Experimental Tests in Equipping Vertical Axis Wind Turbines with Electric Generator

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Abstract- In this paper are presented experimental results obtained by equipping vertical axis wind turbine with electric generator. In the experiments were tested two ways of equipping the turbines, first with a generator connected directly to the rotor shaft and second with a generator, with less power, connected to the rotor shaft through a toothed wheel gear. To achieve these tests were used three types of vertical axis wind turbines, i.e. a single stage Savonius rotor, a double stage Savonius rotor and a single stage type ‘Z’ Savonius rotor.

After tests it was observed that the best solution for equipping wind turbines with electric generator is the one with the connection to the rotor shaft through a toothed wheel gear. In this case, even if the rotor speed values are closer to the first case, the voltage is much higher. At wind speed of 3 and 4 m/s, the single stage Savonius rotor generates more power than the other two. At wind speed of 5 m/s, the greatest amount of power was generated with the double stage Savonius rotor. Following these tests, it can be concluded that, in order to ensure the highest energy production, is recommended to use vertical axis wind turbine with double stage

Keywords Savonius rotor, stage, electric generator, characteristic curves, current, voltage.

1. Introduction

Wind includes an important amount of energy that can be converted into useful energy, usually in mechanical or electrical energy using wind turbines. Currently, wind power exploitations are, in most cases, only in areas with high wind potential, i.e. in areas where the average annual speeds of wind exceeds 7-8 m/s, making only a certain part of the total amount of wind energy to be exploited.

This is caused by the fact that most wind farms are composed of horizontal axis turbines, HAWT, with propeller rotors, which operate on the principle of aerodynamic lift, which, even if in operation at wind speeds of 3-4 m/s, only produce energy while the wind speed reaches 7-8 m/s.

In these circumstances, a large part of wind potential is concentrated in the air masses moving at slower speeds, compared to existing reference values for propeller type turbine, and is not exploited. However, this type of wind energy can be exploited with vertical axis wind turbines (VAWT), which works on the effect of aerodynamic drag (such as Savonius rotors), whose main characteristic is that it can operate and produce energy in severe weather conditions, with low intensity or turbulent wind of nature and frequent changes of direction [1-3].

Due to the simple design and low costs of production and operation, Savonius rotors in different variants, have become increasingly interesting for the production of electricity by converting wind energy into mechanical energy and then into electricity through electric generator.

Choosing the type of the electric generator that should become part of a wind turbine, represents a very important aspect that needs to be treated in accordance with the location of the turbine and with the type of rotor which equips the wind turbine. In what concern the vertical axis turbines, choosing the generator seems to be easier, due to the possibility to be placed at the base of the turbine tower, which makes both the requirements concerning the dimensions and weight of the generator less strict and the process of choosing focused only on the generator's efficiency. However, in this case also appears a discussion on the type of coupling between the generator and the rotor, being the possibility of using both the direct coupling between the rotor and the generator and a coupling through a gearbox or a toothed wheel gear or a belt, in order to multiply the speed of the electric generator. The direct coupling between the generator and the rotor has various important advantages, such as reducing energy loss in the turbine energy chain, high reliability and low investment, maintenance and operation costs, but, in this case, choosing the generator seems to be more difficult due to the fact that it has to produce energy at low speed and highly variable. Coupling the rotor to the generator through a gearbox or a toothed wheel gear or a belt, offers the possibility of using a high speed generator and obtaining a more stable nature of electricity production, but it also has important disadvantages, such as high costs, major losses in the energy chain turbine and numerous problems related to the defects of the system, especially in the case of using gearboxes.

In both equipping solutions, knowing and analyzing the operating characteristic curves of the turbine, namely current variation according to voltage, the I–V curve and the dependence of the power's voltage produced at the generator's terminals, the P–V curve, are very important in exploiting the turbine efficiently, therefore these issues are discussed below.

2. Experimental Tests and Discussions

The analysis of operating characteristic curves of wind turbines was made for the most efficient and representative rotors studied in previous experiments [4,5], that is a simple stage Savonius rotor, with two semi-cylindrical blades with an overlap ratio of blades, e/D=0.3, a double stage Savonius rotor, with two semi-cylindrical blades with an overlap ratio of blades, e/D=0.2 and a Savonius rotor with two blades placed in the shape of the letter 'Z' with an overlap ratio, e/D=0.2. The type „Z" Savonius rotor was used in the experiments because offers a much simpler construction than the one in the case of the Savonius rotor with semi-cylindrical baldes. All rotors used in the experiments have the same constructive sizes (Table 1), so that the swept area of rotors would be the same and all the 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 [6].

Table 1. Constructive sizes of the Savonius rotors used in tests

Dimensional characteristics	Single-stage Savonius wind rotor	Double-stage Savonius wind rotor	Type „Z" Savonius wind rotor
Rotor diameter, D [cm]	18	18	18
Blade diameter, d [cm]	10.8	10.8	10.8
Rotor height, H [cm]	18	18	18
Endplate diameter, D_0 [cm]	19	19	19
Overlap distance, e [cm]	5.4	3.6	3.6
Overlap ratio, e/D	0.3	0.2	0.2

The wind turbines were subjected to the same testing conditions, the experiments being carried out in the case of wind speeds of 3, 4 or 5 m/s, ensured by the open subsonic wind tunnel. All parts of the experiment are shown in Figures 1 to 4.

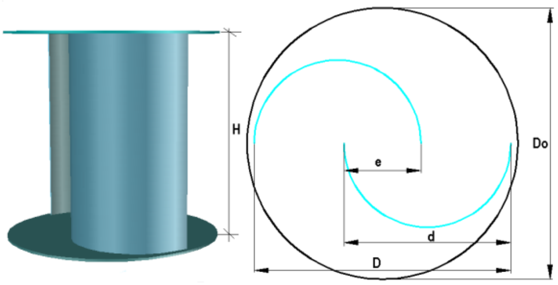

Fig 1. Single stage Savonius wind rotor

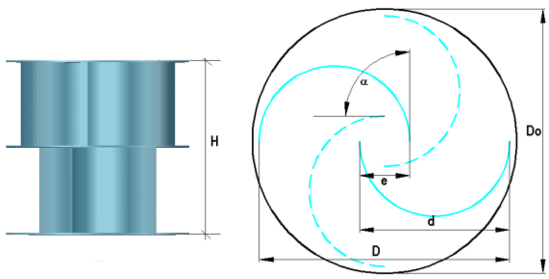

Fig 2. Double stage Savonius wind rotor

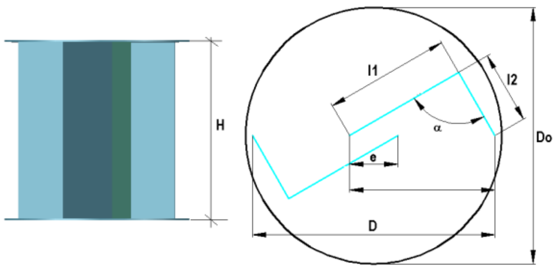

Fig 3. Type ‘Z’ Savonius wind rotor

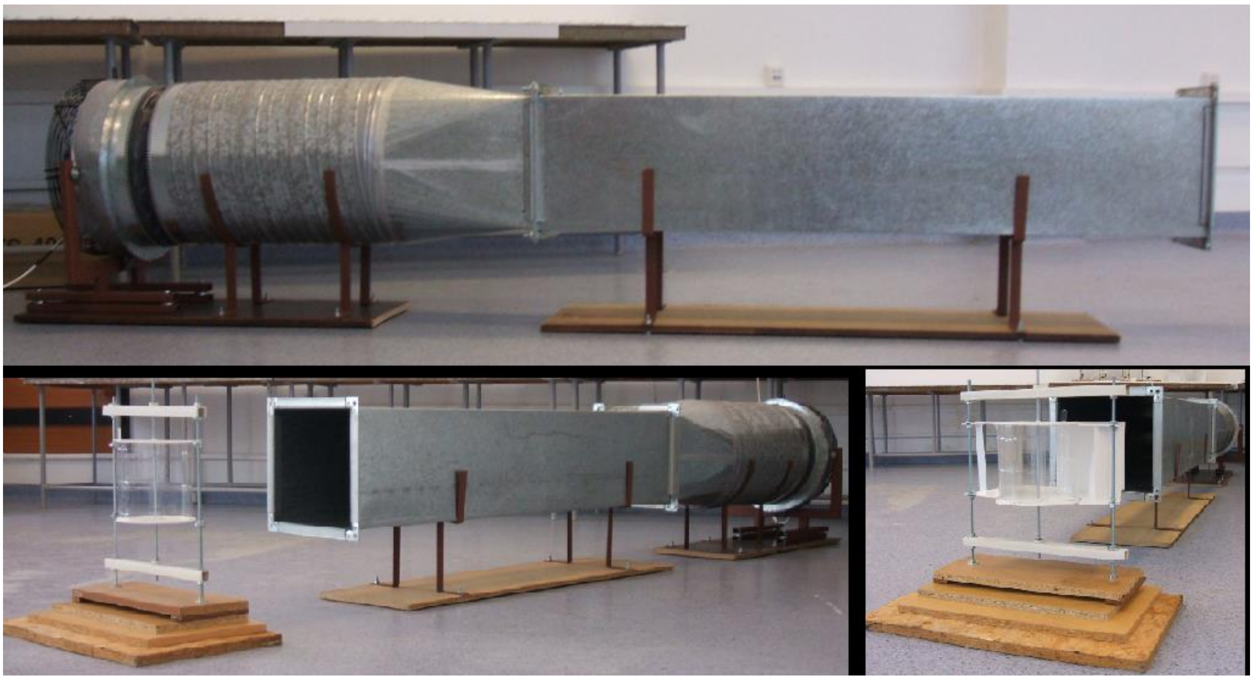

Fig 4. Open-circuit subsonic wind tunnel

In order to achieve the operating characteristic curves of wind turbines, an experimental stand has been used - 'Heliocentris – Clean Energy Trainer' [7] – part of the equipment within the Research Laboratory of the Building Services Faculty from Technical University of Cluj-Napoca. The used hardware and software enable the measuring and record the operating parameters of the turbine, and also simulate some electric charges and enable manual or automatic generation of turbine operating characteristic curves.

In the experiments were tested two types of equipping the turbines, one with a permanent magnet generator, taken from the horizontal axis wind turbine and a rotor propeller that is part of the experimental stand 'Heliocentris' and another one, with a permanent magnet electric generator having a 2 W power.

In the first situation, due to the strong effect of 'cogging' of the electric generator, whose functional characteristics are presented in Table 2 and in Figure 5, the connection between the generator and rotor’s axis, was made directly, through a drive shaft, as it can be seen in Figure 6.

Table 2. The functional characteristics of the CMC-30 generator [8]

Speed	1000 – 3000 rpm
Voltage	2 – 10 V
Current	0.2 – 2 A
Power	0.5 – 6 W
Dimenssions	Diameter: 45 mm; Height: 18.5 mm

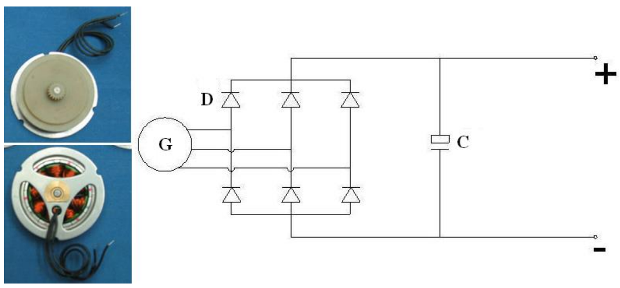

Fig 5. The schematic diagram of the CMC-30 generator

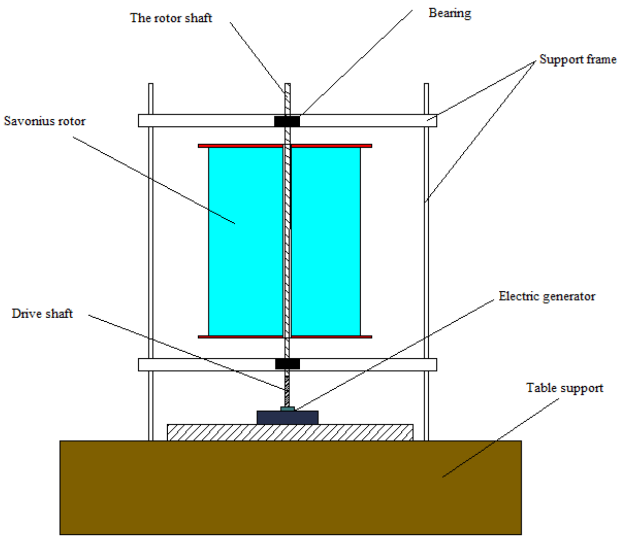

Fig 6. Savonius rotor connected directly at the electric generator

Following the experimental tests conducted, it was observed that the 'cogging' effect causes big problems, both at the start and at the turbine operation, its rotor reaches low speeds, even though the generator's connection type is direct.

The parameters recorded during the tests performed in the case of double stage Savonius turbine are shown in Table 3.

Table 3. The functioning parameters of the double stage Savonius turbine

v [m/s]	V [mV]	rpm
3	191	166
4	313	220
5	380	331

The software and hardware components of the Heliocentris experimental stand, allow the simulation of electric charge corresponding to some values of current up to 500 mA. This aspect, associated with the low values of the voltage measured at the generator's terminals, makes the marking of the characteristic curves I – V and P – V to be impossible. Under these conditions, the experiments were focused on the second wind turbine equipment variant, when an electric generator with permanent magnets and a lower electric power than in the first case was used, of maximum 2 W, connected to the rotor's axis through toothed wheel gear that enables a ratio of speed multiplier 3:1, as it can be observed in Figure 7.

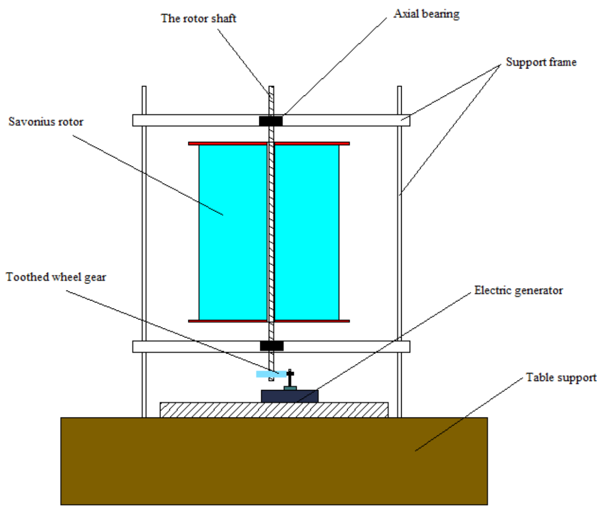

Fig 7. Savonius rotor connected to the generator through a toothed wheel gear

In the case of this wind turbine equipment variant, the results were better, even though the values of the rotor's speed were closer to the ones in the first case, the level of the electric charge in the generator was higher, as it can be noticed in Table 4.

Table 4. The operating parameters of the tested turbines

Turbine type	Registered parameters		
	v [m/s]	V [mV]	rpm
One-floor Savonius	3	1369	293
	4	1782	330
	5	2264	386
Two-floor Savonius	3	1154	302
	4	1476	314
	5	2474	410
Type ‚Z' Savonius	3	967	302
	4	1515	315
	5	1883	335

At the same time, by using the software of the experimental stand Heliocentris, some operating characteristic curves of wind turbines were generated, namely, the dependence curve between current and voltage (I – V curve) and the variation curve of power, according to the values of voltage at the terminals of the turbine's electric generator (P – V curve), corresponding to air flow speeds of 3, 4 or 5 m/s. During the process of tracing these curves, the electrical load was gradually increased, from the minimal value to an appropriate amount of current of 500 mA, all this time registering the voltage variation at generator's terminals and its electrical power. The characteristic curves of the turbines are presented in Figures from 8 to 16, separately for each turbine, depending on the air velocity circulated through the wind tunnel.

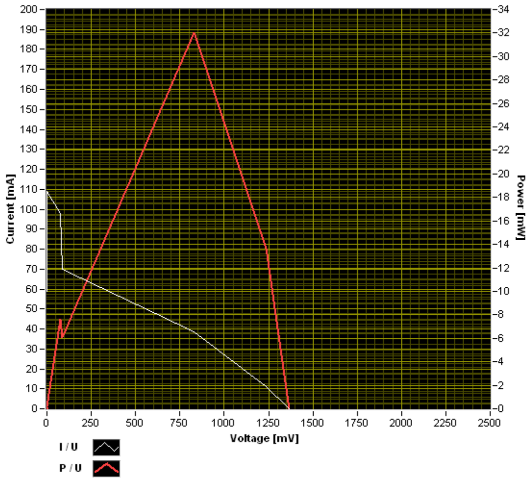

Fig 8. The I–V and P–V characteristic curves for the single stage Savonius turbine, at a 3 m/s wind speed

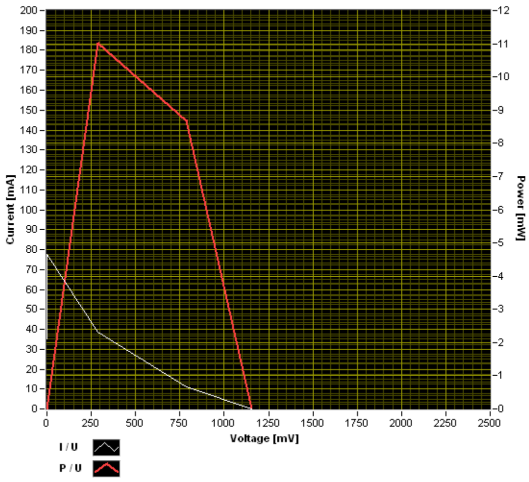

Fig 9. The I–V and P–V characteristic curves for the double stage Savonius turbine, at a 3 m/s wind speed

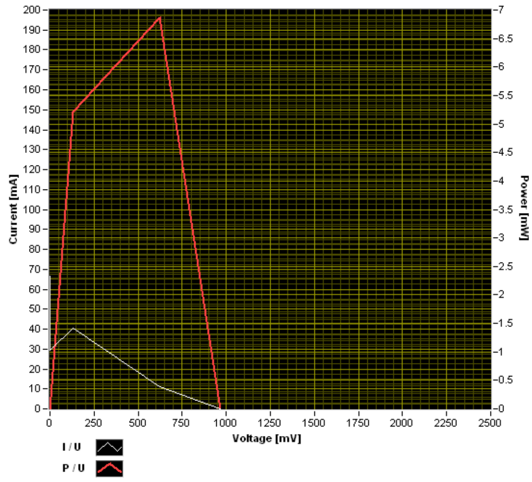

Fig 10. The I–V and P–V characteristic curves for type ‚Z' Savonius turbine, at a 3 m/s wind speed

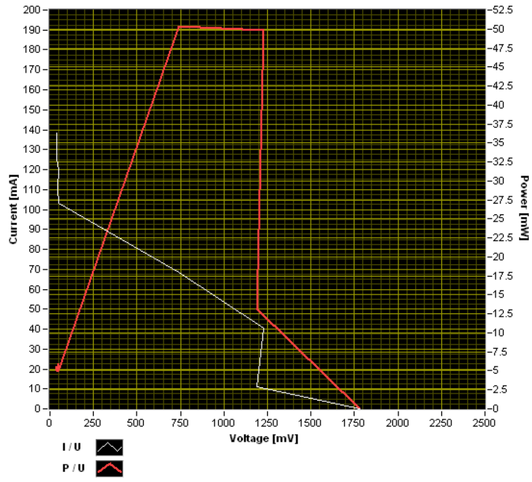

Fig 11. The I–V and P–V characteristic curves for the single stage Savonius turbine, at a 4 m/s wind speed

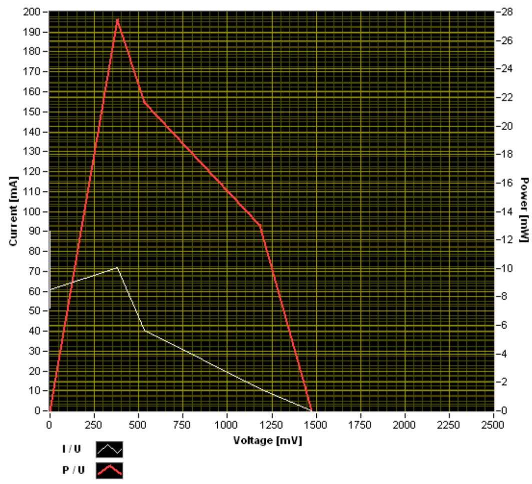

Fig 12. The I–V and P–V characteristic curves for the double stage Savonius turbine, at a 4 m/s wind speed

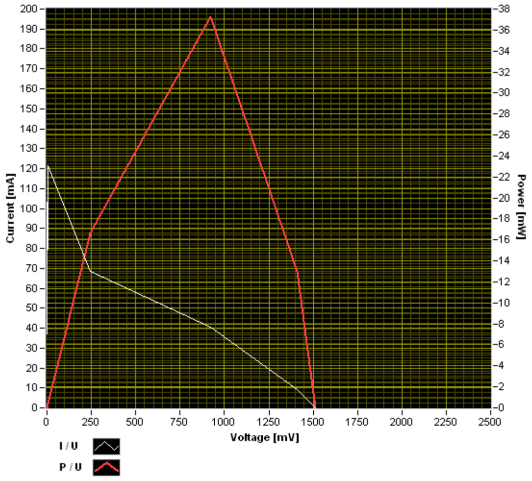

Fig 13. The I–V and P–V characteristic curves for type ‚Z' Savonius turbine, at a 4 m/s wind speed

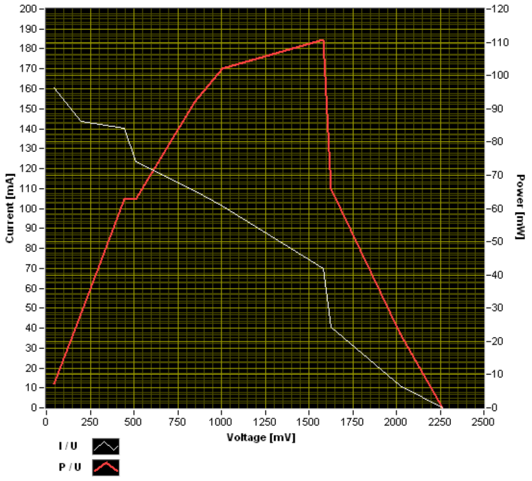

Fig 14. The I–V and P–V characteristic curves for the single stage Savonius turbine, at a 5 m/s wind speed

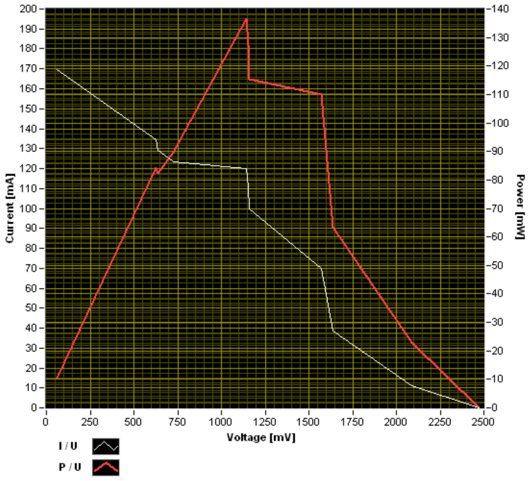

Fig 15. The I–V and P–V characteristic curves for the double stage Savonius turbine, at a 5 m/s wind speed

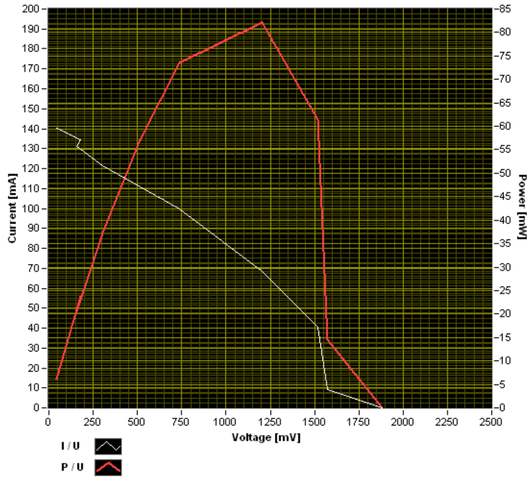

Fig 16. The I–V and P–V characteristic curves for type ‚Z' Savonius turbine, at a 5 m/s wind speed

After a careful analysis of the characteristic curves presented in the previous figures, it can be observed the fact that, in the case of each wind turbine tested and for all air speed that have undergone, the tension measured at the generator's terminals decreases with the increasing of the electrical load, from the maximum value proper to the idle voltage generator, to values close to zero. At the same time, the electrical power of the generator increases from the zero value to maximum value, registered for a certain pair of current – voltage values, than decreasing progressively with the electric load growth undergone by the generator. Likewise, the increase of the electric charge that has to be assured by the generator, leads to a further resistor for the rotational movement of the rotor, registering a progressive decrease of the rotor's speed, from the maximum value obtained in the case of turbine's idling, to a value near to zero, that corresponds to the maximum charge induced using the software, sometimes reaching up to the phenomenon of locking the rotor.

3. Conclusions

In what concern current wind speeds of v=3 m/s, the single stage Savonius wind turbine and a blade overlap ratio of e/D=0.3, generates the highest electrical power, P=32 mW, exceeding the maximum power provided by the double stage Savonius turbine, but also the one assured by the type ‚Z' Savounius wind turbine, that records the lowest values of electrical power. The same pattern is used when talking about an increase of the air's speeds to 4 m/s. The single stage Savonius turbine have the highest power, with the mention that the type ‚Z' Savonius turbine reaches a power superior to that achieved by the double stage Savonius turbine, which is due to the weaker startup. When the wind's speed is increased to 5 m/s, the double stage Savonius turbine reaches the highest power value, P=135 mW, surpassing the other two turbines, the single stage a power of 112 mW and the type ‚Z' reaches a power 82 mW, the same pattern being kept in the case with wind speed values higher than 5 m/s. The conclusions that could be made after analysing the characteristic curves of the vertical axis tested are:

•in order to ensure the highest possible energy yields and to provide a constant torque to the generator's axis, it is recommended to use the double stage turbines with vertical axis;

•choosing the vertical axis turbines, equipped with double stage rotors to the detriment of one stage rotor, must be made only after an analysis of the costs and benefits, this sollution being more difficult to achieve practically and, implicitly, more expensive than the one stage rotors;

•the vertical axis rotorstype ‚Z' offer an excellent replacing sollution of the Savonius rotors with semicircular or semi-elliptical blades, being easier to achieve practically and with minimal financial implications.

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