CONCERNING THE CONVERSION EFFICIENCY INCREASE OF THE AVAILABLE WIND POTENTIAL

Ion SOBOR, Andrei CHICIUC, Rodion CIUPERCA, Vasile RACHIER

Technical University of Moldova,
sre.utm@gmail.com, 4chiciuc@gmail.com, rodionciuperca@gmail.com, rachier.vasile@yahoo.com

Abstract – There are some arguments in favor of the small systems for wind energy conversion directly in thermal energy by using the eddy current heater: the existing structure of power and thermal energy consumption is in favor of the last, reliability and low cost of the eddy current heater, optimal operation at different wind speeds, higher capacity factor of wind turbine, heat accumulation and its use during periods, when the wind doesn't blow, can be solved simply and cheaply. Based on non-dimensional characteristic efficiency factor - tip speed ratio and size of the turbine rotor was calculated power curve, which shows a real possibility to increase the production of thermal energy at wind speeds higher than rated wind speed. The calculation algorithm is presented. In one and the same wind conditions the wind turbine will produce more thermal energy than power. Based on measured wind data for one year and wind turbine power curve, the power and thermal energy production were calculated. In the analyzed example (turbine rated power is 9,8 kW) the amount of thermal energy will be higher by about 6 % for 12 months and in the cold season, when wind speed is higher - with 12 to 18 %.

Keywords*: wind conversion system, eddy current heater, conversion efficiency*

1. INTRODUCTION

Today wind power is associated primarily with power, less with mechanical energy and even less with heat. The explanation is simple: electricity can be easily transported, processed with high efficiency in other types of energy, including mechanical and thermal. Not incidentally, most of wind energy conversion systems are designed to produce the power [1-3]. However, there are several reasons why wind energy conversion systems should be used more widely for the production of heat or hot water for residential using. Arguments are as follows:

1. Energy consumption structure of a country. As an example the Republic of Moldova: the total energy consumption in 2009, equivalent to 2.071 million t.o.e., only 16 % was consumed in the form of power [4], and other resources that constitute 84 % were consumed in the form of heat and mechanical energy. The heat is used mainly for space heating and hot water housing. Of total gas consumption in 2010 which is 1090 million m^3, 31,2 % was consumed by households [5]. In other words, was consumed to produce heat.
2. In 2010 the share of natural gas in a Gcal cost was 712 MDL and will keep upward trend. Wind equipment for heat production is simply and cheaper than for power production.
3. The problem of accumulation of heat and its use during periods when the wind doesn't blow is solved simply and cheaply. The ratio between the cost of electric battery and a heat accumulator with the same capacity is more than 10, and exploitation period for heat accumulator is greater.
4. The last argument, perhaps the most important, is the efficient use of wind potential. The power of air flow is proportional to the cube of wind speed. Wind energy conversion system must work effectively across the range of variation of wind speed in the given site, for example, from 3 to 20 m / s. However, rated power of small wind power systems, (up to 30 kW) corresponds to wind speed of 11-12 m/s. In other words, at the wind speed of 20 m/s a wind energy conversion system should have an overload factor of 5-6. In reality, this factor is equal to 1,2-1,3 [6,7], being limited, primarily, by permanent magnet generator. The permanent magnet generator overload factor is limited by properties of using materials: insulation, enameled copper wire and permanent magnets.

It follows that for wind speeds greater than the rated speed is necessary to limit power converted into electricity, thus energy conversion efficiency drops sharply. It is reasonable to use an other type of converter - direct mechanical energy converter into heat with high overload factor. Such a converter can be eddy current heater.

The paper makes a comparative analysis of two wind energy conversion systems - with electrical generator and eddy current heater that directly converts mechanical energy into heat. The emphasis is on efficiency of these two systems at wind speeds higher than rated speed.

2. PERFORMANCE OF THE MODERN WIND TURBINE

2.1. Performance of the ideal wind turbine

The power available in the wind in watts is done by formula

$$P_W = \frac{1}{2}\rho A V^3, \tag{1}$$

where ρ - air density, kg/m^3; A – swept area of the blades, m^2; V – wind speed, m/s.

The power extracted from the wind by an ideal turbine is limited by so-called the Betz or performance factor C_P. Maximum value of C_P for an ideal turbine is of 0,593. It shows that a wind turbine cannot extract more than 59,3 percent of the power in an undisturbed wind flow [8]. Figure 1 presents the power P_W of the air flow in accordance with (1) and the power of the ideal wind turbine in accordance with (2), dotted line.

$$P = C_P P_W = 0{,}5 C_P \rho A V^3 \tag{2}$$

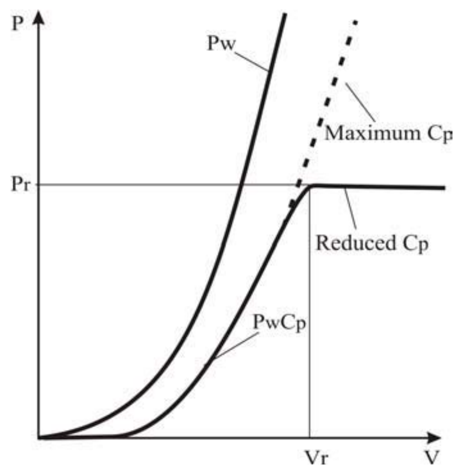

Figure 1. Available Power in the wind and extracted power by ideal turbine

2.2. Performance of the real wind turbine

The usual method of presenting power performance of the real turbine is the nondimensional curve C_P as the function of tip speed ratio λ and this characteristic for a typical modern, three-blade turbine is shown in Figure 2. The tip speed ratio is defined as

$$\lambda = \frac{\omega R}{V}, \tag{3}$$

where R is the maximum radius of the turbine rotor m, ω is the angular velocity of the turbine in rad/s.

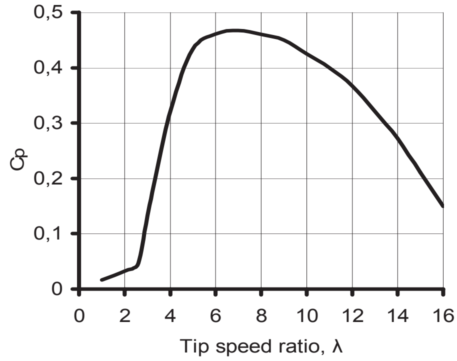

Figure 2. Performance factor of a modern three blade turbine

The rotor speed, n, in RPM, is found from the tip speed ratio (3):

$$n = \frac{30}{\pi}\lambda\frac{V}{R} \tag{4}$$

and the rotor power

$$P = 0{,}5 C_P(\lambda)\rho\pi R^2 V^3. \tag{5}$$

The first point to notice is that the maximum value of C_P is only 0,467, achieved at a tip speed ratio of 7, which is much less than the Betz limit. The discrepancy is caused, in this case, by drag and tip losses [8].

The second conclusion, valid for the case of power generation, is necessity to reduce the power turbine if wind speed is greater than the rated value V_r. The goal is to avoid overloading the generator. In other words, for wind speeds greater than V_R (see Figure 1) performance factor decreases to values of 0.1. For this purpose different methods are used: pitch regulation, stall regulation, furling or brake.

As follows, will be determined the characteristics of a modern wind turbine with three blades *P(n,V),* in which the wind speed is as parameter and power curve *P (V)* for the case of heating production with a eddy current heater. We recognize that the performance factor varies according to Figure 2. Technical data of Aircon 10 turbine: rotor radius R = 3,55 m, rated power P_r = 9.8 kW, rated wind speed V_r = 12 m/s [9]. It was used the following algorithm:

1. With (4) we calculate the rotation speed n depending on λ. Wind speed V is considered a parameter. Characteristics $n(\lambda, V)$ are shown in Figure 3.

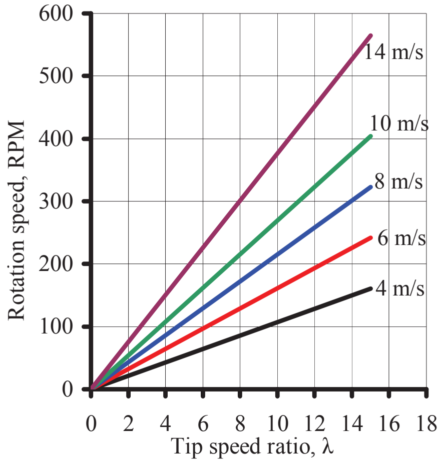

Figure 3. *n(λ, V)* characteristics

2. For constant values of the tip speed ratio λ are determined the values of turbine rotational speed for the entire range of variation of wind speed V.
3. For the same values of tip speed ratio λ from the characteristic $C_P(\lambda)$ are determined the values of efficiency factor C_P.
4. With the C_P values and (5) are calculated the wind turbine power as a function of wind speed. Tip speed ratio λ is a parameter. $P(V,\lambda)$ characteristics are shown in Figure 4.

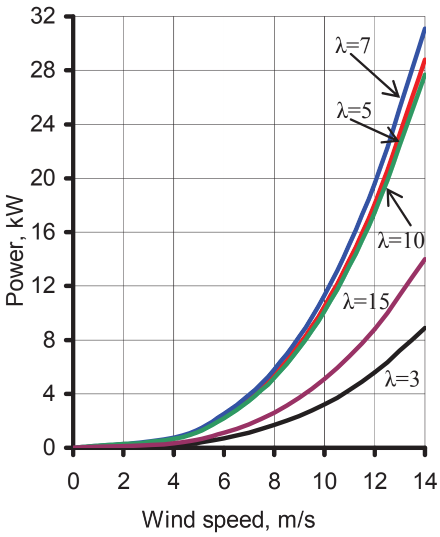

Figure 4. *P(V,λ)* characteristics

5. For the full range of variation of speed ratio λ type, with data obtained above, are determined the characteristics of $P(n,V)$ where wind speed is considered as parameter (see Figure 5).
6. Power curve $P(V)$ is calculated as follows: for a certain value λ_i from Figure 2 is determined $C_P(\lambda_i)$. With (5) is calculated the power $P(V_i)$ for a given wind speed V_i or can be determined from Figure 4 for values of V_i, and λ_i. For example, λ_i=7, $C_P(7)$=0,467, $P(7\text{m/s})$ = 0,5·0,467·1,225x xπ·3,5^{2}x7^3=3,9 kW. In Figure 6 is shown the power curve $P(V)$ of the Aircon 10 turbine calculated in accordance with the algorithm presented above. For comparison the same curve is presented for the case of power production [9].

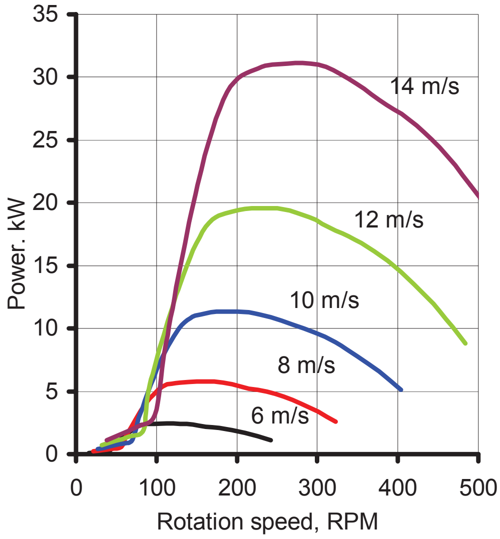

Figure 5. *P(n,V)* characteristics

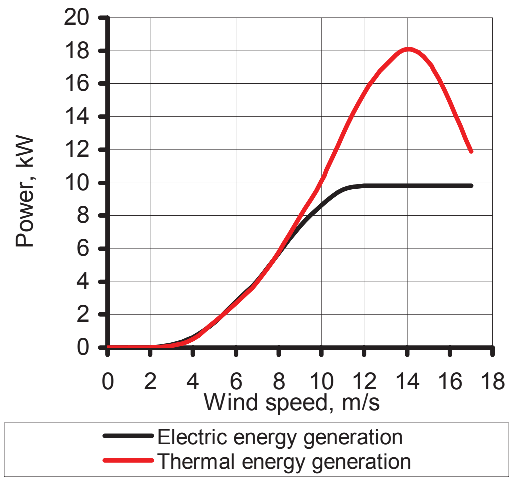

Figure 6. Power curves

According the Figure 6 we found that for wind speeds above 10 m/s the conversion efficiency increases when using eddy current heater. In short terms, we can extract more energy from available wind potential. Moreover, the eddy current heater must have an overload factor equal minimum to 2. There are not technical or economic difficulties to produce of such eddy current heater. It does not contain electrical insulation, copper, electrical sheet steel or other expensive materials [10-12] that would limit the overloads.

Another advantage of the eddy current heater is quadratic variation of the induced power as function of the speed of rotation [10]. In Figure 7 the wind turbine characteristics *P(n,V)* and eddy current heater characteristic *P(n)* are shown. There is an optimal operation of wind turbine for different wind speeds.

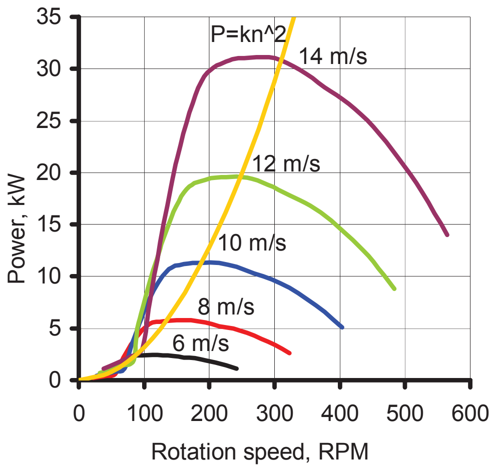

Figure 7. Wind turbine power characteristics *P(n,V)* and eddy current heater power characteristic $P=kn^2$

3. THERMAL AND POWER PRODUCTION ESTIMATION

In order to demonstrate the conversion efficiency increasing of the available wind potential was estimated production of power and heat with the same turbine in the identical conditions. As input data were used the power curves of Figure 6 and wind climatology. Last was determined by wind speed measuring at the height of 30 m above ground level and presented by histograms and frequency of occurrence *f(V)* [13].

Calculations were performed for a period of 12 months and separately for November 2010 and February 2011. The calculation of power and heat production is made with the formulas:

- for the period of 12 months

$$EE_{an} = T_{an} \sum_{i=3}^{n} P_i^{EE}(V_i) f_{an}(V_i), \tag{6}$$

$$ET_{an} = T_{an} \sum_{i=3}^{n} P_i^{ET}(V_i) f_{an}(V_i). \tag{7}$$

- for November 2010

$$EE_{11} = T_{11} \sum_{i=3}^{n} P_i^{EE}(V_i) f_{11}(V_i), \tag{8}$$

$$ET_{11} = T_{11} \sum_{i=3}^{n} P_i^{ET}(V_i) f_{11}(V_i). \tag{9}$$

- for February 2011

$$EE_2 = T_2 \sum_{i=3}^{n} P_i^{EE}(V_i) f_2(V_i), \tag{10}$$

$$ET_2 = T_2 \sum_{i=3}^{n} P_i^{ET}(V_i) f_2(V_i), \tag{11}$$

where EE_{an}, EE_{11}, EE_2 - annual power production, respectively in November and February, ET_{an}, ET_{11}, ET_2 - annual heat production, respectively in November and February, T_{an} = 8760 h, T_{11} = 720 h, T_2 = 672 h - number of hours during these periods, $P_i^{EE}(V_i)$, $P_i^{ET}(V_i)$, - wind turbine power curve in case of power, respectively heat production (see Figure 6), $f_{an}(V_i)$, $f_{11}(V_i)$, $f_2(V_i)$ - frequency of occurrence for those periods, and i - the number of wind speed interval.

In Figures 8, 9 and 10 and tables 1, 2 and 3 are presented data on wind for those periods.

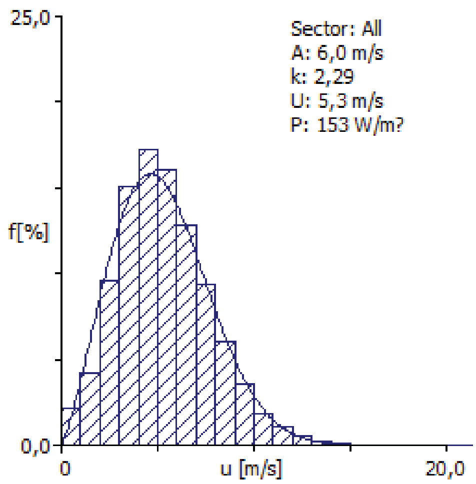

Figure 8. Histogram of measured wind speed for a period of 12 months

V, m/s	*f(V)*, %		*V*, m/s	*f(V)*, %
1	2,1		9	6,1
2	4,3		10	3,5
3	9,6		11	1,8
4	15,1		12	1,0
5	17,2		13	0,5
6	16,0		14	0,2
7	12,9		15	0,1
8	9,4			

Table 1. Frequency of occurrence for a period of 12 months

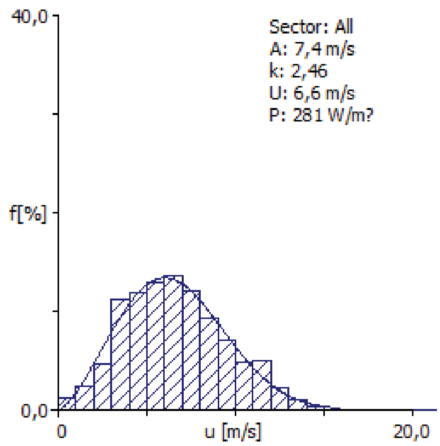

Figure 9. Histogram of measured wind speed for a November 2010

V, m/s	*f(V)*, %		*V*, m/s	*f(V)*, %
1	1,3		9	9,3
2	2,4		10	7,0
3	4,6		11	4,9
4	11,2		12	5,0
5	11,9		13	2,3
6	12,9		14	1,0
7	13,7		15	0,3
8	12,2			

Table 2. Frequency of occurrence for a November 2010

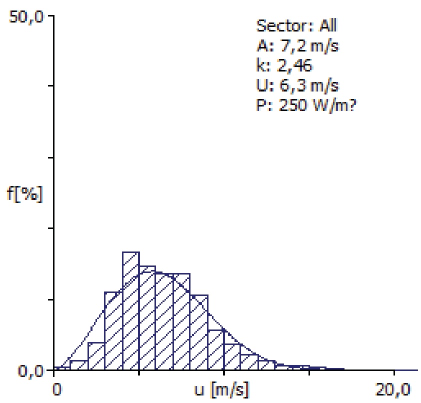

Figure 10. Histogram of measured wind speed for a February month

V, m/s	*f(V)*, %		*V*, m/s	*f(V)*, %
1	1,3		9	9,3
2	2,4		10	7,0
3	4,6		11	4,9
4	11,2		12	5,0
5	11,9		13	2,3
6	12,9		14	1,0
7	13,7		15	0,3
8	12,2			

Table 3. Frequency of occurrence for a February 2011

With (6) - (9) and data presented in Tables 1-3 were calculated power and heat production for a period of 12 months and the months of November and February. The results are presented in Table 4.

Period	Thermal Energy Production, kWh	Power production, kWh	Increase, %
12 month	27621	26124	5,7
November 2010	3799	3222	18,0
February 2011	3165	2815	12,4

Table 4. Power and thermal energy production

4. CONCLUSIONS

Although wind energy conversion systems are seen as systems for power production there are several arguments in favor of producing heat directly. The main argument is the more efficient using of the available wind potential.

As the thermal generator an eddy current heater is recommended, with a overload factor greater than 2 and quadratic power characteristic.

In one and the same wind conditions the wind turbine will produce more heat than power. In the analyzed example (turbine rated power is 9,8 kW) - about 6 % during the 12 months, and during the cold season, when wind speed is higher - with 12 to 18%.

For Moldova's climatic conditions, to produce heat by eddy current heater is rational to use wind turbines designed to rated speed of 11-12 m / s.

Acknowledgments

The work has been performed with the financial support of the Supreme Council for Science and Technological Development, project number 11.838.06.06A.

References

[1] Manfred Stiebler, *Wind Energy Systems for Electric Power Generation*, Springer, 2008.

[2] Gary L. Johnson, *Wind Energy Systems*, Manhattan, KS, 2001.

[3] *Sisteme de conversie a energiilor regenerabile*/ I. Bostan, V. Dulgheru, I. Sobor, V. Bostan, A.

Sochirean, Univ. Tehn. a Moldovei.–Ch.: „Tehnica-Info”, 2007

[4] *Balanța Energetică a Republicii Moldova*, Culegere statistică, Chişinău, 2010

[5] *Raport despre activitatea ANRE în anul 2010.* www.anre.md

[6] *Catalogue of European Urban Wind Turbine Manufacturers*, www.urbanwind.net

[7] *Urban Wind Turbines Technology Review: A Companion Text to the Catalogue of European Urban Wind Turbine Manufacturers*, www.urbanwind.net

[8] Tony Burton et all. *Wind Energy Handbook*, John Wiley & Sons, Ltd, 2001

[9] *Wind Turbine Aircon 10. Technical data* www.aircon-international.com

[10] Tiberiu Tudorache, Mihail Popescu, FEM *Optimal Design of Wind Energy-based Heater,* Acta Polytechnica Hungarica, Vol. 6, No. 2, 2009, pp. 55-70.

[11] Xiaohong Liu et all., *The Study of The Heat Device in Wind-Magnetic Water Heater,* Advanced Materials Research, Vol. 201-203, 2011, pp. 460-464.

[12] I. Dirba1, J. Kleperis, *Practical Application of Eddy Currents Generated by Wind*, Annual Conference on Functional Materials and Nanotechnologies–FM&NT, 2011, Series: Materials Science and Engineering 23, pp. 1-5.

[13] Ib Troen, Erik L.Petersen, *European Wind Atlas,* RISO Natuonal Laboratory, Roskilde, 1989.