An alternative for wind energy conversion using improved Savonius rotor turbine model

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Abstract: The current society development is dependent of the planet energy resources and if we take an overview on renewable energies used worldwide it can be said that they are constantly gaining ground. This trend represents an important step forward towards maintaining a clean environment by focusing on capitalizing considerable resources that are sustainable over time, such as solar energy, together with waves and wind force. Regarding the energy production solution based on the atmospheric air masses movements or wind energy, the alternative to the constructive model of horizontal axis turbines (HAWT), currently widely used in wind farms is presented the alternative of using vertical shaft turbines (VAWT) for reduced installed power wind farms. The aspects that form the advantages of these turbines are presented as well as the fact that although they offer a lower power coefficient, they can play an important role for smaller power farms, the investment being at lower values. The basic rotor construction model is based on the SAVONIUS type which has been continuously improved, the results being better in terms of energy performance. A rotor concept that can be used within wind turbines with better performance results compared to SAVONIUS classic model is presented in this paper. The novelty elements consist in the use of a larger number of blades as well as the placing method on the rotor basic circle profile. The numerical analysis results made on virtual rotor model are presented, which highlight the improved values obtained on the analysed model.

1. Introduction
At present, solutions related to the energy production from renewable sources that do not have a negative impact on environmental conditions are being pursued all over the world, aiming at reducing the fossil fuels consumption and avoiding the CO2 emissions into the atmospheric air.

For this desideratum, wind turbines are used to capture wind force and produce energy, in areas where there is potential in terms of speed and constant wind action over time.

The mainly used turbine types to harvest wind power are represented by horizontal axis turbines (HAWT) with high installed power in the range of 1.8-5 MW with large diameter rotors ranging of 40 to 100 m, placed in towers at 80 m height.

As alternatives to the horizontal axis turbines models that offer the best performance results, the variants of vertical axis turbines (VAWT) are proposed which benefit from lower performance
parameters in order of a few kW, but compensate by aspects related to simpler construction, low-cost price, but also with work and start possibilities at lower wind speeds without the need for a wind direction orientation system. These vertical axis turbine types can take air currents from any direction and even eddy currents, benefit from simple maintenance and has a longer service life [1-4].

For these turbine types the simplest rotor model is the SAVONIUS rotor type, presented in the 1920s, which has maximum efficiency values in the range of 20% compared with three-bladed turbines with horizontal axis of 45%.

Over time, multiple studies have been conducted to change the basic geometry of this type of rotor, and the results indicate an increase in energy performance in terms of power coefficient from 0.1 to 0.2 [5-10].

2. The SAVONIUS turbine rotor model assembly

The SAVONIUS type rotor model is presented schematically to identify the main geometric parameters related to the construction and influence in operation (figure 1) [11-13].

The energy performance of this rotor type depends on the overall dimensions by the ratio between the diameter and the height or aspect ratio ($\alpha = \frac{H_s}{D_s}$), the blades placement distance or blade gap ($b_s$), but also on the blade arrangement on the rotor base circle or overlap ratio ($\beta = \frac{b_s}{D_s}$).

The wind force can provide an available power that can be calculated according to the relation [11-13]:

$$N_w = \frac{D_s A_v v^3}{2}$$  \hspace{1cm} (1)

The efficiency parameters for the SAVONIUS rotor involve the appearance of a rotational movement ($\omega_s$) with a certain speed value ($n$), which leads to the appearance of a torque at the rotor axis ($T_r$). Based on these values, the available torque ($C_t$) and power coefficient ($C_p$) can be calculated that can be obtained with the respective rotor model [11-13].
Regarding the rotor efficiency, the tip speed ratio is defined $\lambda$, which represents the ratio between the tangential speed of the blade tip and the wind speed, being the parameter to which the performance values of a wind turbine rotor are related [11-13].

$$\lambda = \frac{\omega \cdot D_r}{2 \cdot v}$$

3. Improved solutions for the SAVONIUS rotor

Some improved solutions for the SAVONIUS rotor are presented for which the blade geometry modification. Based on the results obtained from numerical and experimental analyzes, it was found that the blade basic geometry can considerably influence the rotor performance parameters.

Such improved solutions are the BACH, BENESH and SIVASEGARAM models whose rotor profile is shown in figure 2 [14-18].

![Figure 2. Improved solutions for the blade rotor.](image-url)
The improved rotor models of BACH and BENESH type were tested by Roy and Saha and the obtained results show an improved energy performance in terms of power coefficient compared to the classic SAVONIUS model (table 1) [17,18].

For SIVASEGARAM blade model, power coefficient values of up to 0.2 are presented by Chen et al. [19].

Table 1. Power coefficient values for improved rotor models.

| Rotor model     | Power Coefficient |
|-----------------|-------------------|
| BENESH          | 0.29              |
| BACH improved   | 0.3               |
| SIVASEGARAM     | 0.2               |

4. The innovative solution for improved SAVONIUS rotor

A rotor model with several circular blades is presented, which has the possibility to better take over the air flow coming in the frontal direction. The model is a rotor model with a vertical axis made on the SAVONIUS principle, but with the blades position change on the rotor base circle.

A virtual model was made with the Solid Edge program for this rotor pattern being subjected to a numerical analysis performed with ANSYS CFX for determining the air pressure values at the blades level (figure 3) [20-22].

The model consists of 7 semi-circular blades arranged symmetrically on the base circle. The diameter of the rotor is 148.5 mm, and its height is 198 mm to which are added the end plates with a thickness of 3.96 mm. The rotor with mounted end plates is made to capture the best possible air flow rate from the main circulation flow.

![Figure 3. Rotor virtual model (dimensions in mm).](image)

5. Numerical analysis of improved SAVONIUS rotor virtual model

Using the ANSYS CFX program, a numerical analysis was performed on the rotor virtual model assembly to determine the specific values of the pressure at the rotor blades, as well as the air flow velocity in the analysed fluid area [23-28].

The assembly consists of the rotor and the adjacent fluid region in which the rotational movement can be declared.

The mesh network is made with a specific automatic method having 75537 nodes and 50847 tetrahedral elements.

Based on these values, the rotor performance values in terms of torque and available power can be determined.
The wind velocity value has been set to start the calculation and multiple cases had been considered. For case 1 a value of 8 m/s wind velocity was declared at inlet, case 2 with 7 m/s and case 3 for 6 m/s. In the range of velocity values, a minimum value of 2.4 m/s were also considered for case 4.

The working fluid is declared as air at normal pressure, temperature of 25 degrees Celsius.

The results show specific values calculated for total and static pressure and air velocity presented in figures 4-7 for all 4 analysed cases.

**Figure 4.** Result values for case 1 (v = 8 m/s).

**Figure 5.** Result values for case 2 (v = 7 m/s).
From the obtained result values can be observed the air pressure distribution across the rotor model function of initial velocity, the velocity distribution at the rotor and blade region and the turbulences created after the air flow rate is passing downward the rotor region.

The calculated values for torque, torque and power coefficient are presented in table 2.
| Case 1 (8 m/s) | Case 2 (7 m/s) | Case 3 (6 m/s) | Case 4 (2.4 m/s) |
|---------------|---------------|---------------|------------------|
| Torque values (Nm) | Torque coefficient (CT) | Power coefficient (CP) |
| 1.86 | 1.68 | 1.16 | 0.34 |
| 0.2 | 0.19 | 0.207 | 0.24 |
| 0.11 | 0.1 | 0.14 | 0.29 |

The diagrams for torque and power coefficient are presented in figure 8.

Based on the obtained results, it can be observed that the presented rotor model works best at low wind speeds, because case 4 obtained the best results in terms of torque and power coefficient. In this case it is achieved an operation improvement. Also, good values are obtained by the case 3 in terms of performance efficiency, the other cases having values close to the SAVONIUS classic rotor model.

6. Conclusions
The aspects related to the construction and operation of the SAVONIUS rotor model are presented in this paper. Based on the classic model, a modification of the initial classic constructive solution had been made and some optimization results were obtained.

An improved rotor constructive version is presented, obtained by modifying the blade profile and adopting an optimal blades number built starting from the classic SAVONIUS model.

Represents a variant with 7 semicircular blades placed symmetrically on the rotor base circle for which a 3D model was made and analyzed with ANSYS CFX program.

Several cases with different input velocity were considered and the results are presented in terms of pressure, velocity, and turbulence kinetic energy distribution calculated at the rotor model fluid region.

For each analyzed case numerical results are presented for rotor torque used forward to determine the specific values of the torque and power coefficients according with tip speed ratio values.

It was found that the case of lower velocity values declared at the rotor inlet the values are better for torque and power coefficient. It means that this constructive rotor type model is intended to be used for lower wind velocities areas with good performance results.

The obtained results are better comparative with SAVONIUS classic rotor model for analyzed cases 4 and 3.
For the cases where higher air velocity values had been declared the results are comparable with the SAVONIUS model.

The obtained results show the efficiency possibilities of the SAVONIUS type rotor model, based on the modification of the number of blades and their positioning on the basic circle profile.

Going further, a change of the blade geometry profile can be made, but also of their specific positioning so that better operating results can be obtained.

7. References

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