Production of Electric Energy by Use of Wind Energy

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***Abstract* – Taking advantage of the wind is one of the oldest ways to acquire energy. Traditional wind power sources are classic windmills. Nowadays, we are trying to focus more on generating electricity from alternative sources and one of these sources is also the energy of the wind. The most often uses of the potential of wind power is to generate electricity. In addition, this energy is attractive today because its use does not produce any waste, does not pollute the air and does not have a negative impact on human health. Recently, we can recognize using of so-called "small wind power plants" in households. This paper provides an overview and technological solutions to be taken into account for designing and realizing the construction of a wind power plant. This paper proposed rotor with a horizontal axis which bears the designation of Savoni rotor. This paper represents a contribution to the development of the use of small wind power plants, as contains a large number of illustrations**

***Keywords* – electric energy, wind power, modern technologies, blade rotor**

DOI: 10.18421/TEM73-13
https://dx.doi.org/10.18421/TEM73-13

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Received: 01 June 2018.
Accepted: 26 July 2018.
Published: 27 August 2018.

1. Introduction

It is important to take into account several factors for constructing a wind power plant. Firstly, it would be a location whose choice should be carefully considered because the wind power plant can not be moved. Secondly, it will be the required power or the impact of its operation on the environment. Another important factor is the decision on the type of wind power plant. Vertical rotors are often used – they may be double, triple or more.

This work proposed rotor with a horizontal axis which bears the designation of Savoni rotor. In the past, these variants have not been used due to their properties but thanks to modern technologies, the properties of these rotors have been exploited such as low operating speeds and high torque for power generation [9]. In the meantime, the Savoni rotor has been used especially in pumping equipment.

Wind power plants use the energy of air to generate electricity. The installed output of wind turbines ranges from 2 kW to 4,500 kW. At present, commonly installed devices have a capacity of about 2 MW. More wind turbines in a common location create a wind park, respectively wind farm. Their power reaches 100 MW. In particular, wind parks installed in coastal seawater are ideal, with ideal wind conditions.

2. Choosing the right location of a wind power plant

Many circumstances play an important role in deciding on the construction of a small wind power plant – the type of rotor and power generator, the purpose of the correct location for the best possible efficiency. In this work, we will be familiar with some important aspects of proposal of wind farm study.

For the correct operation of the wind power plant, it is important to choose the correct location. For large wind power plants, there is a wind map created by the Slovak Hydrometeorological Institute with best locations – with the ideal wind velocity which have been recorded for long time. This map should be used for projects that are planned for a long time with great financial costs. For the construction of a small wind power plant for domestic conditions, the map does not go as far as it is, we definitely did not look at the wind map at the time of acquisition – since the location of our garden or cabin [5]. If a high-power wind plant is planned, it runs independently from the wind measurement map information on the site at least one year before the planned construction.

However, for a small wind farm, we do not use previous procedures but we use simpler alternatives. The basis is to choose a place where trees and buildings do not cause wind turbulence to make the wind flow directly over the rotor without turbulence.

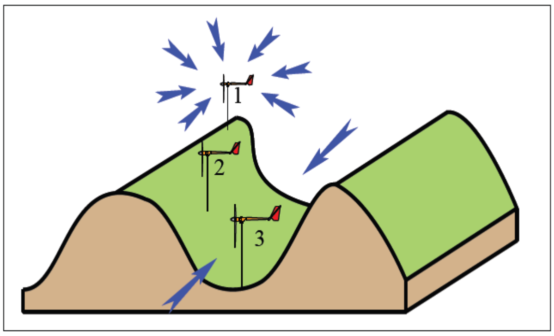

Figure 1. Placement methods depending on the effectiveness of the use, 1-2 good, 3, acceptable

The best place is a completely free terrain without visible obstacles with the closest obstacles like buildings or trees at a distance of 100 to 200 m. In practice, this is difficult, as it would be necessary to use a very long driver which greatly outweighs our investment costs and so in practice this rule is not used much and small wind power plants are built near buildings or gardens.

In order to choose the right place, it is advisable to note that in the Central European countries the wind flow is most often from west to southwest, with the strongest flow being expected from the west. In places where there is a large area or hilly terrain, there are, of course, deviations to be counted on. By regular observation, especially during autumn periods, we can observe the wind flow which creates a circular, spiral flow near the trees. Such places are very unsuitable for site selection because the condition of direct wind flow is not met by wind turbine.

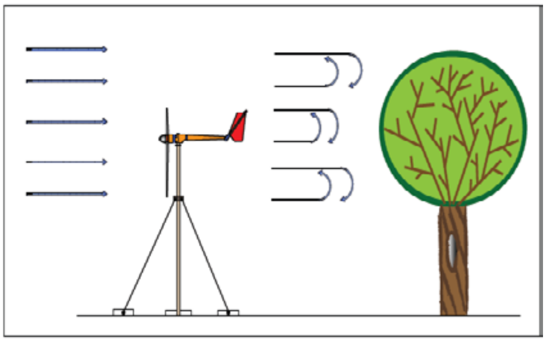

Figure 2. Inappropriate location due to turbulence before the obstacle

3. Processing a wind farm study

When processing a study, it is very important to know local weather conditions or have an available terrestrial map of the territory [1]. Hydrometeorological Institute have performed maps for certain locations and they are available on request in the database of Institute.

The previous chapters already mentioned the correct location of the wind power plant. Now, however, we will still specify the distance that we should observe for the correct efficiency of the device. The easiest way to increase turbine power is to increase the wind speed. This can be achieved either by placing the turbine in a more windy location or by increasing the height of the mast. It is important to note that wind energy can be up to 100% larger at 30 meters than at 10 meters. Appropriate determination is the ratio of obstacle height *H* and height of wind turbine location or distance from obstacle [2, 6]. This will allow for the correct and most efficient operation of the wind turbine during operation.

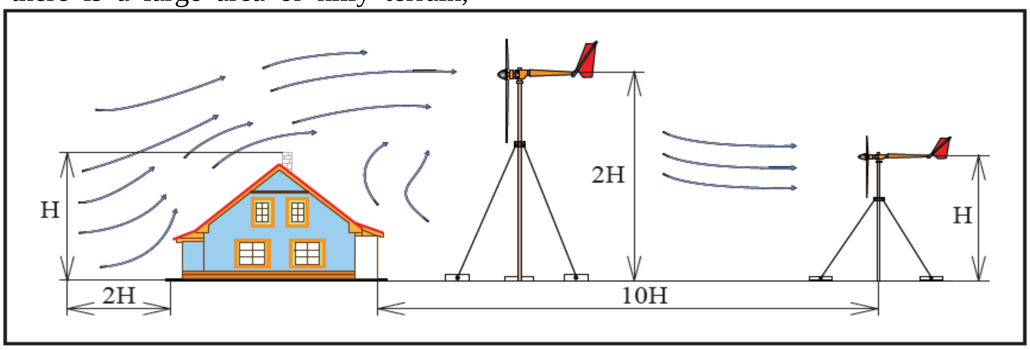

Figure 3. The correct location

The wind power plant must therefore be properly located and easy access should be ensured in the case of repairs or revision checks. As the wind power plant will be used mainly in domestic conditions, it is better to choose an anchor method using a circular cross-section mast which is fixed to the vertical position by means of the anchor ropes [6, 7].

4. Design of a wind power plant with a power of 8 kW

The available literature has been used to process the model which has chosen a suitable alternative for the selection of the wind power structure. It will be necessary to count on the high load of the structure during operation and therefore the variant chosen here contains several anchoring nodes and also beams which interconnect the individual parts of the supporting structure.

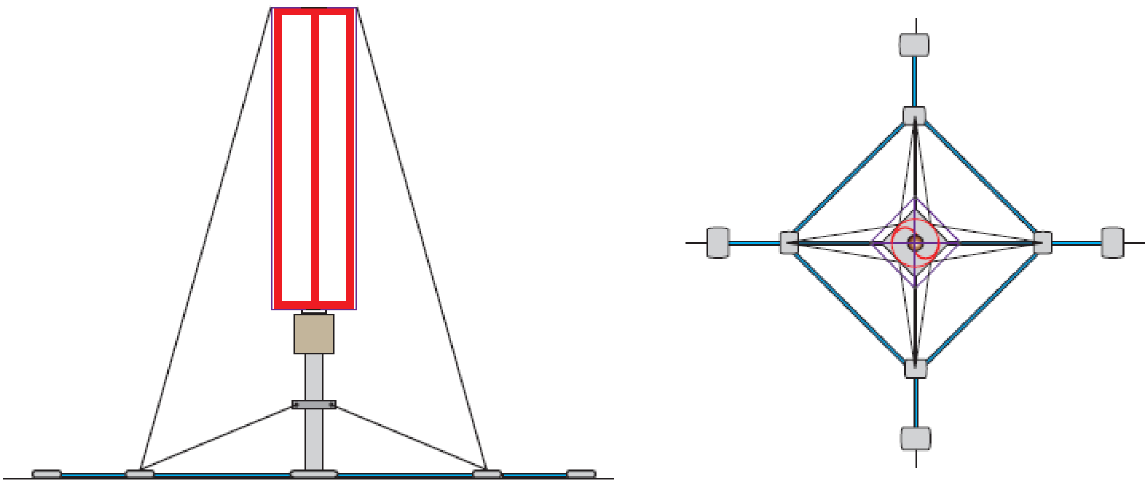

Figure 4. Side and top view of the wind power plant model

Design of the blade rotor:

By acting on the wind turbine air stream, the aerodynamic force is generated which causes movement of turbine. The rotary motion of the turbine is used to drive a generator of the appropriate type which is a direct source of electrical energy [3]. The higher the air flow rate is, the greater is the aerodynamic force acting on the turbine blades. Therefore, the average flow rate is considered to be one of the most important parameters for assessing the suitability of wind power plants. The maximum power we can obtain from wind energy is determined by the Bernoullie equation.

Calculation of pressure when considering airflow:

$$p = \frac{F}{S} = \frac{m \cdot a}{\frac{V}{s}} = \frac{m \cdot a \cdot s}{V} = \frac{m \cdot \frac{v}{t} \cdot v \cdot t}{\frac{m}{p}} = \rho \cdot v^2 \quad [\mathrm{Pa}] \tag{1}$$

Pressure before the turbine:

$$p_1 - p_0 = \rho \cdot \frac{\left(v_1^2 - \bar{v}^2\right)}{2} \quad [\mathrm{Pa}] \tag{2}$$

Pressure behind the turbine:

$$p_2 - p_0 = \rho \cdot \frac{\left(v_2^2 - \bar{v}^2\right)}{2} \quad [\mathrm{Pa}] \tag{3}$$

where: v is the average speed:

$$\bar{v} = \frac{v_1 + v_2}{2} \quad [\mathrm{m}^2 \cdot \mathrm{s}^{-2}] \tag{4}$$

The difference in pressure before and behind the turbine generates an aerodynamic force that causes the turbine to rotate:

$$p_1 - p_2 = \rho \cdot \frac{\left(v_1^2 - \bar{v}_2^2\right)}{2} \quad [\mathrm{Pa}] \tag{5}$$

Aerodynamic force:

$$F = (p_1 - p_2) \cdot S = \rho \cdot S \cdot \bar{v} \cdot (v_1 - v_2) \quad [\mathrm{N}] \tag{6}$$

Followed by:

$$\mathrm{m} = \rho \cdot \mathrm{V} = \rho \cdot \mathrm{S} \cdot \bar{\mathrm{v}} \quad [\mathrm{kg}] \tag{7}$$

After fitting into the Aerodynamic Force:

$$F = m \cdot (v_1 - v_2) \ \ [\mathrm{N}] \tag{8}$$

The power of the wind turbine is determined by the relationship:

$$P = F \cdot \bar{v} = c_p \cdot \rho \cdot S \cdot \frac{v_1^3}{2} \ \ [\mathrm{W}] \tag{9}$$

For executive factor is valid:

$$c_p = \frac{\left(1 + \frac{v_2}{v_1}\right) \cdot \left(1 - \frac{v_2^2}{v_1^2}\right)}{2} \ \ [\text{-}] \tag{10}$$

The maximum value is achieved by the power factor cp at the speed ratio v2/v1 = 1/3. With the aforementioned speed ratio, the highest achieved efficiency of the wind turbine is co called Belz efficiency η=0,5926.

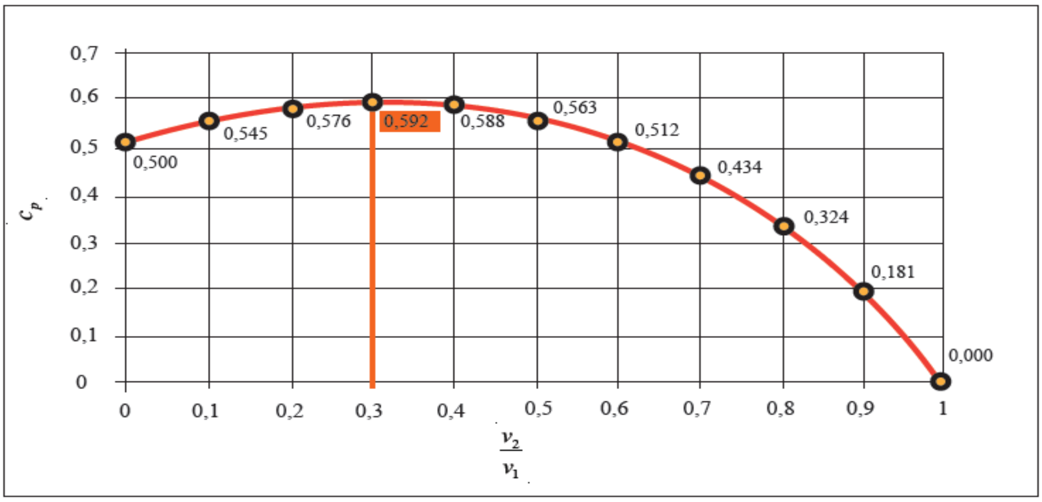

Figure 5. Dependence of the cp power factor on the speed ratio behind and before the turbine

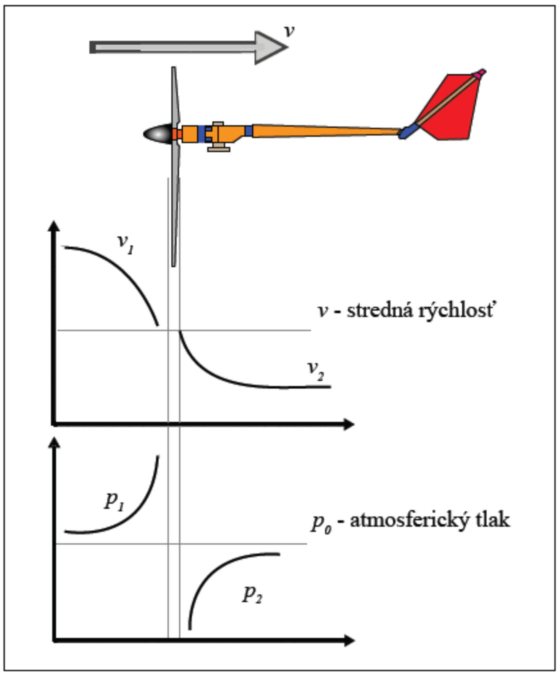

Figure 6. Impression of air flow

5. Study of the modified Savoni rotor

Wind turbines are rated at the nominal running speed, i.e. for a given wind speed. In most cases, especially because of their higher efficiency, two or three paddle speed wind turbines are preferred. Although they undeniably have greater efficiency, this type of wind-driven turbine is not the only option that allows you to get the maximum energy out of the wind.

Using a special method, called the L-σ criterion, it can be shown that a slow-speed vertical wind turbine such as the Savoni rotor, can get more energy than with high-speed horizontal rotors.

This idea seems to be in contradiction with general literature information in the area of Savoni rotors that have aerodynamic properties that clearly lead to low efficiency. In fact, using the same front surface of L and the same mechanical rotor blade loading, it is clear that the Savoni rotor energy delivered is better than in case of other horizontal rotors. In addition, due to its high starting momentum, the Savoni rotor can theoretically produce energy at low wind speeds and due to its low angular velocity, it is capable of delivering electricity at high wind speeds when high wind turbines in general have to be stopped [4, 6]. However, the major disadvantage of Savoni rotor is the high instability of the mechanical torque due to fact that the flow inside the rotor is non-stationary. However, the benefits of this type of wind turbine are numerous. Several studies have taken place over a number of years to increase the performance of these types of rotors.

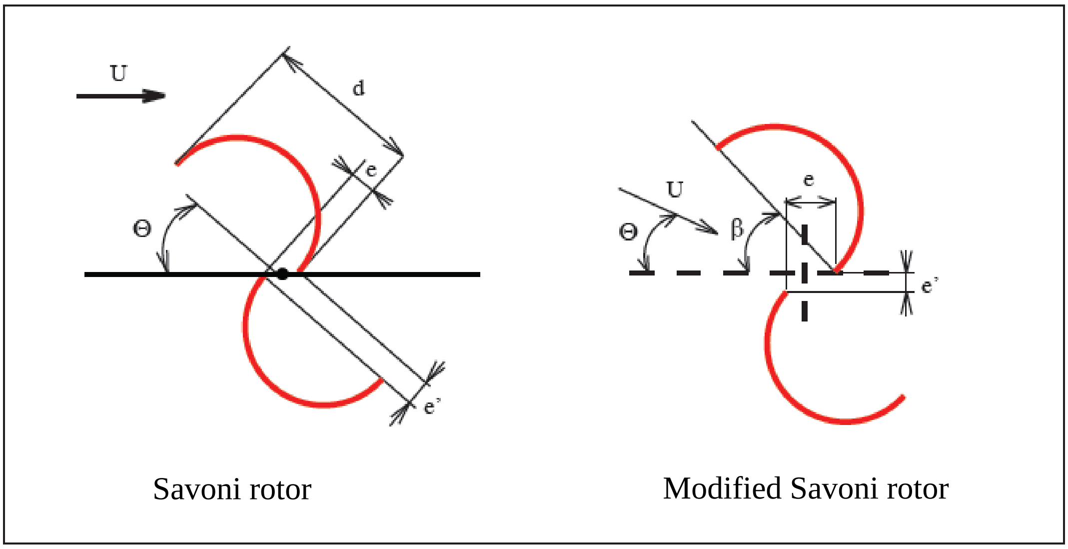

Figure 7. Savoni rotors

The Savoni rotor is made of two vertical semi-cylinders moving around the vertical axis. The modified Savoni rotor comes from a classic Savoni rotor, using three geometric parameters: the main overhang **e**, the secondary overhang **e'**, and the angle β between the vanes. In the following text, we describe the Savoni rotor, for which the geometric parameters e and **e'** are equal to d/6, respectively equal to 0. The characteristic curves of such a rotor (values of *cp* coefficient and torque coefficient *cm* to the relative velocity λ) are shown in the following graph.

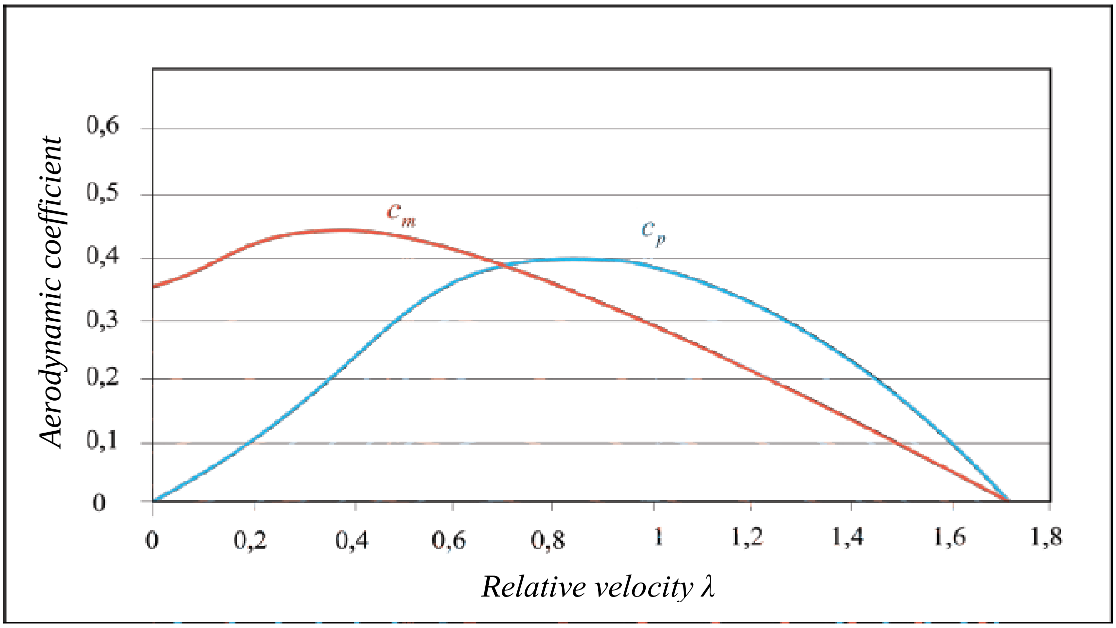

Figure 8. Experimental curves of the Savoni rotor

In this preliminary study the effect on the angle of inclination of the wind flow β on the rotor blades using wind direction values: θ = 90 ° and θ = 45 °. This allows us to determine the optimal value for tilt angle: β = 55 °.

Optimal overlapping values have been systematically examined from obtained values: e / d = 0.242 and e'= 0. The static moment is calculated as in the previous one [7, 8].

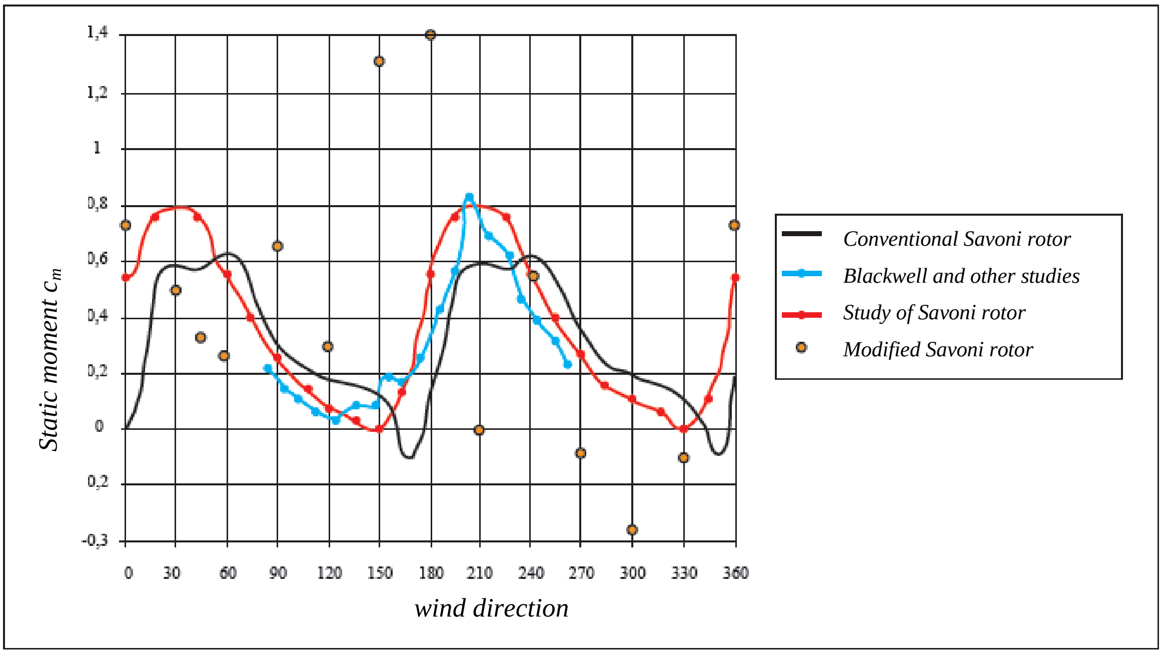

Figure 9. The static moment of the modified rotor
(θ =90°; β =45°; e/d=0.242; e'= 0)

The result is encouraging as a new kind of rotor induces maximum static torque values higher than those that are largely obtained on conventional rotors, even with negative static torque and large angular variations. However, the main torque value is increased: Cm = 0.48, i.e. 60% more than in the case of the conventional rotor.

The correct choice of the three geometric parameters e, e' and θ is necessary not only to increase aerodynamic efficiency but also to correctly select the static torque and the dynamic load of the rotor.

6. Design of own Savoni rotor

The parameters of the Savoni rotor depend on the relative velocity λ which is defined as the ratio of the perimeter velocity *u* to the wind velocity *v*.

The rotor parameters further determine the torque (cm) and power (cp) coefficients. These two coefficients are determined by experimentally obtained curves from the graph where we can obtain the coefficient values for a given relative velocity.

The ratio of 0.8 to 1 applies to the speed at which the Savoni rotor operates at the highest power. We choose λ = 0.9. However, the selected value does not have to agree with the fair value, it is only a preliminary calculation. The actual value is obtained when the finished rotor is tested during the load operation. Only then we will see if the calculated rotor and its operating characteristics result in the selected value λ = 0,9.

After casting the chosen value λ = 0,9 into the graph we get:

- torque coefficient *cm* = 0.33
- *cp* coefficient = 0,3

Subsequently, we will gradually find all the necessary dimensions of the rotor. We start from the value of the required power of the wind power plant, so we work with the value P = 8 kW.

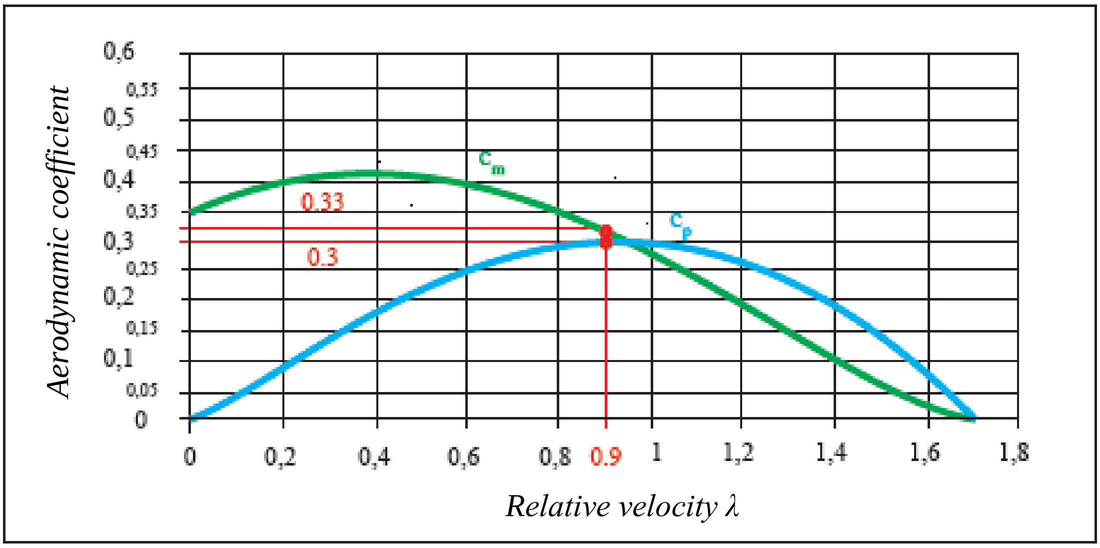

Figure 10. Experimental Savoni rotor curves with plotted values

The Savoni rotor parameter detection procedure is as follows:

1. Calculation of the overall rotor size.
2. Geometry and overlay of blades.
3. Calculation of torque.
4. Calculation of rotor speed.

Calculation of the overall rotor size:

$$P = c_p \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v^3 \quad [\mathrm{kW}] \tag{11}$$

when:
cp – coefficient of power (0,3)
ρ - air density (1,2047)
S – area of the rotor (m^2)
v - wind speed (m/s)

From the formula we can obtain a relationship for calculating the area of the rotor:

$$S = \frac{2 \cdot P}{c_p \cdot \rho \cdot v^3} \quad [\mathrm{m}^2] \tag{12}$$

Thus, after setting the values and wind speeds of 15 m/s which is considered to be minimal for the operation of the wind power plant, we get the resulting value of the area of the rotor:

$$S = \frac{2 \cdot P}{c_p \cdot \rho \cdot v^3} = \frac{2 \cdot 8000}{0{,}3 \cdot 1{,}2047 \cdot 15} = \underline{13{,}11\ \mathrm{m}^2} \tag{13}$$

Then we can calculate the height and diameter of the rotor, starting from the area of the rotor.

Height of the rotor:

$$H = \frac{S}{\sqrt{\frac{S}{4}}} = \frac{13{,}11}{\sqrt{\frac{13{,}11}{4}}} = \underline{7{,}24\ \mathrm{m}} \tag{14}$$

Diameter of the rotor:

$$D = \sqrt{\frac{S}{4}} = \sqrt{\frac{13{,}11}{4}} = \underline{1{,}81\ \mathrm{m}}$$

Geometry and overlay of blades

D – diameter of the rotor (1,81 m)
d – small diameter of the rotor
e - main overhang (216 mm)
da – shaft diameter (25 mm)

The small rotor diameter is calculated from the relationship:

$$d = \frac{e - d_a}{\beta} = \frac{216 - 25}{0{,}207} = \underline{922{,}70\ \mathrm{mm}}$$

For the rotor without the center shaft:

$$d = \frac{e}{\beta} = \frac{216}{0{,}207} = \underline{1043{,}47\ \mathrm{mm}}$$

where β is the value of overlay of blades and it is 0,207.

Calculation of torque

For calculation, we count from the relationship:

$$M_k = c_m \cdot \frac{1}{4} \cdot \sigma \cdot D \cdot S \cdot v^2 \tag{15}$$

We calculate the value of the torque for two extreme wind speeds – for a minimum value of 15 m/s and a maximum value of wind speed of 25 m/s.

$$M_{k15} = c_m \cdot \frac{1}{4} \cdot \sigma \cdot D \cdot S \cdot v^2 = 0{,}33 \cdot \frac{1}{4} \cdot 1{,}2047 \cdot 1{,}81 \cdot 13{,}11 \cdot 15^2 = \underline{7959{,}538 \text{ Nm}}$$

$$M_{k25} = c_m \cdot \frac{1}{4} \cdot \sigma \cdot D \cdot S \cdot v^2 = 0{,}33 \cdot \frac{1}{4} \cdot 1{,}2047 \cdot 1{,}81 \cdot 13{,}11 \cdot 25^2 = \underline{36849{,}71 \text{ Nm}}$$

Calculation of rotor speed

The rotor speed is again calculated for two extreme situations, for minimum and maximum wind speeds.
Relationship for calculating rotor speed:

$$n = \frac{\lambda \cdot v}{2 \cdot \pi \cdot R} \left[{}^{ot}/_{s}\right]$$

Speed for a minimum flow rate of 15 m/s and a maximum value of 25 m/s.:

$$n_{15} = \frac{\lambda \cdot v}{2 \cdot \pi \cdot R} = \frac{0{,}9 \cdot 15}{2 \cdot \pi \cdot 0{,}905} = \underline{2{,}375 \left[{}^{ot}/s\right] \to 142{,}5 \left[{}^{ot}/min\right]}$$

$$n_{25} = \frac{\lambda \cdot v}{2 \cdot \pi \cdot R} = \frac{0{,}9 \cdot 25}{2 \cdot \pi \cdot 0{,}905} = \underline{3{,}95 \left[{}^{ot}/s\right] \to 237{,}5 \left[{}^{ot}/min\right]}$$

Table 1. Summary of calculated values for the proposed rotor

v – relative velocity	0,9
C_p – coefficient of power	0,3
C_m – coefficient of the moment	0,33
S – area of the rotor	13,11 m^2
H – total rotor height	7240 mm
D – diameter of the rotor	1810 mm
e – the main overhang	216 mm
d – small diameter of the rotor	922,70 mm
d_a – shaft diameter	25 mm
β – overlay of blades	0,206
C_ρ – density of air for 20°C	1,2047 kg/m^3
Power, v = 15 m/s P15	7995,5 W
Torgue, v = 15 m/s Mk15	7959,538 Nm
Number of roations, v = 15 m/s n15	142,5 ot/min
Power, v = 25 m/s P25	37016,28 W
Torgue, v = 25 m/s Mk25	36849,71 Nm
Number of roations, v = 25 m/s n25	237,5 ot/min

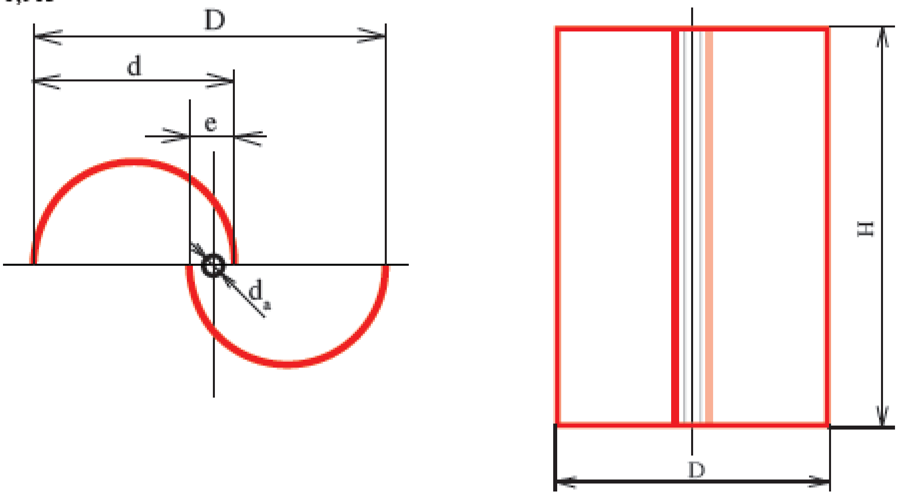

Figure 11. Rotor parameters

For the load and performance required, the proposed equipment is the following:

- As a generator, Siemens asynchronous engine with the designation 1LA7 131 and power of 8.6 kW is used. This is a 2-pole motor that is rotated by the gearbox at a speed corresponding to the generator state, i.e. the state when the engine starts to produce electric power.
- It is advisable to use a gearbox as a multi-gearing gear, since the input shaft has a low speed and a speed of about 3000 rpm is required at the output. These conditions best match the transmission from Wikow.
- Recuperative converter is the model used by VONSCH and the designation QUATROFREM 400 011.

The prepared technical solution for this type of wind power plant will have the following basic features:

- The power plant will use the Savoni rotor for wind power conversion.
- Rated power of the power plant is 8kW.
- The power plant is equipped with an asynchronous generator with gearbox and regenerative inverter.
- The power plant can be connected to the public grid during its operation.

7. Conclusion

The aim of the work was to prepare a study of a wind power plant with an output of 8 kW. The resultant product is the construction of a preliminary model of the wind power plant and also the design of the used rotor. It is not possible to give a precise answer to the question whether the rotor we used when designing a given wind power plant is the most appropriate. The work suggests that considering the many technical factors, it is very important to thoroughly map the site where the wind power plant is to be built. After the basic measurements, design of the wind farm and its rotor can be started.

Important aspects for building of wind power plants:

- renewable source without harmful substances,
- developed technology (although research is not over yet),
- relatively simple construction, suitable for local use,
- land at wind farms can be further used to grow grain, pastures, many wind farms are located on deserts that have not yet been used,
- the best conditions for wind power plants are in winter through the day,
- create job opportunities.

This work represents a contribution to the development of the use of small wind power plants, as contains a large number of illustrations, so it can be recommended to students of technical schools.

Acknowledgement:

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic (Project VEGA 1/0251/17 and VEGA 1/0376/17).

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