctness of the conducted analyses and the correctness of using such turbines.

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