# EXPERIMENTAL STUDY ON THE INCREASE OF THE EFFICIENCY OF VERTICAL AXIS WIND TURBINES BY EQUIPPING THEM WITH WIND CONCENTRATORS

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**Abstract – The vertical axis wind turbines, which are operating on the principle of aerodynamic drag, have relatively low efficiency of about 20 to 30%, but they have the great advantage that they can operate at full capacity and produce energy in areas with low wind potential or with turbulent winds. There are several ways one can improve the power coefficient of this type of wind turbine, such as establishing the ideal shape of the rotor blades or by choosing the optimal number of stages of the rotor. In this study, for the improvement of the power coefficient of the wind turbine, a concentrator (curtain) was used in order to cancel the negative moments that affect the rotational movement of the rotor and to increase the speed of the airflow at the entry into the rotor. By analyzing the behavior of the rotors without a concentrator and equipped with various types of wind concentrators one could determine the optimal configuration of the concentrator and the influence that it has on the operation of the wind turbines.**

**Keywords:** wind turbine, rotor, blades, concentrator, wind tunnel, rotational speed.

## 1. INTRODUCTION

Wind energy is one of the most important sources of clean energy and the generation of electricity by converting this type of energy has become increasingly important in recent years. The installed capacity of wind farms is strongly increasing from year to year, this increase being accentuated also by the support programs granted to the investors in green energy technologies, existing in most developed countries. There are many types of wind turbines that are currently used to produce electricity, which can be divided into two categories depending on the orientation of their axis of rotation [1,2]: horizontal axis wind turbines, HAWT's and vertical axis wind turbines, VAWT's (Fig. 1).

The wind turbines that have the axis of rotation in a horizontal position are performed almost exclusively based on the principle of operation of the propeller and they work based on the effect of aerodynamic lift. The superiority of this design over other solutions developed so far is based on the following characteristics:

- the rotor speed and the amount of energy produced can be controlled by pitching the rotor blades in relation to their longitudinal axes;
- the shape of rotor blades can be aerodynamically optimized;
- the technological advances in the design of the propeller blade type, favored by the development of the aeronautic industry, constitute a decisive factor.

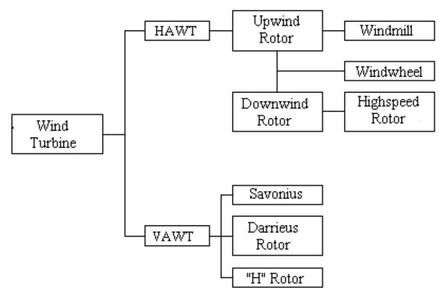


**Fig. 1. Classification of wind turbines after their constructive form**

In general, the performance coefficient of modern turbines has values between 0.4 and 0.5, values that are approximately 70 to 80% of the theoretical limit of this coefficient, which is 0593 [3].

Vertical axis wind turbines can operate both on the principle of aerodynamic lift, such as Darrieus turbine and the „H" rotor, and based on the effect of aerodynamic drag, such as Savonius wind turbines and their different variants. Although these turbines do not meet the performances of the horizontal axis wind turbines, having performance coefficients, *Cp* between 0.25 and 0.4 (Fig. 2), the turbines in this category have several important advantages compared to the others [4]:

- they do not require yaw mechanisms, having the ability to accept wind from any direction;
- the orientation of their axis of rotation allows the generator to be located at the bottom of the tower.

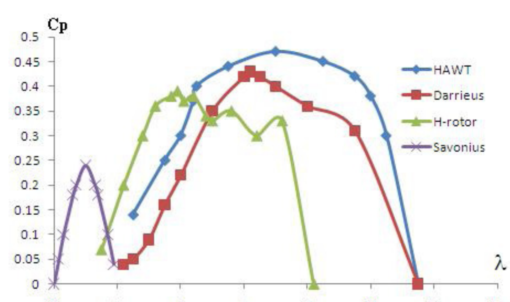


**Fig. 2. Power curves for different turbine types**



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Also, Savonius type wind turbines, which operate based on the principle of the aerodynamic drag, can provide high starting torque, can operate in areas with low wind potential or turbulent wind, and the manufacturing costs of the rotor blades can be very low, because they can be made, in many cases, by recycling other items such as metal and plastic drums or other similar cylindrical objects, aspects which makes them very attractive for low power electricity generation facilities.

## 2. VERTICAL AXIS WIND TURBINES

Vertical axis wind turbines may be divided, as was shown before, in two categories, depending on their operating principle: wind turbines that operate under the effect of aerodynamic lift and wind turbines that are operating under the principle of aerodynamic drag. The wind turbines from the first category need, in order to operate at full capacity, high wind speeds, similar with those needed in the case of horizontal axis wind turbines, this, combined with their lower power coefficient, makes this type of wind turbine to be less attractive for use at the expense of conventional wind turbines, with propeller type rotor. The turbines from the second category, because they are using the aerodynamic drag in order to get a rotational move, can operate in low wind conditions, at air speeds of about 2 to 4 m/s, and they are very suitable to be located in areas with low wind potential, how, as a matter of fact, most areas of our country are, areas where horizontal axis wind turbines are totally inefficient.

One of the main wind turbine from this category is the turbine invented by the Finnish researcher S.J. Savonius, which is composed of two semi-cylindrical or semi-elliptical blades placed in the shape of the letter "S", as shown in Figure 3, the convex and the concave side of the rotor being under the influence of the wind at the same time [5, 6].

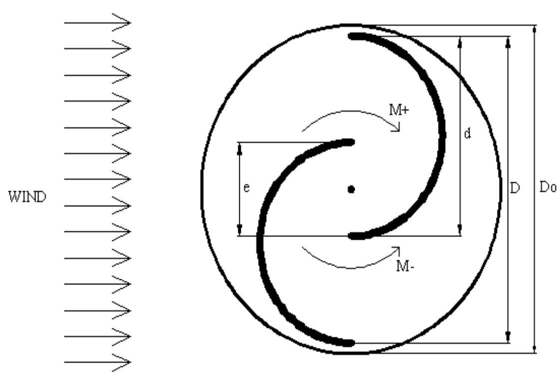


**Fig. 3. Principle scheme of the Savonius rotor D0 – endplate diameter; D – rotor diameter; e – gap distance; d – blade diameter**

The operation of the Savonius rotor is based exclusively on the effect of aerodynamic drag and the rotational motion is possible because the coefficient of friction of the concave surface of the blade is greater than the one corresponding for the convex surface so that the force acting on the first surface is greater than the force acting on the second surface, generating a higher torque which moves the rotor. Because the torque which generates the rotational motion is the result of the difference between the torque provided by the force that is acting on the concave surface and the one that is acting on the convex side of the blade, the Savonius wind rotor has a relatively low performance coefficient of about 0.2 - 0.3. A very adequate solution for improving this power coefficient is to install a concentrator nozzle to the Savonius rotor (Fig. 4), in order to increase the speed of the air at the entry into the rotor and to direct the airflow only over the concave blade, thus providing the cancellation of the negative moment produced by the action of the wind on the convex side of the blades and to offer the possibility that the movement of the rotor to take place only under the action of the positive momentum, which leads to an increase of the rotor efficiency [7]. However, it should be noted that, by equipping the Savonius wind rotors with a wind concentrator, the possibility of the vertical axis wind turbines to receive wind from any direction, i.e. their omni-directional nature, will be cancelled.

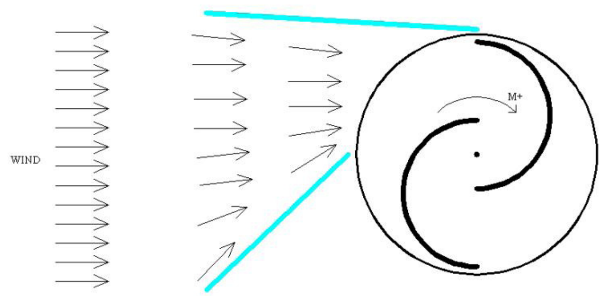


**Fig. 4. Savonius wind turbine equipped with a wind concentrator**

## 3. EXPERIMENT SET-UP

Experimental studies were held in the Research Laboratory of the Faculty of Building Services of the Technical University of Cluj-Napoca. For the proper conduct of the experiments it was necessary to build an open subsonic wind tunnel, which can generate speeds o the air masses of 0 to 13 m/s, the manufacture of three types and configurations of vertical axis wind turbines based on the Savonius principle and the design of three wind concentrators with different constructive sizes.

### 3.1. Vertical axis wind turbines

All the rotors used in the experiments have the same constructive sizes, i.e. the diameter of the rotor, D=18 cm and height of the rotor, H=18 cm, so that the swept area of the rotors would be the same and all the wind rotors would benefit from the same amount of wind energy. The rotor blades were made of plastic materials (PET) and the endplates of the rotor of comatex, and they were placed on a metal frame by means of axial bearings [8]. The rotors were chosen so that the experimental study can cover the most common configurations of vertical axis wind turbines, namely:

- a simple Savonius rotor, with two semi-cylindrical blades and one stage of the rotor, with an overlap ratio of the blades, e/D=0.2 (Fig. 5);
- a double Savonius rotor, with two semi-cylindrical blades and two stages of the rotor (Fig. 6);
- a Savonius rotor, with two blades placed in the shape of the letter “Z”, design that offers a much



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simpler design than the one in the case of the Savonius rotor, with semi-cylindrical blades (Fig. 7).

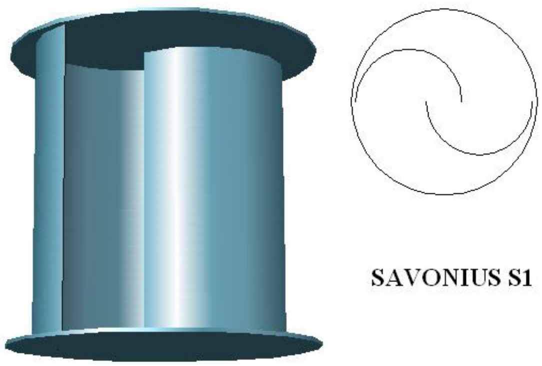


**Fig. 5. Single-stage Savonius wind rotor**

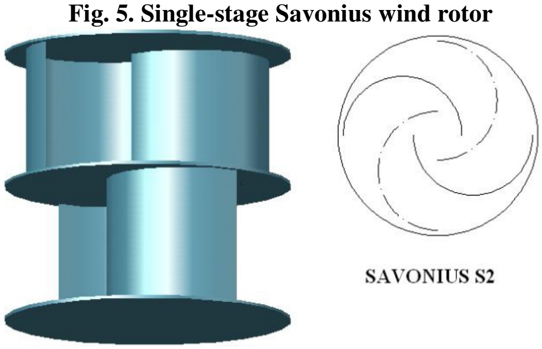


**Fig. 6. Double-stage Savonius wind rotor**

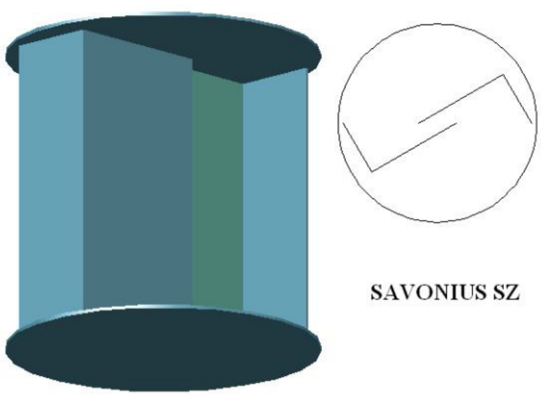


**Fig.7 Type "Z" Savonius wind rotor**

### 3.2. Wind concentrators

In this experimental study three wind concentrators were used, which have been designed so that their central side have the same size as the rotor diameter, in order to exist a correlation between the overall sizes of the two components, i.e. concentrator and rotor, of the wind turbine [7]. The wind concentrators were made of comatex, their scheme and design principle are shown in Figure 8, and their constructive sizes, are summarized in Table 1.

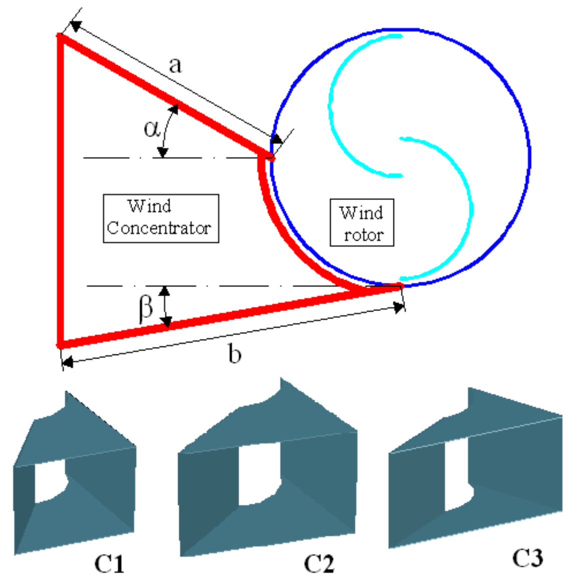


**Fig. 8. The constructive scheme of the concentrators used in the experimental study**

**Table 1. The constructive sizes of the used wind concentrators**

| Type | Dimensions | | | |
|---|---|---|---|---|
| | a | b | α | β |
| C1 | 18 cm | 25 cm | 30° | 10° |
| C2 | 18 cm | 23 cm | 45° | 15° |
| C3 | 18 cm | 21 cm | 60° | 25° |

### 3.3. Aerodynamic wind tunnel

Uniform main flow is produced by an open-circuit subsonic wind tunnel [9, 10], presented in Figure 9, which has a rectangular exit section with dimensions of 300x300 mm. Airflow is provided with an axial fan that can deliver a maximum flow of 4300 m³/h.

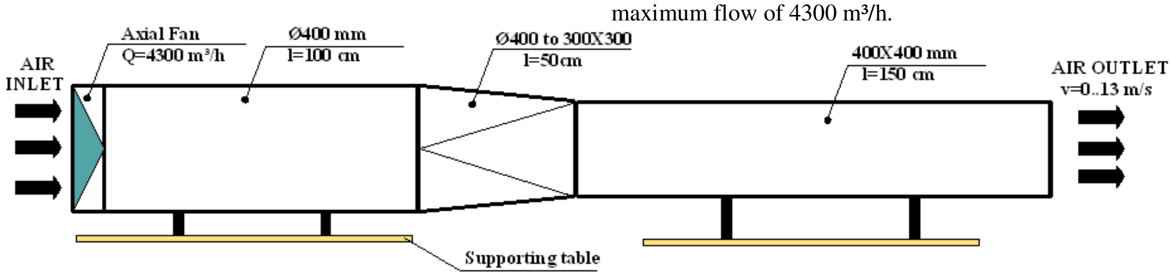


**Fig. 9. Aerodynamic subsonic wind tunnel**



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In terms of existing size of the exit section of the wind tunnel and the air flow circulated by the axial fan, the wind tunnel can provide air speeds, *v* up to 13 m/s. Figure 10 presents a single-stage Savonius wind rotor equipped with a wind concentrator, and the schematic diagram of the experimental installation is shown in Figure 11.

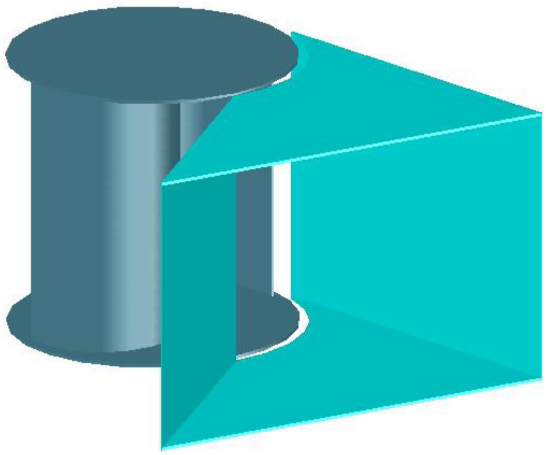


**Fig. 10. Savonius wind rotor equipped with a wind concentrator**

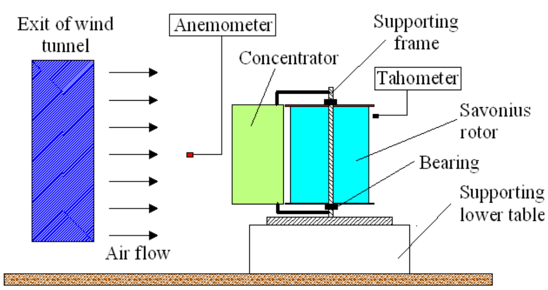



**Fig. 11. Schematic diagram of experimental set-up**

## 4. RESULTS AND DISCUSSION

Although the wind tunnel that was available for the tests offers the possibility that the measurements to be made for winds speeds between 0 and 13 m/s, as vertical axis wind turbines, which are operating on the principle of aerodynamic drag, are of interest only in the case of low wind speeds, the measurements were performed for airflow speeds between 0 and 7 m/s. The air flow speed was monitored using a propeller anemometer placed at the exit of the wind tunnel and the rotational speed of the turbine, corresponding to different wind speeds, was recorded with a digital tachometer.

In the first part of the experiment, the three wind rotors have been subject to the same test conditions, the airflow speed was increased from 0 to7 m/s, with the aid of a speed controller mounted on the motor of the axial fan, and the correlation between the wind speed and the rotational speed of the rotor, unequipped with a wind concentrator, was monitored. The results obtained from the measurements were synthesized through the graphs presented in Figure 12, that show the correlation between the rotational speed (rpm) of the wind rotors and the speed of the air flow (or the wind speed, v).

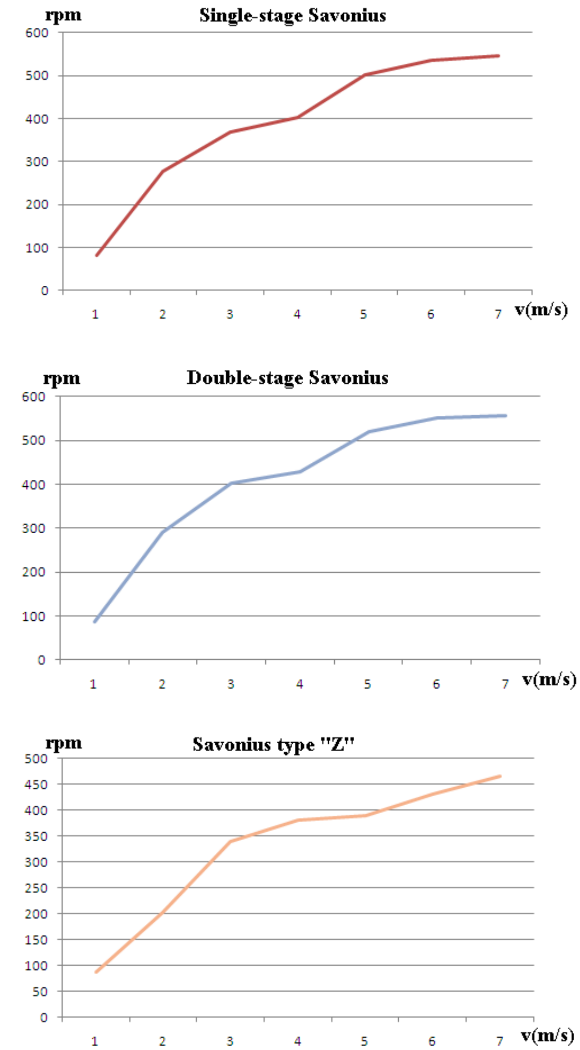
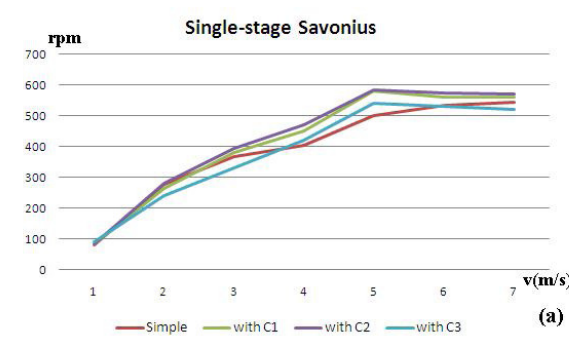



**Fig. 12. The *rpm-v* curves of the vertical axis wind turbines, VAWT's**

In the second part of the experiment, the wind rotors were fitted in turn with each of the three wind concentrators and were subject to the same test conditions as those in the first phase of testing. Based on the data obtained from the measurements, the comparative charts (Fig. 13a, b, c) which are presenting the variation curves of the rotor speed depending on the speed of the air flow for all three configurations of the wind concentrators, as well as if the rotors were not equipped with a concentrator were made.




(a)



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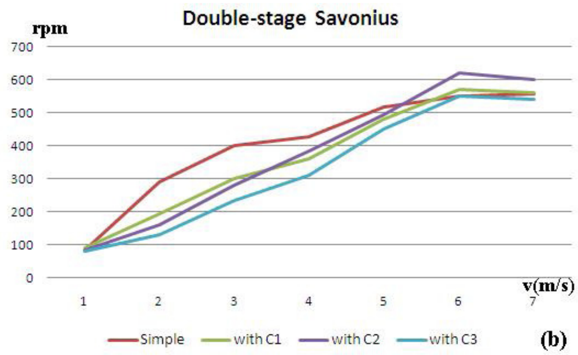


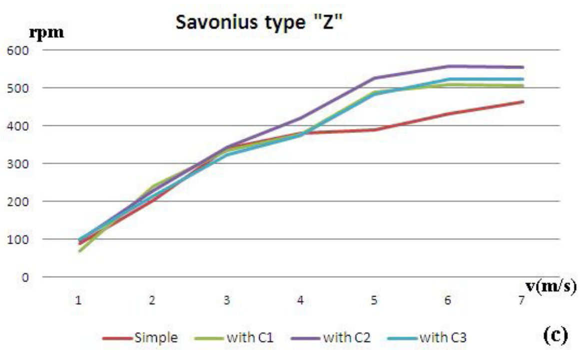


**Fig. 13. The *rpm-v* curves of the vertical axis wind turbines with and without a concentrator**

After the graphs which are showing the *rpm-v* curves of the wind turbines with various constructive configurations were made, and by interpreting the results of the experimental tests, it has been observed that the Savonius rotor with two semi-cylindrical blades and two stages is the most efficient between the three vertical axis rotors used in the experiments, starting at the lowest wind speeds and reaching the highest rotational speeds for all the wind speeds for which it was tested, and thus is the most suitable to be used for electricity generation, in the configuration without a wind concentrator. Also, the Savonius type "Z" wind turbines should be taken into consideration for the replacement of Savonius wind turbines with semicylindrical or semi-elliptical blades, because it is a much more simpler and economical solution in terms of construction, even if this rotors can't reach the performances of the above-mentioned rotors.

Both in the case of the wind turbines with two semicylindrical blades and two stages of the rotor, and in the case of Savonius turbines with a type "Z" rotor, providing a wind concentrator leads to an improvement of the rotor speed by 10 to 20%, values that approach or even exceed the values recorded for the Savonius wind rotor with two stages, in both cases the best results being obtained with the "C2" type concentrator, so using wind concentrators is a very useful method for improving the performance of this type of wind turbines. Regarding the case of the Savonius wind turbines with two semicylindrical blades and two stages of the rotor, no significant improvements of the rotor efficiency are brought by the wind concentrator, its rotational speed having even lower values for wind speeds between 0 and 5 m/s. This is caused by the fact that the construction of the Savonius rotors with two stages, where the upper stage is rotated with $90^{o}$ relative to the lower stage, is based on the very principle of reducing the negative moments acting on the rotor blades, just as in the case of wind concentrators.

It should also be noted that installing wind concentrators on vertical axis wind turbines will cancel the possibility of the turbines to receive wind from any direction, that is why this solution is appropriate only if the air flow has a predominantly unidirectional character, or if some constructive solutions are taken in order to keep the omni-directional nature of this wind turbines, such as the yaw mechanisms used at the horizontal axis wind turbine, with a propeller-type rotor (fig. 14).

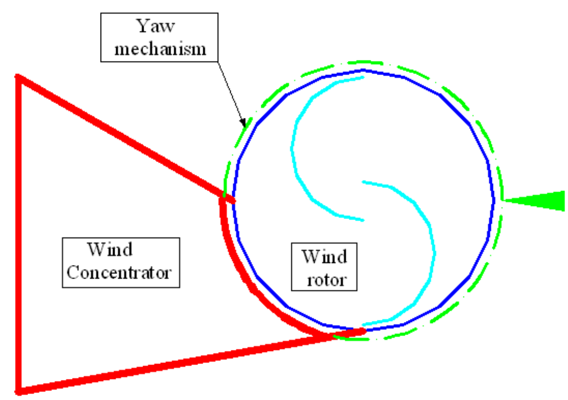


**Fig. 14. Vertical axis wind turbine equipped with a concentrator with a yaw mechanism**

## 5. CONCLUSION

The use of vertical axis wind turbines, which are operating on the principle of aerodynamic drag, can be a very suitable solution for electricity generation in areas where the wind potential is low. However, the relatively low values of the power coefficient of these rotors make them to be very rarely used for equipping wind turbines installations. The improvement of the performance coefficient of these rotors can be achieved by several methods, one of which is the subject of this experimental study, namely equipping the wind rotors with wind concentrators. The most important results obtained after carrying out this experimental study are presented below:

- in the version without a wind concentrator, the rotors with two blades and two stages have the best efficiency;
- by equipping the rotors with wind concentrators, an increase of their efficiency by 10-20% is achieved, but only in the case of single-stage rotors; in the case of double-stage rotors the advantages of the provision of a wind concentrator are insignificant;
- the best results on improving the efficiency of vertical axis rotors were obtained when using concentrators "C2";
- the property of these wind rotors to receive wind from any direction is cancelled when a concentrator is mounted on the rotor, which is why this solution should be adopted only in the



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case of predominantly unidirectional air currents.
- the use of wind concentrators equipped with yaw mechanisms is appropriate, but this solution should be carefully analyzed in terms of cost-benefit.

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## REFERENCES

[1]. Eriksson S., Bernhoff H., Leijon M. – Evaluation of different turbine concepts for wind power, Renewable and Sustainable Energy Reviews 12, 2008, pg. 1419-1434

[2]. Al-Bahadly I. – Building a wind turbine for a rural home, Energy for Sustainable Development 13, 2009, pg. 159-165

[3]. Hau E. – Wind Turbines, Springer, New York, 2006, pg. 81-89

[4]. Deda Altan B., Atilgan M., Ozdamar A. – An experimental study on the improvement of a Savonius rotor performance with curtaining, Experimental Thermal and Fluid Science 32, 2008, pg. 1673-1678

[5]. Deda Altan B., Atilgan M. – An experimental an numerical study on the improvement of the performance of Savonius wind rotor, Energy Conversion and Management, 2008, pg. 3425-3432

[6]. Savonius S.J. – The S-rotor and its applications, Mechanical Engineering 53, 1931, pg. 333-338

[7]. Deda Altan B., Atilgan M. – The use of a curtain design to increase the performance level of a Savonius wind rotors, Renewable Energy 35, 2010, pg. 821-829

[8]. Mussell D. – Build your own wind turbine, The Pembina Institute – Sustainable Energy Solutions, Ontario, 2006

[9]. Hayashi T., Li Y., Hara Y., Suzuki K. – Wind tunnel tests on a three-stage out-phase Savonius rotor, Tottori University, Tottori, 2011

[10]. Kamoji M.A., Kedare S.B., Prabhu S.V. – Experimental investigations on single stage, two stage and three stage conventional Savonius rotor , International Journal of Energy Research, vol 32, 2008, pg. 877-895.



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