Analysis of the impact of increasing the efficiency of Savonius turbine working in a hybrid system trough the using of building's elements as curtains

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The paper presents Savonius turbine and the results of worldwide research. Statement was made the most optimal geometric parameters and shows how increase a turbine efficiency of energy generation without interfering with the turbine structures, through the use of appropriately selected curtains. Proposed use of building elements to improve the efficiency of the turbine and to create a hybrid system, attaching photovoltaic panels. Calculated energy yield of the entire system and installation diagram is shown in off-grid system.

1. Introduction

Renewable energy constitutes one of the essential elements of sustainable development of any country aiming at limiting the emission of pollution produced by burning energy fuels and looking for new, alternative energy sources. The „Strategy for renewable energy development" adopted with an act of the Council of Minister of 5 September 2000 and, finally, with an act of the Parliament of the Republic of Poland of 23 August 2001, specifies the volume share of energy produced from renewable sources for the years 2010 and 2020 as respectively 7,5% and 14% in the primary energy balance [11].

The energy of wind which is a distributed source of electrical power, independent of supplies and fossil fuel prices as well as political influences, has an advantageous effect on the energy security of the country. The production process in the case of this type of energy takes place close to its recipients which reduces the need for expensive modernization or extension of the electrical power network to meet the growing demand for electrical power in the economy, limits transmission losses, and makes the power system independent of the consequences of failures in large system power plants. What is more, the natural distribution of investment predicted for the future eliminates the risk of a sudden shutdown of all the power coming from the installed wind power plants and the damages to the electrical power system that it could cause [11].

The most important advantages of wind power engineering in the distributed model compared to the wind farm model are as follows [17]:

- no need to obtain large areas of land;
- easier social negotiations or even no need for such negotiations;

- increased chances of obtaining the conditions for connection to the electricity distribution system;
- no need to construct subscriber switching stations and expensive terminals;
- no need to construct 110 kV high-voltage power lines connecting the farm with local switching stations;
- lower design costs;
- shorter completion time;
- easier compliance with environmental conditions.

Wind turbines can be divided into two basic types – with horizontal and vertical axis of rotation. Because of their highest efficiency, the most commonly used turbines are horizontal axis turbines equipped with three blades. Turbines with the power of up to 50 kW are usually used as power supply for family houses. Sometimes they work, for example, in connection with photovoltaic systems forming the so-called hybrid systems used to power the equipment in places where no electricity network is available [16]. The possibilities of using wind turbines in small household power plants are, however, limited. In accordance with the provisions specified in the regulation of the Minister of Environment of 9 January 2002 on noise threshold levels (Journal of Laws of the Republic of Poland 2002, no 8, item 81), the objects and equipment that produce noise must be placed in such a way so as not to exceed the permissible noise levels. For residence areas the threshold is 50 – 60 dB. The machines that generate the lowest noise values are vertical axis power plants, such as, for example, Savonius wind turbines [12, 20].

2. Savonius turbine characteristics

A Savonius turbine which is an example of a vertical axis wind turbine (VAWT) consists of two vertical scoops. The cross section of the rotor of this turbine resembles the letter “S” and its basic geometric parameters are presented on Figure 1.

The rotation of the rotor is induced by the drag difference of the wind acting on the convex and the concave side of the turbine blades and its operation is not dependent on the wind flow direction. It generates high pull-up torque values at low wind speeds and its characteristic feature is quiet operation resulting from low rotation speed, considerably lower than in the case of vertical axis wind turbines [2, 8]. The selection of the appropriate low-speed generator poses a serious problem due to such low rotation speed levels. However, in the case of vertical axis wind turbines, it is possible to place a heavy generator on the ground (instead of the gondola), generating high loads for the blade rotation system in the direction of the wind flow. A Savonius turbine is also much more resistant to mechanical tensions than any other turbine, including both horizontal and vertical axis ones. Thanks to that, the energy of the wind is much more efficiently directed onto the turbine blades at the same level of mechanical tensions than in the case of other wind turbine constructions. Considering the L-σ criterion (maximum mechanical stress), the turbine is the best out of all the different types of constructions [9, 10]. However, its wind flow efficiency ratio c_p (coefficient of power) is relatively low, which is shown on Figure 2.

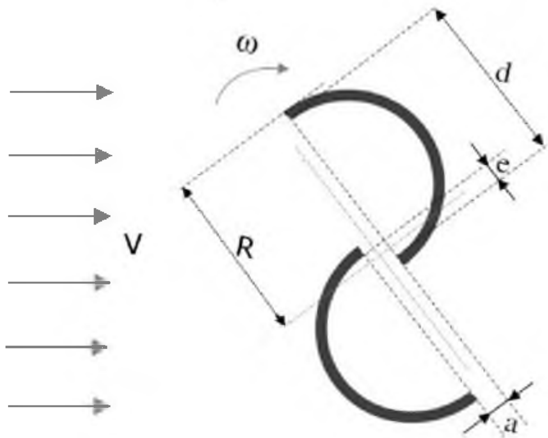

Fig. 1. Schematic drawing of a Savonius turbine [8]

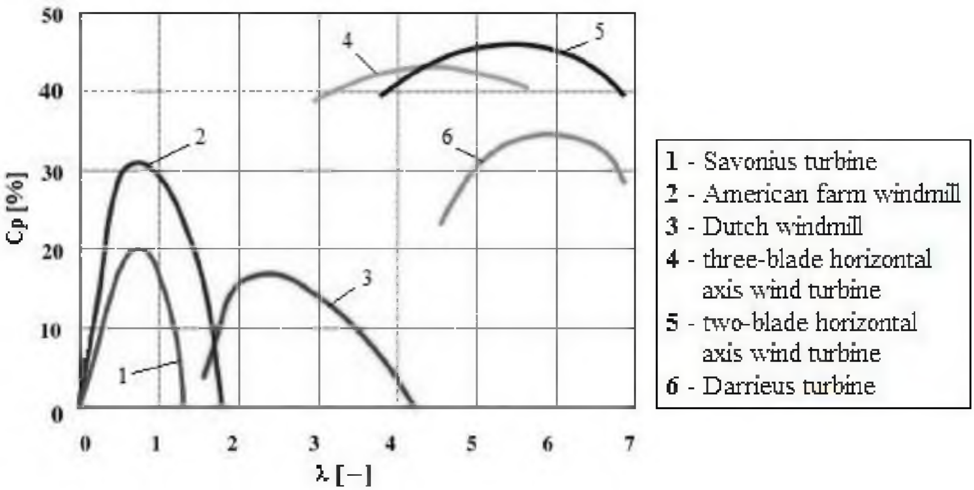

Fig. 2. The dependency between the c_p coefficient and the λ coefficient for different wind turbines [8]

The c_p coefficient is defined as the proportion of the turbine power P to the total power of the air flow flowing through the turbine surface. The characteristics presented are usually provided in relation to the so-called tip speed ratio λ which is the ratio between the rotational speed of the tip of a turbine blade and the velocity of the wind [15].

In Table 1 you can see the most common average values of the parameters belonging to wind turbine efficiency.

Table 1. Average parameters of wind turbines [1]

Type	VAWT (Vertical Axis Wind Turbines)				HAWT (Horizontal Axis Wind Turbines)			
	Darrieus			Savonius	2-blades	3-blades		
	3-blades (small)	H-rotor						
		1kW÷10kW	10kW÷30kW			>5kW	5kW÷20kW	20kW÷100kW
Rotor diameter Ø [m]	1-3	2-6	7-10	0,5-3	2-15	1-3	4-11	10-20
Sectional area [m^2]	3-7	3-30	40-80	2-15	3-170	0,8-7	12-100	80-310
Rated power [kW]	0,5-2	1-10	10-30	0,5-6	1-30	0,5-5	5-20	20-100
Power coefficient max. cp [-]	0,25	0,4	0,4	0,2	0,4	0,3	0,4	0,45
Tip-speed ratio [-]	3-7	2-5	2-5	1	6-12	5-7	5-7	5-7
Start-up wind [m/s]	-	2-3	3	2	3	2-3	2,5-4	2,5-4
Cut-out wind [m/s]	-	30	30	no lim.	50	25-40	25-40	25-40

The works devoted to the subject provide descriptions of different tests aimed at improving the efficiency of the turbine, determined either by means of experiments or analytically with the use of numerical analysis methods. The work [8] presents the most optimal geometric parameters of a turbine providing the highest c_p coefficient values. They are presented in Table 2.

Table 2. Comparison of geometric parameters allowing to obtain the highest c_p coefficient values [8]

Turbine height H	Separation gap e	Separation gap a	Number of blades	Number of blade pairs twisted by 90°	Blade tip radius
4R	0,15d – 0,3d	0	≥2	≥2	1,1 R

The rotor can be divided into parts and every part can be twisted by 90°. This solution is used in order to increase the pull-up torque values when the wind blows from different directions. Adequate torque stability is guaranteed by 2 blade pairs and the fact that the turbine is equipped with more blades than it is necessary [8]. Using numerical analysis methods, the author of the work [8] proves that the most optimal value of the e gap with respect to the torque coefficient c_m is 0,242 d.

3. Using a curtain to increase the efficiency of the turbine

The efficiency of a Savonius turbine can be achieved by means of changing its construction parameters. In order to eliminate negative torque occurring on the convex side of the turbine, curtains directing the wind flow can be used, as in the set presented on Figure 3.

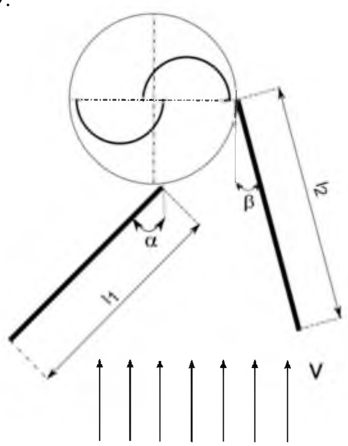

Fig. 3. Schematic drawing of the curtains used including their parameters [2]

The author of the work [1] conducted tests on a turbine whose height was equal to its diameter (H = D) for three different curtain sets. The curtain dimensions l_1 and l_2 dependent on the turbine diameter are compared in Table 3.

Table 3. Dimensions of different curtain types in proportion to the turbine diameter [2]

Name	Length l_1	Length l_2
Curtain 1	1,41·D	1,63·D
Curtain 2	1,06·D	1,22·D
Curtain 3	0,69·D	0,81·D

At the average wind speed of 7 m/s, the best results were obtained for curtain 1. Tests with the angles α and β, at which they should be positioned, made it possible to determine their values as α = 45°, β = 15°. The value of the c_p coefficient for those parameters was 0,38 and the coefficient values for curtains 2 and 3 were respectively 0,34 and 0,26 [2].

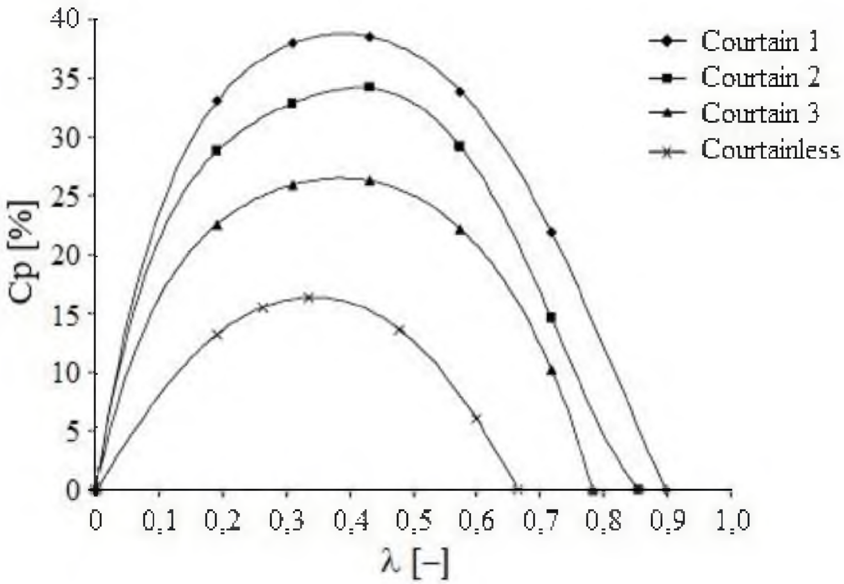

Fig. 4. The influence of using curtains on the coefficient of power in proportion to the tip speed ratio [2]

Both the tested turbine model without curtains and the conventional Savonius turbine model presented in works [3, 4, 5] exhibit the c_p wind flow power coefficient values in the range between 0,16 – 0,17. Using appropriately selected curtains that made it possible to achieve the highest utilization of the air flow directed to the rotor allowed to increase the c_p values over two times, which is presented on Figure 4.

4. An example of an implementation of a hybrid electric energy generation system using elements of the existing infrastructure

A Savonius turbine can be used for electricity generation everywhere where it is important for the turbine to work as quietly as possible, e.g. in residential areas. What is more, the existing buildings (that is: building objects, fences, walls) can serve as curtains enhancing the increase in wind utilization efficiency, without compromising the aesthetic values of the surroundings.

An example of such an implementation can be placing the wind turbine in the garden behind a family house. The back wall of the utility building with appropriate dimensions can serve as one of the curtains. The second curtain can be used for constructing a frame supporting photovoltaic panels directed towards the south in order to achieve the best sunlight exposure of the panels. Thanks to such a solution, we can achieve a hybrid system in which the wind turbine and photovoltaic panels will charge a common battery. The electric energy accumulated in the battery can be used to power the garden lighting or building façade highlights, to power a water pump watering the garden or even a separate circuit in the residential building. In order to achieve the highest energy output, all the components of the system must be placed in accordance with the conditions described earlier in the present work. A suggested arrangement is presented on Figure 5.

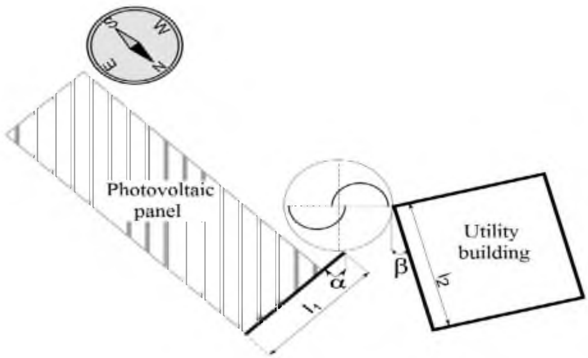

Fig. 5. Arrangement conditions for particular components of a hybrid system

The assumed height of the turbine is H = 2 m. Its radius R, in accordance with the information included in table 1, should be 4 times shorter than the turbine height, which means that the radius value equals R = 0,5 m. Let's also assume the lengths and the positioning angle of the curtains to be exactly the same as the values determined in the point above, that is $\alpha = 45°$, $\beta = 15°$, $l_1 = 1,4$ m, $l_2 = 1,6$ m. The curtain height is equal to the turbine height. Such values of particular quantities will make it possible to achieve an optimal value of the wind flow power coefficient – c_p [8].

The mechanical power of a Savonius turbine can be calculated with the use of the following equation [8]:

$$P = c_p \cdot \rho \cdot R \cdot H \cdot v^3 \; [W] \qquad (1)$$

where: v – wind velocity [m/s], H – turbine height [m], R – turbine radius [m], ρ – air density [kg/m^3], c_p – wind flow power coefficient [–].

The nominal power of horizontal axis wind turbines that are currently used is calculated for wind velocity within the range between 10–11 m/s [6]. Similar velocity values, that is values ranging between about 10–12 m/s [14], are assumed in power calculations for vertical axis wind turbines. Let's then assume for the purpose of the present consideration that the wind velocity is v = 10 m/s.

Air density in standard meteorological conditions (that is when the atmospheric pressure is p = 111,3 hPa and the temperature is t = 15°C) equals ρ = 1,225 kg/m^3 [23].

The value of the c_p coefficient obtained for an appropriately selected and positioned curtain and the direction of the wind compatible with the positioning of the curtain is c_p = 0,38. Substituting the data provided above into equation (1), we can obtain the value of the mechanical power of the turbine P = 465,5 W.

If we assume that the average working time of the turbine generating the nominal power is 20 % of days in a year (in accordance with the information provided by the manufacturers [18, 19]), we can obtain the amount of electric energy generated by the turbine equal to 815,56 kWh per year.

Assuming the most advantageous inclination angle of the photovoltaic panels from the surface of the Earth, that is $\varphi = 30°$, and the frame height of 2 m, its width must be 3,46 m. The dimensions of the area that is obtained on such a frame are 4 x 1,2 m, which makes it possible to mount 7 panels with the nominal power of 80 W and with the dimensions of 1,2 x 0,54 m. Basing on the information provided in work [7] with relation to the amount of solar radiation reaching the Earth and the method of calculating the energy output obtained from photovoltaic panels, we can estimate the annual amount of energy that can be obtained from the suggested photovoltaic installation. For the city of Poznań, where the annual insolation is about 1050 kWh/m^2 with panel orientation to the south, we can obtain 84,05 kWh of electric energy per every 1 m^2 of photovoltaic panel area, which gives the annual energy output of 375,7 kWh for the complete installation with the area of 4,47 m^2.

The total electric energy generated by the suggested hybrid system can amount to 1,19 MWh per year. Assuming energy losses on particular components of the system whose schematic drawing is presented on Figure 6 as amounting to 20 %, we can obtain the generated energy amount of about 953 kWh, which is over a half of the yearly demand of an average household, whose total energy consumption was estimated by the Polish Foundation for Energy Efficiency as amounting to about 1,66 MWh/year (this is an averaged value considering different housing model types) [13].

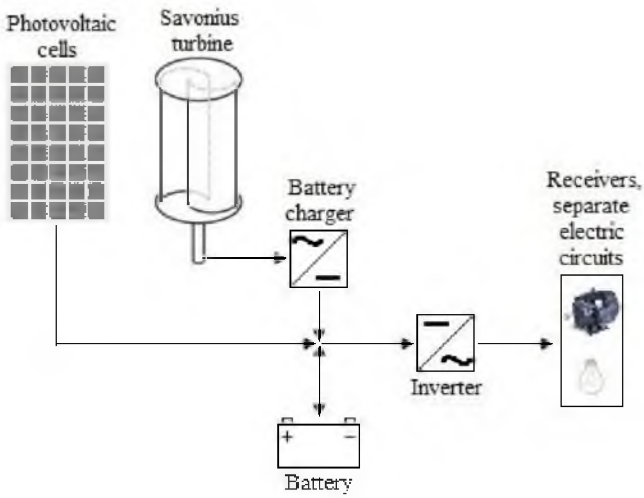

Fig. 6. Schematic drawing of a hybrid system connection in the off-grid system [22]

5. Conclusions

A characteristic feature of a conventional Savonius turbine is a low value of the wind flow power coefficient. However, there are means of increasing the value of this parameter. Using additional curtains can double the efficiency of energy generation, which was presented in point 3. This value is high considering the fact that it is constant and, additionally, that the existing buildings can serve as the curtains. The criterion of noise that is generated by the wind turbine becomes an important factor in residential areas and that is why the solution presented in the present work can serve as a good alternative in the case of areas with high-density housing. An advantage of the hybrid solution is that electric energy can be produced in different weather conditions. Appropriately situated elements that constitute the hybrid system of energy generation from the power of wind and solar radiation make it possible to increase the efficiency and guarantee the operation of the connected electric circuits for a longer period of time throughout the year.

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