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SMALL WIND TURBINES - PERFORMANCE INVESTIGATION

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Abstract: *Wind turbines operate differently in urban wind regime which is influenced by wind regime, season, obstacles, other buildings, and other factors, so to know the performance of wind turbines in this environment becomes a necessity. This paper proposes to analyze the performance of low power wind turbines installed in urban areas by comparing the performances provided by the manufacturers and experimentally. With Wind Power program is draw the power curves and calculates energy production possibilities for each turbine, and finally quantify performance ranges for studied turbines.*

Key words: *small wind turbines, performance, power coefficient, VAWT, HAWT, urban, standard deviation.*

1. INTRODUCTION

Wind energy is one of the most important renewable energy sources, with a significant increase in urban and rural areas. Wind is inexhaustible, free and non-polluting, does not produce radioactive waste and produces no emissions into the atmosphere.

Wind energy participates in decentralized renewable wind energy, thus being an energy source that can adapt to small-scale applications, such as private consumption, or it may be a solution for small towns which are far from the old-fashioned energy sources. Urban wind turbine development has gained greater importance in recent years. Moreover, studies have shown that turbines mounted on tall buildings can provide a considerable amount of green energy and carbon savings.

2. PERFORMANCE INVESTIGATION

In order to analyze as good as possible the performance of small wind turbines, it was utilized WindPower program, an interactive program which helps us to calculate the performance of wind turbines, with rotor diameter of one or two meters until those of high capacity, the rotor having a diameter of about 100 m. The application can be used for both horizontal axis wind turbines (HAWT) and with vertical axis (VAWT).

The program addresses to individual users interested in installing a turbine in order to assess the performance and economies of possible installations, or land owners interested in building wind farms, consultancy firms to advise clients on the installation of wind turbines and the installation options, but also for students and teachers from universities or any type of organization.

The site also allows downloading a database with basic producers of wind turbines. Database updated, discharged in May 2013, is divided into two categories, turbines HAWT and VAWT turbines, each with four and three categories of turbines with installed capacity below 5 kW, between 5 kW and 50 kW, 50 kW and 500 kW and also over 500 kW .

Based on the data producer it can be calculated the followings:

- the average power and the annual energy production based on the average wind speed at a particular place;
- the estimations regarding the return on investments based on the average wind speed and reference costs of electricity;
- the estimations on the payback period based on the average wind speed and reference costs of electricity;

- the estimations of the cost per kilowatt-hour, depending on the average wind speed and the lifespan of the turbine ;
- the power profile showing the percentage of time during which the turbine produces a certain power level, including cases where it is zero ;
- how much energy will be used locally and how much energy will be exported to the grid for a wind turbine which produces energy locally.

The version used is the trial program, which allows calculation of all stored parameters, but does not allow saving the calculated data. Based on the results obtained in the program, there were outlined specific diagrams.

Due to the nonlinear variation of power relative in relation to the wind speed, the rated power obtained under varying wind speeds, U_m is not equal to the power obtained under constant wind, at the same speed. In the next chart it is shown the power curve ***W (u)*** for a wind turbine under constant speed u, and the probability density distribution p (u) for nominal speed U_m = 6 m / s (Figure 1).

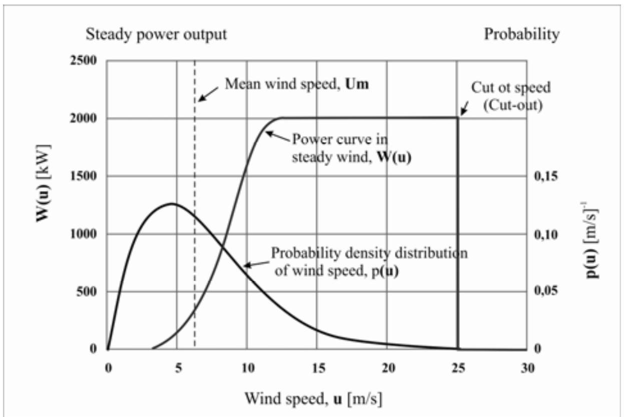

Fig.1. Power curve for variable wind and the probability density distribution

Final rated power corresponding to nominal speed U_m is the product of the power ***W (u)*** and the probability density distribution ***p(u)***, integrated throughout full range of wind speed. The formula power is then calculated as follows:

1 (1)

With the help of the program WindPower this integral is calculated in the range of speeds between 5 m /s and 10 m/s, with an increase of 0.2 m/s. This range includes the range of average speeds found in most wind turbines [1].

As it can be seen the wind does not blow at a constant speed and in order to calculate the nominal power produced by a wind turbine is necessary to know exactly how often and how strongly the wind blows, to know the probability density distribution of wind speed, in other words, the distribution of the proportion of time spent by the wind in a certain range of speeds. Normally, the wind is measured with an anemometer and the average wind speed is recorded every 10 minutes. The data can be sorted into classes of wind speed of 1 m/s for each. The wind energy enclosed in a given location can be expressed through this frequency distribution. In order to best approximate wind speed distribution it is used Weibull distribution:

$$f(U) = \frac{k}{A}\left(\frac{U}{A}\right)^{k-1} \exp\left(-\left(\frac{U}{A}\right)^{k}\right) \quad (2)$$

where A is the Weibull scale parameter m/s, a measurement of the wind distribution velocity. A is proportional to average wind speed. K is the parameter Weibull. This specific form of Weibull distribution and takes a value between 1 and 3. A small value of k denotes highly variable winds, while constant winds are characterized by a higher k.

The program allows changing the standard deviation. The default value of the standard deviation is 52 % of the average wind speed that is equal to the distribution Rayleight, for which the Weibull parameter k is 2, as used in the wind industry standard deviation.

Standard deviation of the wind distribution reported to the average wind speed is approximately constant in rural areas, while in urban areas it is influenced by buildings or other constructions.

The turbines selected for analysis are wind turbines with vertical axis and horizontal axis, forming part of the small wind turbines with power up to 50 kW. The selected wind turbines are turbines installed in urban areas as being attractive as performance and design. In the following paragraphs are analyzed one by one each of the selected wind turbines, and specific graphs are plotted for each, based on data from the manufacturer, interpreted in WindPower application.

3. SMALL WIND TURBINES

3.1 Turby 2,5 kW

Turby is a Dutch wind turbine with vertical axis and a power of 2.5 kW, rotor diameter 2 m, height 2.65 m, designed to be used in built environment, especially in built mounted on buildings. The speed at which the turbine turns on is 3.5 m/s and the nominal speed of 14 m/s. Based on the data taken from the turbines catalogue [2;3] is calculated power coefficient C_p corresponding to each gear, then it is drawn the corresponding power curve (Figure 2).

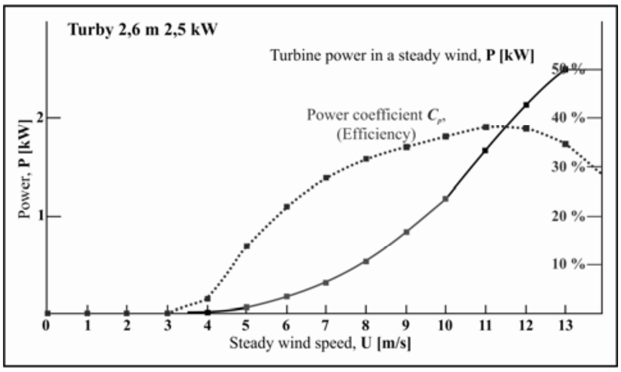

Fig.2. Power curve and power coefficient of Turby 2.5 kW turbine

The following chart is compared to the average power of a turbine in variable wind conditions with the power curve for a constant wind. The value of the standard deviation for which it was drawn the power curve in variable wind condition is the standard of 0.52. The influence of the wind on the rated power variation is typical for most of the Eolina wind turbines and generally below the wind speed that is 8 m/s, it is higher than the power obtained under conditions of steady wind. Above this value, the situation is reversed because of the area corresponding to the line power curve; area that ends up with turbines speed reached.

3.2 Quiet Revolution qr5 6 kW

Qr 5 wind turbine was designed by Quiet Revolution in London, to meet the demands in the urban and rural areas. This turbine was designed to integrate the built environment and ensure a strong performance even in windy conditions.

According to the manufacturer's specifications, the turbine is quiet and produces restored vibrations, necessary for the proposed location. Qr 5 is a compact turbine with a rotor diameter of 3.1 m and a height of 5m, easy to install and maintain. Qr 5 is a vertical axis wind turbine with three helical blades with power 6 kW and a life given by the manufacturer for 25 years [3].

So far the wind turbine has been successful among traders, developers, schools and universities, government institutions etc.

The rank speed of the turbines is between 4 m/s, thus being the starting speed and 19 m / s, the closing speed having a rated speed of about 12.5 m/s , as shown in the following table . At this value, the turbine reaches maximum efficiency around 22%. Annual electricity production is estimated at 4197 kWh at a wind speed of 5 m/s.

The power curve was calculated for a turbine connected to a local network and is about 10% lower because of the energy losses caused due to the conversion of AC to DC and vice versa. The power graph is plotted in Figure 3.

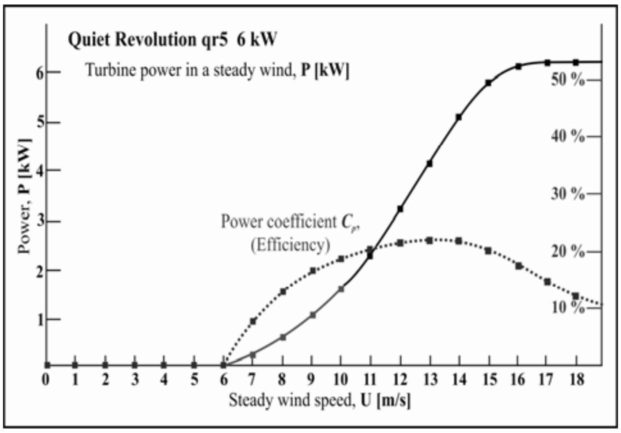

Fig.3. Power curve and power coefficient of Qr 5 turbine

3.3 Windspire 1,2 kW

Windspire wind turbine is the type VAWT, aesthetically attractive, and quiet running. Windspire turbines produced in the USA, has been designed to operate in areas with relatively low wind speeds of about 4.5 estimated average power Windspire turbine for a range of average wind speeds, wind speed using Rayleigh distribution To find the annual energy average power is multiplied by the number of hours in a year (eg 8760) .

The model chosen for the analysis is designed for a power of 1.2 kW, with a starting speed of 3.8 m/s and survival of 47 m/s. The nominal power of the turbine is around 11 m/s. Windspire is a small turbine, having a rotor with the diameter of 1.2 m and a height of 6.1 m and total height of 9.1 m with the possibility to increase. The estimated output power under optimal conditions is of 200 kWh/year with the possibility of increasing up to 40 %, expanded in terms of height.

The power coefficient obtained with the help of WindPower program indicates that the maximum efficiency is above 20% and it is obtained for wind speeds of 7 to 11 m / s (Figure 4).

In order to find the annual energy average power, it is multiplied the average power with the number of hours in a year (eg 8760).

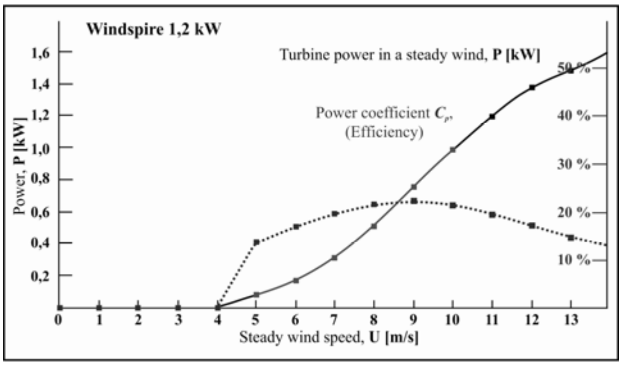

Fig.4. Power curve and power coefficient of Windspire 1.2 kW turbine

3.4 Energy Ball 2,5kW

Energy Ball is an atypical horizontal axis wind turbine, having a spherical structure with curved blades, form which gives the product a higher aerodynamic efficiency compared to traditional patterns. The turbine is designed and produced by the Swedish company Home Energy, a turbine called completely silent due to very low noise compared with other sources of everyday noise [4].

Energy Ball is found in two versions, depending on the power they were designed, V100 variant with a power of 1 kW and V200 with a 2.5 kW power installed. The option chosen for analysis is 2.5 kW with a rotor diameter of 1.98 m. The producers estimate that the turbine could attain 50 % of the electrical needs of a common housing. The speed at which the turbine turns on is 3 m/s and operates smoothly until a speed of 40 m/s.

From the aesthetic point of view, the turbine fits within the urban environment and in accordance with Figure 5 it gets an efficiency of around 25 % in a wide range of speeds ranging from 5 m/s to 17m/s.

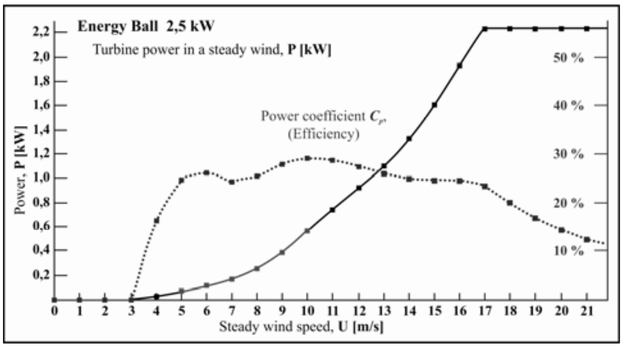

Fig.5. Power curve and power coefficient of Energy Ball 2.5 kW turbine

3.5 Skystream 3.7

Skystream is a horizontal axis wind turbine with three blades shaped, manufactured by Southwest Windpower of Arizona. This turbine has been carefully developed and tested over several years in collaboration with the National Renewable Energy Laboratories (NREL) in Colorado. Originally it was called the Storm, but after further research and developments it was renamed Skystream.

Skystream is a turbine with the diameter of 3.7 m and an installed power of 2.4 kW. The control of the rotational speed and of the power generated is conducted by electronic control of the generator, which helps to stop the turbine when wind speeds rise above 25 m/s or if there is an error in the electrical network to which turbine is connected. In addition to the normal braking system there is also a braking system back- up used in the event of primary system failure.

The starting wind speed is of 3.5 m/s, the maximum efficiency obtained is around 30 % , a reasonable value that spans the range of wind speeds between 5.4 m / s and 11 m/s (Figure 6).

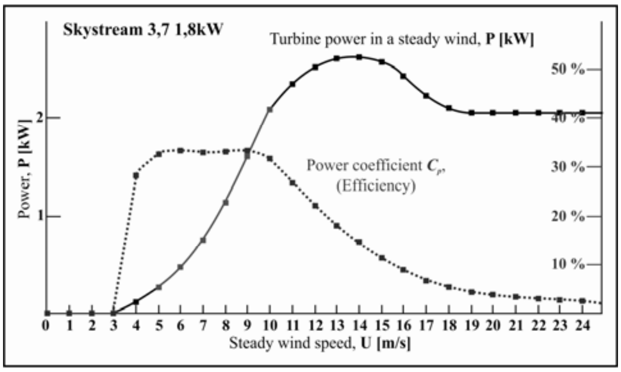

Fig.6. Power curve and power coefficient of Skystream 3.7 turbine

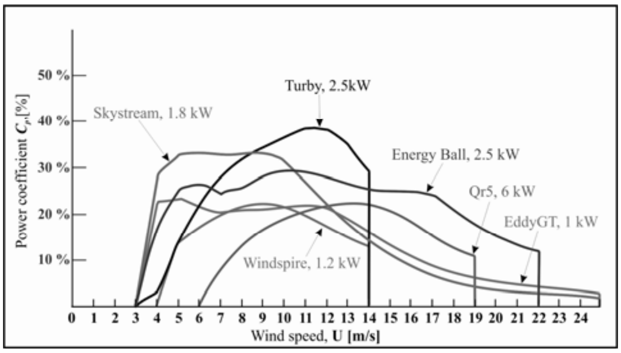

Fig.7. The power coefficient of analyzed turbines

4. CONCLUSIONS

The comparison of the studied turbines, depending on the particular power curves in relation to the wind velocity are shown in Figure 7. Turby turbine has a higher performance compared to the other, only speed range is limited. The turbine that provides a power coefficient relatively stable over a wide range of speeds is Energy Ball. The poor performance touches Windspire turbine [5].

Following this analysis, there were quantified functional and geometrical parameters of wind turbines which are summarized in Tables 1 and 2 [6].

5. ACKNOWLEDGEMENTS

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Table 1

The technical characteristics of small capacity wind turbines (1)

Type				Rotor diameter (m)	Swept area (m2)	drag/lift	Rated power (kW)	Power coeficient Cp
VAWT	Darrieus	3 blades		1 ~ 3	3 ~ 7	L	0,5 ~ 2	~ 0,25
		Rotor H	1 kW<PN<10 kW	2 ~ 6	3 ~ 30	L	1 ~ 10	~ 0,4
			10 kW<PN<30 kW	7 ~ 10	40 ~ 80	L	10 ~ 30	~ 0,4
	Savonius			0,5 ~ 3	2 ~ 15	D	0,5 ~ 6	~ 0,2
	Other design	Helical	Helical blades	2 ~ 3	5 ~ 15	L	2,5 ~ 6	~ 0,3
			Helical scoops	1 ~ 2	4 ~ 12	D	1 ~ 8	~ 0,25
HAWT	2 blades			2 ~ 15	3 ~ 170	L	1 ~ 30	~ 0,4
	3 blades		20kW<PN<100kW	10 ~ 20	80~310	L	20 ~ 100	~ 0,45
			5 kW <PN< 20 kW	4 ~ 11	12~100	L	5 ~ 20	~ 0,4
			PN <5 kW	1 ~ 3	0,8 ~ 7	L	0,5 ~ 5	~ 0,3

Others	Aerial/ floating	5 ~ 14	50 ~ 40	D	10 ~ 100	-
	Wind Belt	-	liniară	vibration	1mW~5W	-

Table 2

The technical characteristics of small capacity wind turbines (2)

Tip				Tip speed λ	Cut in speed (CIS) (m/s)	Cut out speed (COS) (m/s)	Self-starting Yes/No
VAWT	Darrieus	3 blades		3 ~ 7	-	-	With Savonius starter
		Rotor H	1kW<PN<10kW	2 ~ 5	2 ~ 3	~ 30	Pitch control
			10kW<PN<30kW	2 ~ 5	~ 3	~ 30	Pitch control
	Savonius			~ 1	~ 2	unlimited	Yes
	Other design	Helical	Helical blades	~ 4	~ 4	~ 15	Yes
			Helical scoops	~ 1	~ 2	unlimited	Yes
HAWT	2 blades			6 ~ 12	~ 3	~ 50	No
	3 blades		20kW<PN<100 kW	5 ~ 7	2,5 ~ 4	25 ~ 40	Pitch control
			5 kW <PN< 20 kW	5 ~ 7	2,5 ~ 4	25 ~ 40	Yes
			PN <5 kW	5 ~ 7	2 ~ 3	25 ~ 40	Yes
Others	Aerial/ floating			-	~ 3	~ 30	Yes
	Wind Belt			-	-	-	Yes

TURBINE EOILIENE DE PUTERE MICA - ANALIZA PERFORMANTELOR

Rezumat: Turbinele eoliene functioneaza diferit in mediul urban, acesta fiind influentat de regimul vantului, anotimp, de obstacole, alte cladiri si alti factori, astfel cunoasterea perfoemantelor turbinelor eoliene in acest mediu devine o necesitate. Lucrarea propune analiza performanţelor turbinelor eoliene de putere mică instalate în mediul urban, prin compararea performanţelor obţinute furnizate de producători şi pe cale experimentală. Cu ajutorul programului WindPower se traseaza curbele de putere şi se calculeaza posibilităţile producţie a energiei pentru fiecare turbina, iar la final se cuantifica intervalele de performanţă pentru turbinele studiate.

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