Wind energy conversion within agricultural farm using vertical axis turbines of optimized SAVONIUS type

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Abstract. Wind force is a considerable resource on the basis of which a significant amount of energy can be obtained, necessary in an agricultural farm that is not connected to the energy distribution network. For this case a low capacity wind turbine can be used as a practical solution, which has the possibility to supply the necessary amount of energy within the farm. The solution is represented by the use of a vertical axis wind turbine with that has component an improved SAVONIUS type rotor. Constructive and energy performance aspects of this rotor type are presented based on studies conducted by various researchers over time, being presented the optimal model to be used in the agricultural farm for energy generation. Values of the energetic performances obtained from analytical but also experimental studies of the optimized models of the turbine rotor with vertical axis that works on the Savonius principle are presented. It is also emphasized the advantage of using this solution in terms of protecting the environment by avoiding fuel burns to obtain the energy needed on the agricultural farm.

1. Introduction

In the current context, there is a general tendency to reduce the use of fossil fuels for energy production, being used more and more ecological and environmentally friendly renewable resources. One of the resources is the force of action of the wind resulting from the continuous movement of atmospheric masses from one area to another.

Different types of turbines are used to achieve the conversion of wind energy, in which the main role is played by horizontal axis turbines (HAWT), which offer the highest efficiency in terms of energy performance. In addition to these, other types of turbine construction are used, such as those with vertical axis (VAWT), whose simple model was presented in the 1920s by the Finnish engineer Siguard Savonius. Vertical shaft turbines have a lower efficiency than horizontal shafts, but benefit from a simple construction principle, operation independent of wind direction, easy start even low wind speeds. According to Zemamou et al., the Savonius rotor had 31\% maximum efficiency, while the prototype obtained a value of 37\%. [1]

The Savonius rotor type has been continuously improved in order to obtain better energy results, and at present different models with much better values in terms of torque and power coefficient is presented.

The paper presents the improved rotor types as well as the values obtained by each in terms of torque and power supplied to the rotor shaft by various researchers, these constructive types being the solution to be applied in agricultural farms for energy generation, where it is necessary to install a generator due to the absence of the distribution network in the respective area.
2. Main performance parameters for Savonius rotor

The Savonius rotor has two or more blades that are positioned along the central axis in order to take over the air flow rates from the main stream in which they are positioned. There are many types of blades that have different section shapes, placed at a different distance from the central axis of the rotor, the distance known as blade gap (bg).

The rotor functional parameters are represented by the total available wind power, \( N_w \), the angular velocity ensured at the rotor axis, \( \omega_r \), the ratio between the wind speed and the blade rotation speed or tip speed ratio (TSR), the rotor torque \( T_R \), air pressure coefficient \( C_p \), torque coefficient, \( CT \), power coefficient \( CP \) corresponding to each type of turbine rotor used.

The total wind power is given by the relation: \[ N_w = \frac{1}{2} \rho_a A_R v^3 \] (1.1.)

Tip speed ratio (TSR) is described by the following relation: \[ \lambda = \frac{1}{2} \frac{\omega_r D_r}{v} \] (1.2.)

The coefficients related to air pressure on the rotor blade, torque and power are given according to the following relations: \[ C_p = \frac{2(p - p_a)}{\rho_a v^2} \]
\[ CT = \frac{4T_R}{\rho_a v^2 D_R H_R} \]
\[ CP = \frac{2T_R}{\rho_a v^3 D_R H_R} \] (1.3.)

where: \( D_R, H_R \) - rotor diameter and height;

\( T_R \) - rotor torque;

\( \rho_a \) - air density;

\( v \) - air velocity.

The energetic performances of the rotor are described by means of the parameters presented above. The rotor operation efficiency is obtained due to the advantages related to the simple design elements ensuring a good starting torque and the possibility of operation in any wind conditions. All these advantages make it possible to use these turbines for lower power applications represented by agricultural farms with low energy generation requirements.

3. Constructive variants for improved Savonius rotor types

Starting from the basic design of the Savonius rotor, several constructive variants for the rotor have been developed, paying attention to the constructive shape of the blades which have been modified in order to ensure an improved operation in terms of rotational movement under normal wind conditions. Also, an optimized operation of the rotor was followed by adding special curtains that cover the inactive blade, while the active blade has the possibility to take over the entire air flow, thus avoiding the negative moment value at the rotor axis.

The basic model of the Savonius rotor has in its component 2 or more semi-cylindrical blades attached to a vertical axis, had been considered to operate on the drag force principle while the wind action is
directed in normal direction on the blades arranged symmetrically to the axis having a convex part and a concave one, the pressing forces being exerted on both surfaces of the 2 blades. The drag type force is the component that ensures the movement of the blade in rotating motion. Experimental research has shown that at low attack angle values the lift force has a contribution in providing torque to the rotor shaft. That is why it can be said that the Savonius rotor has the peculiarity of operating on the basis of a combination of drag and lift force. [2]

The constructive and functional principle of classical Savonius rotor is presented in figure 1.

![Diagram of classical Savonius rotor model](image)

**Figure 1.** Schematically representation of classical Savonius rotor model. [3]

The energy performance parameters of the Savonius rotor are presented in terms of torque (CP) and power (CP) coefficients according to Zemamou et al. in figure 2.

![Graph of torque and power coefficient values](image)

**Figure 2.** Torque and power coefficient values for classical Savonius rotor model. [1]

In order to avoid the negative moment values, the installation solution of a curtain covering the inactive blade was introduced, which also has the role of directing the air stream on the active blade. This solution is presented by Altan et al. who conducted experimental research on the rotor model with and without curtain.
The experimental researches were initially performed on the rotor model without curtain, then 3 types of curtains were tested whose wall has a small length (curtain 1), intermediate length (curtain 2), up to the longest length (curtain 3). The obtained results highlight the advantage of using curtains in order to direct the air flow rates on the active blade, through the higher values of power coefficient (CP) obtained, but also the higher values for the larger dimensions of the curtain wall as shown in figure 4.

The aim was to increase the energy efficiency of the Savonius rotor. Experimental research was carried out by Roy and Saha which aimed to optimize the blade profile. The models on which research was done are presented in figure 5.
Figure 5. Rotor models used in experimental research by Roy and Saha. [4]
The experiments were performed for several values of Reynolds number (Re) in the range of $45 \times 10^4 \leq Re \leq 1.5 \times 10^5$ starting with a wind velocity value of 6 m/s in order to determine the torque, power and static torque coefficients at the level of the analyzed rotor model.
Figure 6. Power coefficient (CP) for $Re = 6 \times 10^3 + 1.5 \times 10^5$ for analyzed rotor models by Roy and Saha.[4]

The results show the specific values recorded for each type of rotor, highlighting the functional characteristics for each type of rotor. The best results are obtained by the rotor model proposed by Roy and Saha, which obtained the best values in terms of power coefficient at different tip speed ratio values function of Reynolds number (figure 6). It is followed by the Bach modified model, and Benesh model. The lower values are obtained by semi-elliptic model and Savonius classic. It can be observed the TSR values where the CP results are obtained for each model as function of Reynolds number.

**Conclusion**

For the constructive rotor models presented in the paper, the experimental results are presented in terms of power coefficient (CP). These results are valuable resources for establishing the optimum model for a turbine rotor with vertical axis that can offer improved values of energy performance in operation comparative to classical Savonius model.

Based on the experimental results obtained by Roy and Saha, the constructive rotor model can be identified to be used at certain values of tip speed ratio or at specific values of wind velocity. In order to optimize the model, in addition to the constructive blade profile, the method of using the curtain can be used in order to avoid the negative moment values that act on the inactive blade during operation. In this case the curtain must be directed in the wind direction in order to achieve rotor start. Such an assembly can be an optimal solution to be applied for wind energy conversion within lower power applications such as the headquarters of an agricultural farm.

**References**

[1] Zemamou, M., Aggour, M., & Toumi, A. (2017). *Review of savonius wind turbine design and performance*. Energy Procedia, 141, 383-388.
[2] Kacprzak, K., Liskiewicz, G., & Sobczak, K. (2013). Numerical investigation of conventional and modified Savonius wind turbines. Renewable energy, 60, 578-585.
[3] Altan, B. D., Atılgan, M., & Özdamar, A. (2008). *An experimental study on improvement of a Savonius rotor performance with curtaining*. Experimental thermal and fluid science, 32(8), 1673-1678.
[4] Roy, S., & Saha, U. K. (2015). *Wind tunnel experiments of a newly developed two-bladed Savonius-style wind turbine*. Applied Energy, 137, 117-125.
[5] Kamoji, M. A., Kedare, S. B., & Prabhu, S. V. (2009). *Experimental investigations on single stage modified Savonius rotor*. Applied Energy, 86(7-8), 1064-1073.