Experimental Research on a Savonius Helical Turbine with Integrated Transparent PV Cells

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Abstract: *Starting from the observation that the hybrid wind-solar systems are perfectly complementary both during a day and during a year, an experimental facility was designed and built, consisting of a Savonius wind turbine with helical blades, covered with thin, transparent film of flexible photovoltaic cells. The experimental results show a power coefficient of 0.265 for the Savonius helical rotor and operation starting from wind velocity of 0.65 m/s. This facility can produce energy from two sources, wind and sun, and even more, it ensures the cooling of the photovoltaic panel, which leads to better energy efficiency. The passive air cooling of the photovoltaic panel can achieve a reduction of its temperature by 10°C. When using the active cooling – resulting from the rotation of the Savonius rotor – a cooling with up to 40°C can be obtained. Regarding the efficiency of the photovoltaic panel, an improvement by 10-12% as effect of the cooling is recorded. The electrical energy obtained from the photovoltaic panel placed on the blades can ensure the wind propeller movement at lower wind velocities – it can give the propeller the impulse necessary to overcome the inertia, before entering the nominal working regime. The total power of this small hybrid system with D = 0.456 m, ranges between 20 ÷ 60 W.*

Keywords: *Savonius helical; wind turbine; flow spectrum; photovoltaic cells*

1. Introduction

Closely related to the concept of sustainable development and correlated with the express requirement to use energy from renewable sources, this project proposes the creation of a hybrid, innovative facility for capturing energy from wind and solar sources and converting it to electricity.
The facility consists of a small wind turbine, with vertical shaft and helical profiled blades, covered with a thin film of photovoltaic (PV) cells, on the principle 2 in 1 (wind and sun in one element).
Compared to the separate use of the two energy sources, the proposed system ensures a higher efficiency of the wind turbine by profiling the blade, estimating a power coefficient of 0.25 ÷ 0.3 and starting at low wind velocities, below 1 m/s. At the same time, a good efficiency is ensured to the photovoltaic source, through active air ventilation, which leads to superior performance.
The Savonius type vertical axis wind turbine was chosen for its advantages: simple construction, low tower height, no need for wind direction orientation and for defeating inertia very easily. The innovative idea was to cover the blades with photovoltaic cells and ensure a convenient exposure to the sun. The article presents the capture of wind and solar energy by designing the wind turbine blade, profiled-helical, slightly twisted, and wide enough to ensure a surface corresponding to the photovoltaic source.
The advantages of such a compact hybrid facility are:

- using the 2 wind and sun sources in one element;
- more uniform energy generation, more uniform distribution in winter and summer, the complementarity of the two solutions resulting from figure 1;
- the vertical wind turbine operates regardless of the wind direction;
- the turbine tower is much smaller compared to the horizontal variants;
- the turbine starts from low wind velocities;
- the hybrid facility uses a system of photovoltaic cells with parallel connections, to minimize losses;
- the surface required for the location of the hybrid solar wind facility is much smaller than in the case of separate use of the two components;

- the costs of energy obtained in hybrid systems are slightly higher than those of wind energy, but significantly lower than those obtained only from photovoltaics.

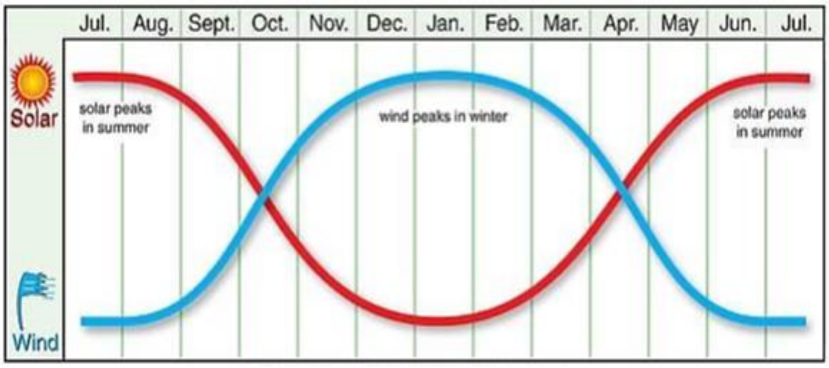


Fig. 1. Solar output peaks in summer and wind output peaks in winter

2. Experimental Set-up

Savonius wind turbines have many advantages, including a high value of starting torque, a simple design and the ability to operate regardless of wind direction, although they have low aerodynamic efficiency.
Savonius type vertical shaft wind turbines have been studied in terms of geometry and shape by Keum Soo Jeon [1], Akwa [2]. "Savonius rotor performance is affected by operational conditions, geometric and air flow parameters. Maximum averaged power coefficient includes values around 0.05 ÷ 0.30", [2]. In [3] Kacprzak et al. examine three cross-sections: classic, bach-type and elliptical. Power coefficients, torque coefficients and torque variation with the angle of incidence are also determined. Kumar et.al. [4] propose a hybrid design between Darrieus and Savonius turbines and test the prototypes with asymmetrical profile SH3055 and symmetrical NACA 0018. Helical Savonius Turbine with different blade type semi-circular (U), elliptical (S), and banesh (L) are tested in [5] by Wijianti and Saparin. Their tests show an influence of the blade design to the turbine performances: S type wind turbine rotors have a higher rotational speed than the ones of type L. Sobczak et al. [6] show the results from a set of numerical investigations on a Savonius turbine with deformable blades and found power coefficients exceeding 0.30.

2.1 Wind turbine design

Mendoza et al. in [7] investigated partial twisted blades for Savonius blades and Debnath et al. in [8] proposed a Savonius helical wind rotor for wind turbines with twist angles of 90º and 180º and investigated the effects of geometric parameters such as the overlap ratio, the effect of the twist angle on the turbine characteristics. Savonius wind turbines with helical blades have a positive static torque for all rotor angles and better performance than conventional Savonius wind turbines.
The following models are considered in the design/profiling of vertical axis wind turbine (VAWT) blades:
a) CFD aerodynamic modelling in order to obtain the optimal blade profile, a method approached more and more often lately;
b) Maximum momentum / torque theory (Blade Element Momentum BEM).
From aerodynamic modelling and analysis of multiple construction solutions, the vertical wind rotor must have minimum torque at low speed, to start easily (Savonius type) and high torque at high speed, to ensure driving force and extract the maximum power from the wind. However, for good aerodynamic performance, the blade must have a convenient profiling – for the present study, a helical profile was chosen, by correlating the two forces – lift and drag, and with a good power coefficient at higher wind velocities.
The velocity distribution on the Savonius helical rotor, with two and three blades [8], was analysed for different specific twisting angles. Static velocity and pressure distributions were obtained at rotor angles of 30°, 90° and 180° as shown in figures 2, 3 and 4 (results from CFD simulations [8]).

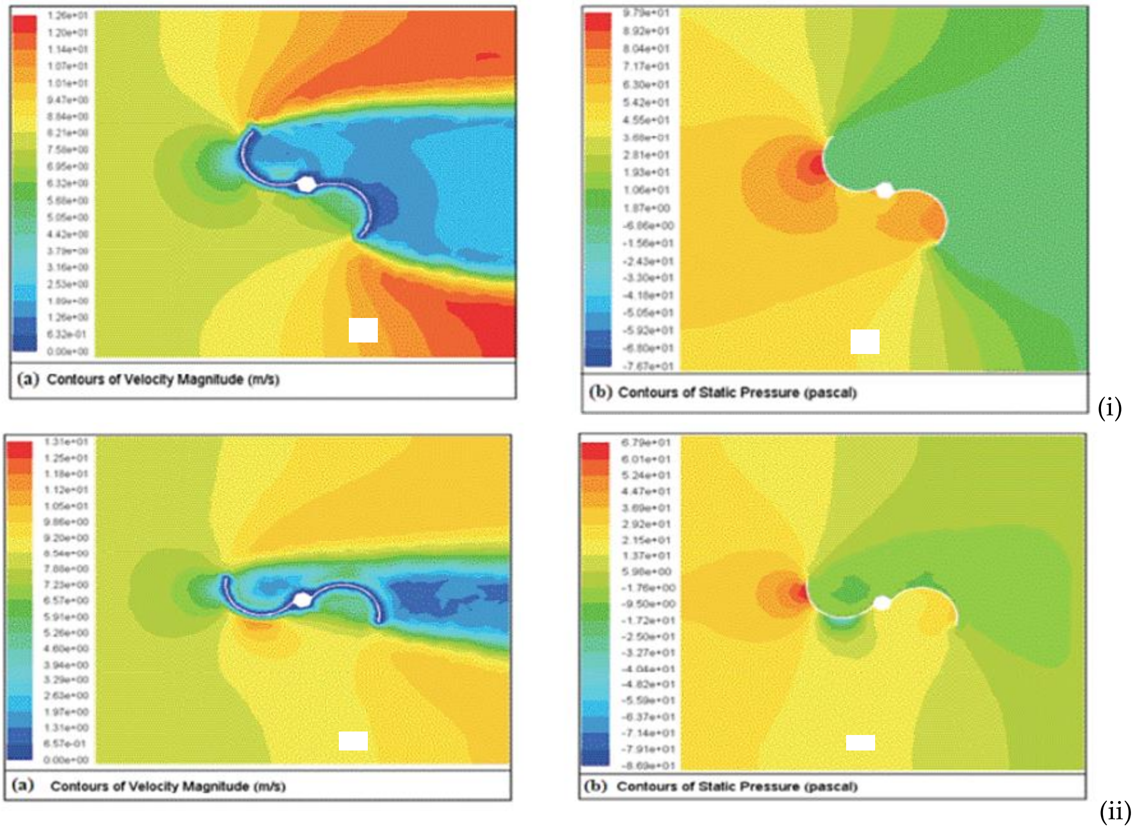


Fig. 2. Velocity and pressure distributions on the rotor, at rotor angles of 30° (i) and 90° (ii) [8]

Debnath's conclusions [8] were: the 2-blade rotor ensures a better power coefficient; the twisting of the helical blades with 180° ensures maximum torque.
The power coefficient (C_p) and the torque coefficient (C_t) can be calculated using the following equations:

- the power coefficient of any rotor can be expressed as: $C_p = \frac{P_{rotor}}{P_{max}}$; (1)
- the effective turbine power P_t can be expressed as: $P_t = \frac{1}{2}\rho A\left(V_1{}^2 - V_2{}^2\right)R\omega$, (2)

  where V_1 and V_2 are the wind velocities upstream and downstream of the turbine rotor;
- P_{max} is the useful power extracted from the wind, given by the relation: $P_{max} = \frac{1}{2}\rho A\mathrm{v}^3$; (3)
- the power coefficient is: $C_p = \frac{\frac{1}{2}\rho A\left(V_1{}^2 - V_2{}^2\right)R\omega}{\frac{1}{2}\rho AV^3}$; (4)
- the TSR or the wind rotor speed ratio is given by: $\lambda = \frac{u}{V} = \frac{R\omega}{V} = \frac{\pi Dn}{60\,v}$; (5)
- the torque coefficient of the rotor is: $C_t = \frac{C_p}{\lambda}$. (6)

The dimensions of the wind turbine are H = 0.8 m and D = 0.456 m. Figure 3 presents a picture of the wind turbine and a detail with the stiffening profiles of the blades. The twist between the four stiffening profiles is 180°. The low weight of the turbine and the well-executed mechanical parts ensure an overcoming of the rotor inertia at wind velocities of 0.65 m/s.

The working hypotheses and characteristics of the wind turbine were calculated as follows:

- wind velocity upstream the rotor: V = 5 m/s;
- turbine mass: m_t = 2.498 kg (consisting of blades with photovoltaic collector, shaft and bearing);
- theoretical power of the wind turbine: $P = \frac{\rho}{2}A\mathrm{v}^3$ = 27.81 W; (7)

- maximum force: $F_{max} = \frac{\rho}{2} v^2 DH$ = 22.78 N; (8)
- pressure and pressure force: p = 165.4 Pa, F_p = 74.43 N;
- torque: $M_t = mgR$ = 5.58 N·m. (9)

a)

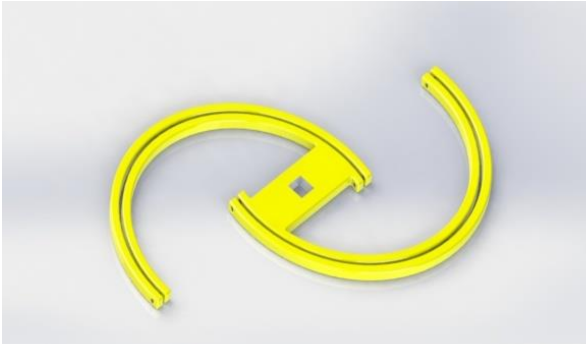
b)


Fig. 3. Picture of the Savonius wind turbine (a) and detail with the stiffening profiles of the blades (b)

2.2. The Photovoltaic System

The innovative solution consists in the fact that the helical blades of the Savonius turbine are made of thin, flexible film of photovoltaic panel. A number of state-of-the-art technologies have led to the successful development and testing of various photovoltaic cell variants [9], [16]. Fluoropolymer-coated solar cells (a transparent film) [10] capture sunlight from any angle and can be applied to curved surfaces, making it possible to completely cover the curved blades of the wind turbine with solar cells. Tandem Semi-transparent Perovskite technology [11] ensures an efficiency of approximately 12.7%. Such a panel was tested in the Renewable Sources of Energy laboratory of the Hydraulics Department – University Politehnica of Bucharest within the current study.

The characteristics and structure of the photovoltaic panel are shown in Table 1, Figure 4 and Figure 5.

Table 1: Electrical characteristics of the flexible photovoltaic panel FWAVE 92W [16]

1000 W/m^2, 25°C		
Maximum output power	100	W
Maximum operating voltage	319	V
Intensity	0.313	A
Open circuit voltage	429	V
Short circuit	0.390	A
800 W/m^2, 25°C		
Maximum output power	80	W
Maximum operating voltage	298	V
Intensity	0.235	A
Open circuit voltage	393	V
Short circuit	0.317	A

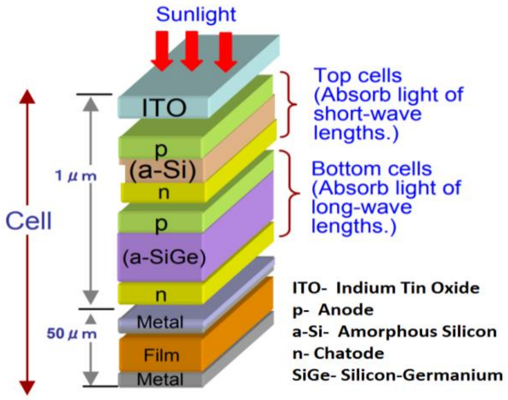


Fig. 4. The structure of the photovoltaic panel FWAVE 92W [16]

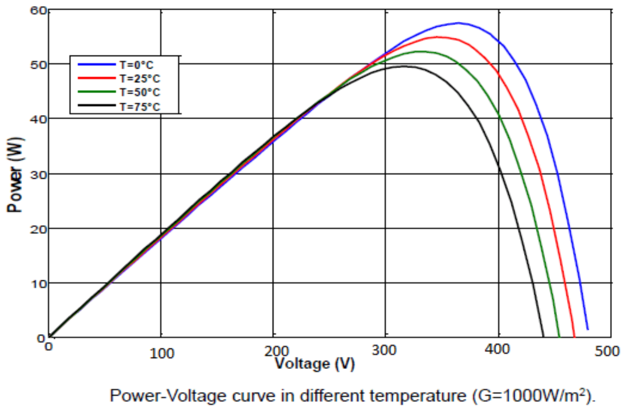


Fig. 5. Characteristic curves of the 92W flexible photovoltaic panel [16]

From the design data of the Savonius turbine, a sun exposure surface of the panel of 0.365 m^2 can be ensured with the two blades, so that at a maximum solar radiation of 1000 W/m^2 a power of 16.79W can be obtained. If the effect of active cooling is considered, a final power of up to 19W was obtained.

For photovoltaic panels to have good efficiencies, they must meet two conditions: their contact surface with incident sunlight must be clean; the temperature must be as low as possible.

A better option would be a transparent solar panel, so that there are no shading areas, with the disadvantage that these technologies still have low efficiencies, below 13% [11]. A two-sided (bifacial) solar panel [12] would be another option.

The cooling methods of photovoltaic solar panels are: air/wind cooling, ice cooling, water cooling or cold water vapor. Research has shown that the most efficient would be ice cooling [13], which can increase the energy efficiency by up to 60% [13].

When cooling the photovoltaic panel with air, previous studies have shown that the efficiency can be improved by 12 – 18%. Kaldellis et al. have found that the efficiency (or power) temperature coefficient increases between 0.30%/°C and 0.45%/°C when the temperature decreases [14].

3. Results

3.1. Operating characteristics

The operating characteristics of this wind turbine are represented graphically in Figure 6. Measurements were made up to wind velocities of 4.5 m/s, the values above this velocity resulted by polynomial extrapolation.
The measurements showed that the rotor overcomes inertia and rotates uniformly at velocities below 1 m/s, more precisely 0.65 m/s.

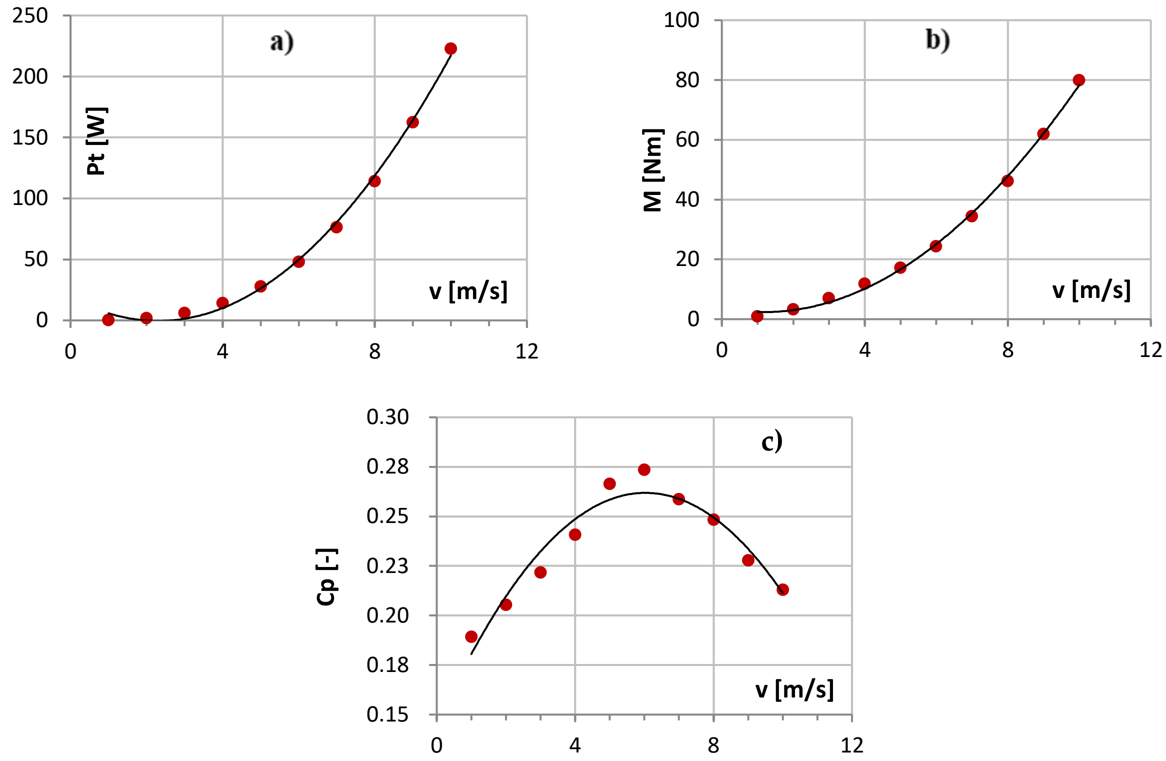


Fig. 6. Power (a), torque (b) and power coefficient (c) of the wind turbine

3.2. Visualization of the flow spectrum on the Savonius helical rotor

The air flow around the Savonius rotor was experimentally visualized using a smoke generator and a plane laser, and pictures were taken with a video camera. Images were obtained for two different rotational speeds of the turbine shaft, resulting from wind velocities of 3 m/s and 4.5 m/s respectivelly, as it can be seen in Fig. 7. An extensive study on this subject is presented in [15].

Fig. 7. Flow spectrum for wind velocity of 3 m/s (a) and 4.5 m/s (b)

3.3. Cooling efficiency

Using passive cooling with air of the photovoltaic panel, a reduction of its temperature by only 10° C can be obtained; by using active cooling, resulting from the rotation of the Savonius rotor, a cooling by over 40°C can be obtained for high wind velocity. The efficiency can increase by 12%, so for panels with an efficiency of 18%, by cooling it can exceed 20%, and for transparent or 2-sided panels with an efficiency of 9% it can reach 10.6%. This has the effect of producing additional electricity.
The effect of cooling the photovoltaic panel at different wind velocities was studied. If the effect of active cooling of the photovoltaic panel is considered, which increases by a maximum of 12% the efficiency of the panel, a final power resulting from the sun of 19 W can be obtained. This adds to

the 19.95 ÷ 44.33 W generated by wind energy, which leads to a promising result for such a hybrid system, over to 60 W.

4. Conclusions

In this article, the authors propose a hybrid solar wind system in an innovative solution of Savonius wind turbine with helical blades, covered with thin film of photovoltaic panel.
Experiments were made on the wind turbine and a small twisting moment was obtained at wind velocity of 0.65 m/s. The operating characteristics of the wind turbine proposed in the article were outlined. The paper also includes the visualization of the flow spectrum for two wind speeds, confirmed by numerical studies from the literature.
The effect of cooling the flexible photovoltaic panel was checked. The total power of the hybrid system was between 20 ÷ 60 W.

Conflicts of Interest: The authors declare no conflict of interest.

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