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RESEARCH ON THE EFFICIENCY OF SMALL CAPACITY WIND TURBINES IN THE BUILT ENVIRONMENT

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Abstract: *Renewable resources are an important source of green energy to be integrated both in the built environment, not only in industrial parks. The paper aims to identify the main characteristics of small capacity wind turbines, power conversion mode, and the development of concepts to be implemented successfully in the built environment. Efficiency of small capacity wind turbines differs from that of industrial turbines and to establish the main potential users needs and the performance characteristics for such turbines were applied competitive engineering techniques.*
Key words: *small capacity wind turbine, efficiency, speed, HAWT, VAWT, built environment.*

1. INTRODUCTION

Wind potential of an area is determined by the wind speed and its distribution in time. High capacity wind turbines are found in wind parks where the wind potential of the area has been proven, and setting up a wind park is profitable. Instead, small capacity wind turbines are found in areas where the wind regime is changing and it is influenced by many factors.

Wind speed is not constant for a location, as it is influenced by climate, season, area, height, etc., and in order to determine the best use of it is, an assessment should be carried out regarding the annual average wind speed over a period of 10 years [1].

Urban or rural areas are characterized by low wind speeds, which is why the interest would be to improve wind turbines so as to capture more energy in the given conditions.

The role of small capacity wind turbines is to ensure the energy needs of a consumer or group of consumers, such as householders or various urban systems, as well as street lighting, parking taximeters, etc.

Small capacity wind turbines have a capacity of up to 100 kW, representing the maximum power that can be connected to a low voltage network.

According to a Carbon Trust study on the energy potential of small capacity wind turbines, it has been showed that these could provide 1.5 TW/year of electricity, that is 0.4% of all electricity in the UK, which would reduce CO2 emissions by 0.6 million tons per year [2].

In terms of manufacturing technologies, these turbines differ from those of large capacity due to special requirements in terms of installation locations. Differences are found in many subsystems, both in the electrical and control ones, and also in terms of the geometry of the active parts, their appearance, materials that need to be used, etc.

A wind turbine typically works in environments subject to weather such as rain, ice, dust, strong gusts, turbulence, so it must bear all the variations of wind speed and direction, but it also has to fit aesthetically into the environment where it is located.

2. GENERAL TECHNICAL SPECIFICATIONS OF SMALL POWER WIND TURBINES

- **CIS (Cut in speed) –** Wind speed at which the turbine starts.

The torque exerted on wind turbine blades at low wind speeds may be insufficient to make the rotor spin. The speed at which the turbine begins to rotate and produce energy is called the cut in speed and it usually is in the range of 3-4 m/s, while for the low-capacity turbines it may be less than this value, even 1 m/s [3, 4]. Table 1 shows the percentage of low-capacity wind turbines that have the cut in speed at different values.

Table 1

Distribution of small capacity wind turbine in relation to the cut in speed

Cut in speed (CIS)	Percentage (%)
< 3 m/s	47
≥ 3 m/s < 4 m/s	38
≥ 4m/s	14

- **Nominal power and nominal speed of the wind**

If the wind speed goes above the starting point, the generated power starts to increase until it reaches a maximum obtainable power.

This limit is typically within 12-17 m/s. The maximum generated power is called the nominal power, and the speed at which it is reached is called the nominal speed of the wind (Figure 1).

In urban areas, where the wind speed is lower, wind turbines achieve the nominal power at lower speeds, making it capable of producing the maximum power for a longer period of time. In the table below one can see the percentages of turbines power that reach the nominal power at a certain wind speed [4].

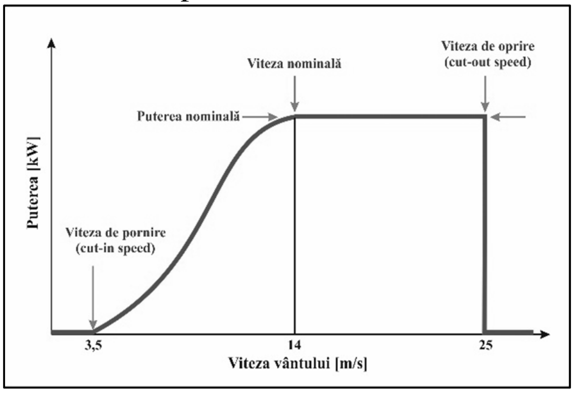

Fig. 1. The power produced by a turbine in relation to the undisturbed wind speed

Table 2

Distribution of small capacity wind turbines in relation to the nominal speed of the wind

Nominal wind speed	Percentage (%)
< 11m/s	26
≥ 11m/s < 13m/s	46
≥ 13m/s < 17m/s	21
≥ 17m/s	7

- **COS (Cut out speed) –** Wind speed at which the turbine stops operating and safety systems

The higher the wind speed rises above the nominal speed, the greater the forces acting on the turbine, in such a way that from a certain value there is a risk of damaging the blades, the generator, the rotor and other parts. In order to prevent the damage, systems can be used that help breaking the wind capture or stop the rotor. The methods by which the wind speed can be controlled or lowered are:

- Passive stall control: turbine blades are designed so that at high wind speeds they lead to its slowdown.
- Active pitch control: turbine blades incline so that the amount of energy to be reduced and this happens by changing the angle of attack of the blade.
- Yaw or tilt control: rotor axis is actively or passively controlled in order to move away from the wind. When controlling the deviation, the platform is rotated so that the profile of the turbine to reach the wind direction, whereas at tilt control, the nacelle inclines until the axis of rotation is perpendicular to the ground.
- No control is necessary – mechanical and electrical components are built sturdy enough to cope with any wind conditions.

For most turbines currently available in the market there is no power control. They are designed to withstand winds of high speed and not stop working at any wind speed. Their percentage based on the cut out speed is shown in table 3.

Table 3

Distribution of low capacity wind turbines in relation to the cut out speed

Cut out speed (COS)	Percentage (%)
No limit	54
≥ 20m/s	36
≥ 15m/s < 20m/s	7
≥ 10m/s < 15m/s	3

- **Auto-start**

Some wind turbines require additional power to start. As far as the small capacity wind turbines are concerned, more than 95% are able to start on their own.

- **Life expectancy**

The estimated lifetime is of 20 years, which means the equivalent of approximately 120,000 hours of operation. In reality, it is influenced by the operating conditions, turbulence, temperature, and climate, the quality of the turbine or other factors.

- **Maintenance**

Maintenance differs depending on the type of turbine; it may be easier or more complicated due to the location of mechanical components, in the platform at height for HAWT or at ground for VAWT. In general, wind turbines require little maintenance. However, most producers consider it necessary to lubricate the bearings once or twice a year and an overhaul of the turbine once a year in order for the system to be controlled at optimum parameters.

2. WIND ENERGY CONVERSION

The role of wind turbines is to transform the kinetic energy of moving air masses into mechanical energy. Power conversion scheme is shown in Figure 2.

The process of converting kinetic energy into mechanical energy comes with energy losses, varying from one turbine to another.

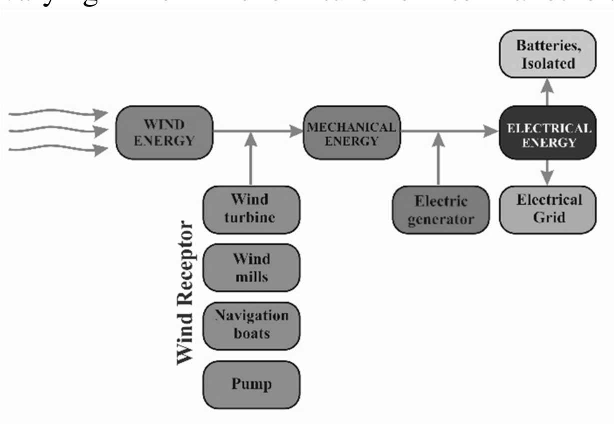

Fig. 2. Energy conversion diagram

In order to determine the energy extracted by a wind turbine, the rotor is replaced with an active disk, where energy absorption occurs when airflow passing through the active disc, due to the fall of static pressure $\boldsymbol{p_1}$ on the upstream area of the disc and $\boldsymbol{p_2}$ corresponding to downstream areas, the pressure drop beeing considered constant over the disc surface. Applying the Bernoulli's law, called the mechanical work of pressure forces we can calculate the pressure losses of airflow speed after the ideal rotor.

$$p_2 + \frac{\rho U_1^2}{2} = p_1 + \frac{\rho U_0^2}{2} \qquad (1)$$

where $\boldsymbol{p_2}$ and $\boldsymbol{p_1}$ are the static pressures, $\boldsymbol{p_2 < p_1}$, then $\boldsymbol{U_0 > U_1}$.

Ideal power coefficient $\boldsymbol{C_p}$ is calculated as the ratio of output power taken by the idealized rotor and airflow power in front of the active disk.

$$C_p = \frac{P_u}{\frac{1}{2}\rho A U_0^3} \qquad (2)$$

Regardless the aerodynamic performance of a turbine in all operating conditions and its location or the geographic characteristics of the site or airflow specific properties, the maximum energy that can be extracted from an air stream is 59.3%. In reality, the efficiency of wind turbines is under Betz factor, for the most performant turbines being between 0.45 and 0.50% [5].

By analyzing the previous relations we can say that the optimal speed of air flow in the rotor is $\boldsymbol{U_{opt}} = 2/3\boldsymbol{U_0}$. Thus, after the rotor the air flow velocity is three times lower than the flow velocity in front of it.

3. CONCEPT DEVELOPMENT

An analysis of the performance of small capacity wind turbines was presented in [6], and the results, as is illustrated in figure showed that the turbine Turby has the best performance in a restrains speed range, while Energy Ball provides a power coefficient relatively stable over a wide range of speeds. The worst performance is for Windspire turbine [6].

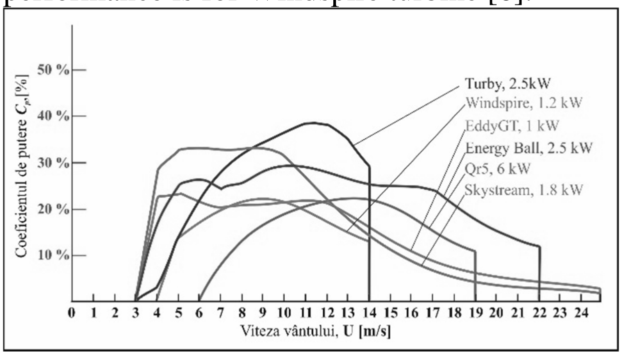

Fig. 3. The power coefficient of analyzed turbines

Based on the performance of small capacity wind turbines and the identified criteria it is aimed the conceptual development of small capacity wind turbines installed in the built environment.

The main needs for such wind turbines have been identified based on questionnaires completed by potential client and based on the results previously obtained. These needs were analyzed using Qualica QFD software.

The main needs of such wind turbine are:

1. The turbine must start at low speeds
2. The wind turbine could be mounted on buildings
3. Low noise
4. The turbine have to capture the wind from any direction
5. The turbine has to withstand extreme weather conditions, wind gusts, frost, turbulence etc.

Considering the main needs for the wind turbine, the development of the concept was performed in two stages. In the first stage, the specific requirements and their importance have been identified, which were then translated into a technical language representing the performance characteristics for the proposed turbine. The second phase consisted of choosing the concept and its development.

3.1 The first stage

Based on the "Voice of the Customer Table" method, in which the requirements, needs, preferences and expectations for the product are identified, were determined the critical requirements of the product that must satisfy the demanded requirements.

In order to understand the relative importance of each requirement and to establish a hierarchy based on this importance, the "Analytic Hierarchy Process" was used and the results are shown in Figure 4. The first four most important requirements which were identified are:

1. The turbine has to withstand extreme weather conditions, wind gusts, frost, turbulence etc. (15%)
2. The turbine have to capture the wind from any direction (11,6%)
3. The turbine must start at low speeds (8,9%)
4. Reduced vibrations (8,1%)

The final result was obtained using the geometric method [7]:

$$R_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j}^{n} a_{ij}\right)^{\frac{1}{n}}} \tag{3}$$

where:

- R_i represents the importance index of the requirement *i*
- a_{ij} represents the relationship between element *i* and element *j*

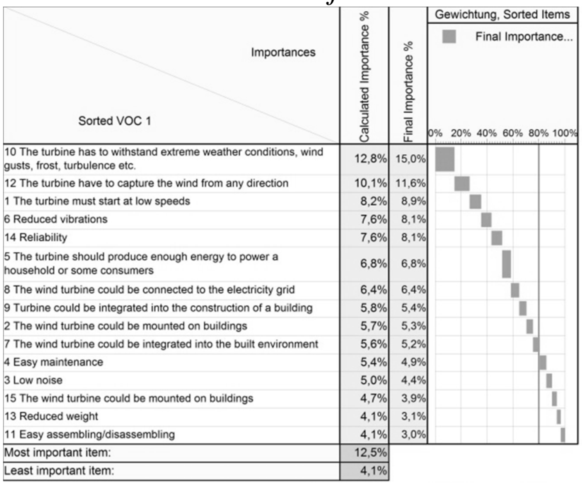

Fig. 4. AHP Diagram

For quality planning at the performance characteristics level were determined the measurement units, the target values and the optimization direction for each feature. "The House of Quality" method was used to establish correlations between the user requirements and the technical performance characteristics, to determine how much contribution the improvements of the performance characteristics have on achieving the requirements and, at the same time, to identify the conflicts arising between them.

The importance value of each characteristic was obtained with the formula [7]:

$$W_j = \sum_{i=1}^{n} R_i \cdot a_{ij} \ , j = 1, \dots, m \tag{4}$$

where:

- R_i represents the requirement importance index *i*, *i=1,…,n,*
- a_{ij} represents the relations between element *i* and element *j,*
- W_j is the value weight of characteristic *j*, *j=1,…,m.*

The relative importance value for each characteristic was obtained with the formula:

$$W_j^{rel} = \frac{W_j \cdot 100}{\sum_{t=1}^{m} W_t} \ , j = 1, \dots, m \tag{5}$$

Eighteen performance characteristics were identified, the most important of which are shown in the graph in Figure 5. As it can be seen from the graphic, the most important requirements are those that satisfy the need of producing enough energy to power a consumer, the possibility to be integrated in the build environment and the characteristics related to the wind capture.

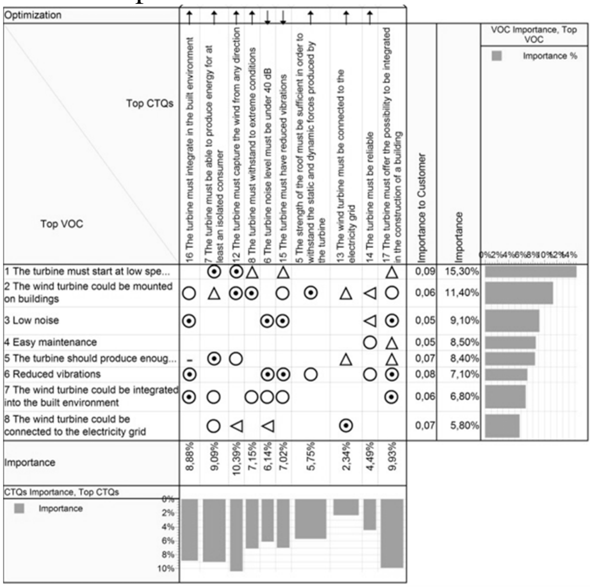

Fig. 5. QFD Diagram

3.2 The second stage

Based on the performance characteristics, constraints and functions that must be satisfied by the turbine various design concepts were taken into consideration, ultimately choosing the concept that resolves as many conflicts without compromising some features. The main conflicts or negative correlations identified are those between the following characteristics:

- The possibility to be mounted on buildings and the noise and vibration level
- The wind speed and the need to produce enough energy to power a household or other consumers.
- The fact that the turbine have to withstand extreme weather conditions with the possibility to be integrated and monted on buildings

Considering these conflicts and the other performance characteristics were developed two wind turbines constructive solutions based on H-Darrieus concept which ensures achievement of significant benefits that will help improve the overall performance of the mentioned concept. First concept refers to a vertical axis wind turbine type H with straight blades (Figure 6) and the second one for a vertical wind turbine with helical blades, which provide more uniformity of rotation, and, respectively, to a increasing utilization coefficient of wind power (Figure 7) . For each model were adopted several blade models with different design elements.

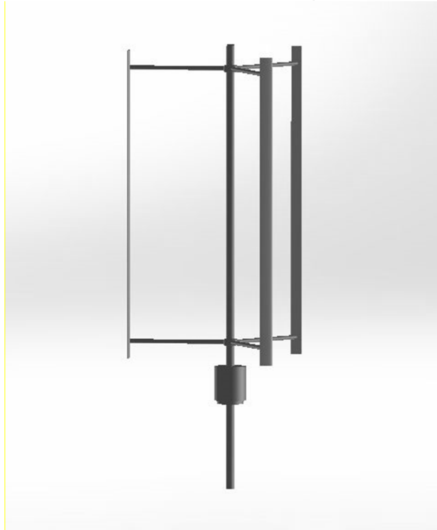

Fig. 6. H rotor wind turbiene with straight blades

Based on the build environment conditions the proposed wind turbines were designed to operate in a wide range of climatic conditions, with working temperature ranges within – 40º C and + 40º C, the wind speed - between 3 and 25 m/ s and with a structural design of the turbine to withstand wind gusts of about 50 m / s. It should be noted that the proposed constructive solutions can be used for a wide range powers of wind turbines: at very low powers up to several hundred kW.

Also, these turbines were designed to cover the energy needs of a individual consumer and small rural households and to install them in urban areas such as roofs.

For each type of turbines were carried out numerical simulations that provides the performance for each turbine. The numerical simulations offers the possibility to obtain relevant information on wind turbines aerodynamics, in a shorter period of time and with considerably less financial resources, compared to the traditional methods for testing the wind turbines, which often requires testing in large wind tunnels or in situ experiments for extended periods of time.

The results of the simulations were presented in [8], and have demonstrate a higher performance for the helical blades wind turbines, due to the existence, in any position, of an optimum blades positioning area relative to the flow direction. In case of straight bladed turbine, the performance is lower, due to dead zones, when the blades are opposed to the flow direction.

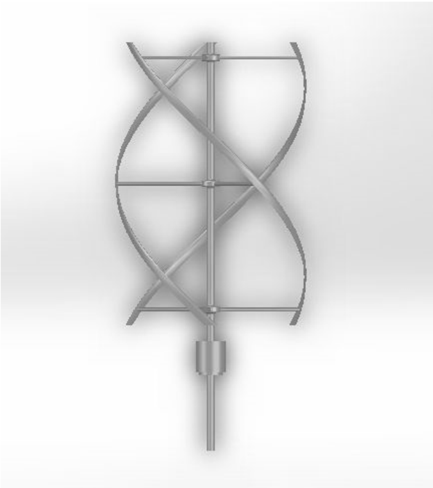

Fig. 7. Vertical wind tubine with helical blades

4. CONCLUSIONS

Over the past few years, the interest was for developing small wind turbines and most of these designs are marketed as being roof-mounted, many of them using vertical axis technologies.

The current trends are for integrating wind turbines in the built environment, a dynamic environment that on the one hand imposes many constraints, but at the same time offers many possibilities for designers. Installing turbines in urban environment involves a complex process, based on many researches that imposed applying optimizations both to the blades shape and also to the whole wind rotor design.

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CERCETARI PRIVIND EFICIENTA TURBINELOR EOLIENE DE CAPACITATE MICA IN MEDIUL CONSTRUIT

Rezumat: Resursele regenerabile constituie o sursa importanta de energie verde, ce trebuie integrata atat in mediul construit, nu doar in parcurile industriale. Lucrarea are rolul de a identifica principalele caracteristici ale turbinelor eoliene de capacitate mica, modul de conversie a energiei, cat si dezvoltarea de concepte pentru a fi implementate cu success in mediul construit. Eficienta tuebinelor eoliene de capacitate mica difera de cea a turbinelor industrial, de aceea pentru stabilirea principalelor nevoi cat si a caracteristiclor de performanta pentru astfel de turbine s-au aplicat competitive engineering techniques.

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