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The influence of power properties of the wind turbine on energetic and economic indicators of electric energy production

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Abstract

In the article the influence of the parameters describing the characteristics of the wind power station on the performance and economical factors of production of electrical energy was shown. The parameters describing the characteristics of the wind turbine were as follows: the nominal power, the speed of gaining the nominal power and the speed of the starting up of the power station. The degree of the usage of the nominal power of the power station was taken as the performance factor. The net cash flow and discount payback time were assumed as the economical factors.

Keywords: Velocity of wind; Wind turbine; Production of energy

1 Introduction

The use of renewable sources of energy in the power industry is a problem both technical and economic. The wind power industry is developing the most dynamically among the technologies using renewable energy sources for the conversion into electricity. First of all, local wind resources decide on the development of the wind power industry in a given area. The second important factor are power properties of wind turbines. The influence of local resources of wind on the economic

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indicators of energy production by wind turbines was a subject of many publications. The paper describes how the power characteristics of the wind turbine influence the economic indicators of electric energy production.

2 Description of local resources of wind energy

Wind velocity as well as its kinetic energy both have stochastic nature. These types of values can be characterized only by stochastic distribution. Weibull distribution describes wind velocity as a random process with a good probability. Depending on the distribution parameters you can match the actual values with a probability of more than 90%. Weibull's distribution is presented in Fig. 1 as the statistical characteristics of wind. On the abscissa there are marked wind

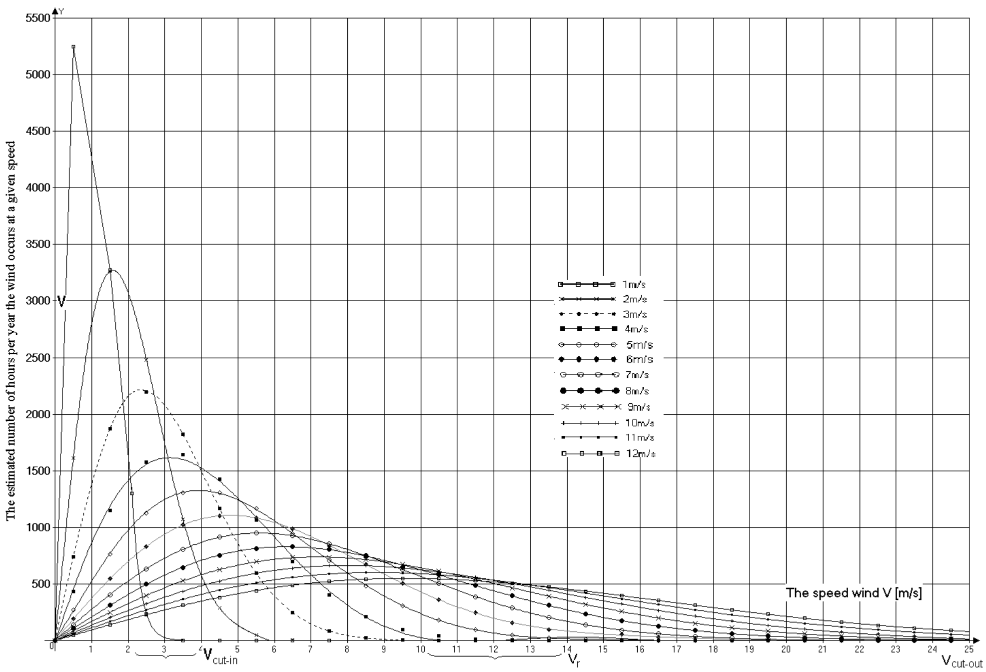

Figure 1: The Weibull distribution; V_{cut-in} – cut-in speed, V_r – speed generating the rated output power, $V_{cut-out}$ – cut-out speed.

velocities that occur during the year, while on the axis of ordinates there is the number of hours per year during which this velocity would occur. An average annual wind velocity is considered as the family of curves parameter, which characterize wind energy resources at a given location in the atmosphere. Of course not all the resources of wind energy that occur in the particular location can be used to produce electricity by a wind turbine. The degree of local wind energy utilization resources depends on the parameters characterizing the used wind turbine. The local resources of wind energy are defined on the basis of the measured average annual wind velocity and the Weibull distribution [2].

3 Power properties of wind turbines

The power characteristic of the wind turbine has been shown in Fig. 2. It depicts the power generated by the wind turbine as the function of the wind speed. The power properties of each wind turbine are defined by four parameters: rated

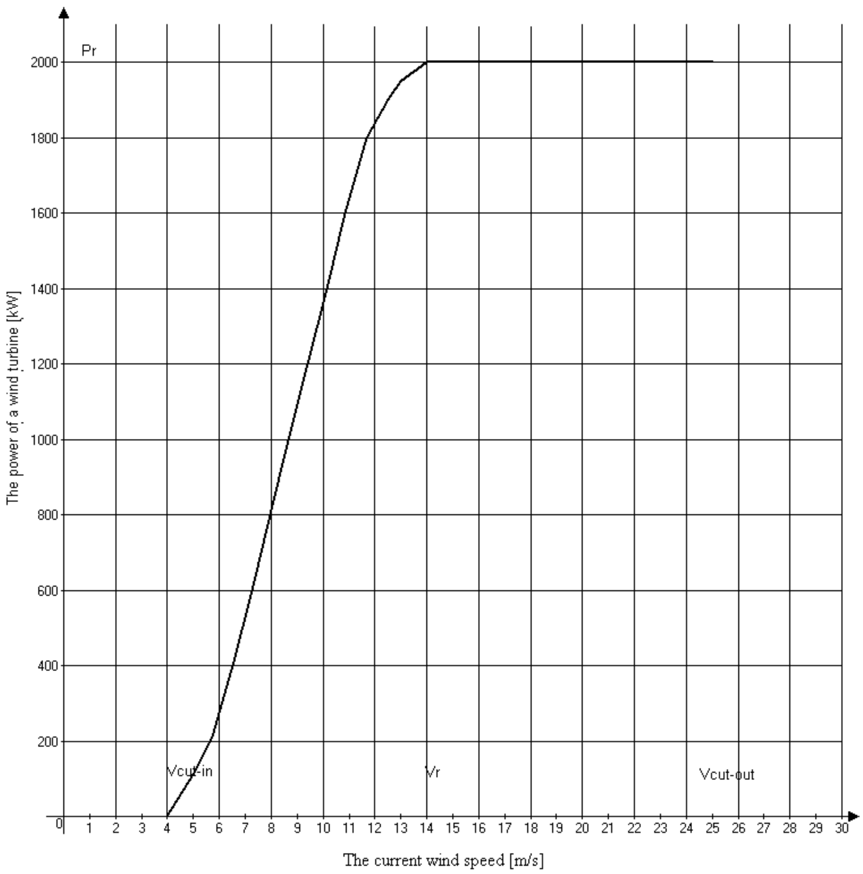

Figure 2: The power properties of the wind turbine.

output power (installed) – P_r, cut-in speed – V_{cut-in}, speed generating the rated output power (nominal or rated output speed) – V_r, and cut-out speed – $V_{cut-out}$. In the range of speed changes from V_{cut-in} to V_r the dependence between generated power by the wind turbine and wind velocity can be approximated by parabola of the third degree. In the range of wind velocity from V_r to $V_{cut-out}$ the wind turbine works with the constant power equal to the power rating [1,2,4].

The cut-in velocity in the wind turbine should be as low as possible. It is the velocity of wind at which torque, which is formed in the shaft of wind turbine, overcomes the resistance of motion of its all necessary components required for the machine to be fully operational and wind turbine begin to rotate and generate electrical power. The rated velocity is the speed at which the power plant reaches the rated output (nominal) power. The rated output power is the power of built-in electric generator. Power should be distributed in such a way that the generator could work with that power for a sufficiently large number of hours in a year. After reaching the rated output power, the power of wind turbine is no longer increasing, although the wind velocity can increase. Within the range between the rated output and the cut-out velocity, the wind turbine works with the constant power equal to the rated output power. The cut-out velocity is the velocity above which the wind turbine may no longer work due to the mechanical strength of the whole structure. Above this speed, the rotor of the power plant is halted and positioned perpendicular to the direction of the wind, so that the aerodynamic forces acting on the power plant become as little as possible.

4 Influence of power rating of the wind turbine on performance and economic indicators of the electric energy production

4.1 Performance indicators

Here, the performance indicator of the wind turbine work will be defined asthe degree of the use of its power rating. The assessment of utilization degree of the rated output power of wind turbine requires the knowledge of local wind resources and characteristics of wind turbine's power capacity [3].

In order to determine the rated output power utilization degree we need to specify the amount of electricity produced by a power plant. We can determine it on the basis of Weibull's distribution, the average annual wind velocity in the location of the power plant and its characteristics. The production of energy can be estimated by multiplying the value of energy achieved, by the power plant, at the given wind speed by the number of hours during which the wind at that speed can occur. The 100% utilization of power of the wind turbine would occur in the situation when the wind turbine worked all the time with the rated output power (installed). It means that the electric energy production expressed in kWh would be equal to the power rating of the wind turbine expressed in kilowatts multiplied by the number of hours in a year. This theoretical amount of electricity is assumed as the reference level and the degree of power use of the wind turbine will be defined in relation to it. The degree of wind power plant utilization will thus be expressed in percentages by the quotient of energy produced by the power plant within one year and the maximum producible amount of energy (the energy produced when the wind turbine would work all the time with the rated output power).

The degree of utilization of the wind turbine power, depending on its power rating at different values of average wind velocity, will be defined on the basis of the description of local wind resources defined as the average annual wind velocity and the Weibull distribution, the wind turbine power. To define above dependence, six wind turbines with the power values of 160, 320, 500, 1000, 1500, and 2000 kW have been taken into consideration. The cut-in speed, that is the speed at which the wind turbine starts to work, $V_{cut-in} = 4$ m/s, and the rated output speed that is the speed at which the wind turbine starts to work at the power rating, $V_r = 14$ m/s were assumed as the constant parameters of the description of the wind turbine. Thus, the series of types of the wind turbines differing only in value of the rated output power have been assumed.

Such calculations were performed for all wind turbines taken into consideration. The results of calculation are shown in Fig. 3, which presents the relationship between the degree of the rated output power utilization in wind turbine (expressed in percentages) and the average annual wind velocity. The presented calculations show that the degree of the rated output power utilization does not depend on the size of the rated output power. It only depends on the average annual wind velocity. The calculation results of the influence of power rating value on its utilization degree have been shown in the graphic form in Fig. 3.

4.2 Economic indicators

The simplest and commonly used indicators to assess the economic efficiency of investments in power industry are net cash flow (NCF) and discount pay back time (DPBT). These indicators show how cash flow occurs when the object which produces the energy is being performed, in other words, how expenditure on investments is compensated by incomes from energy production. This process can

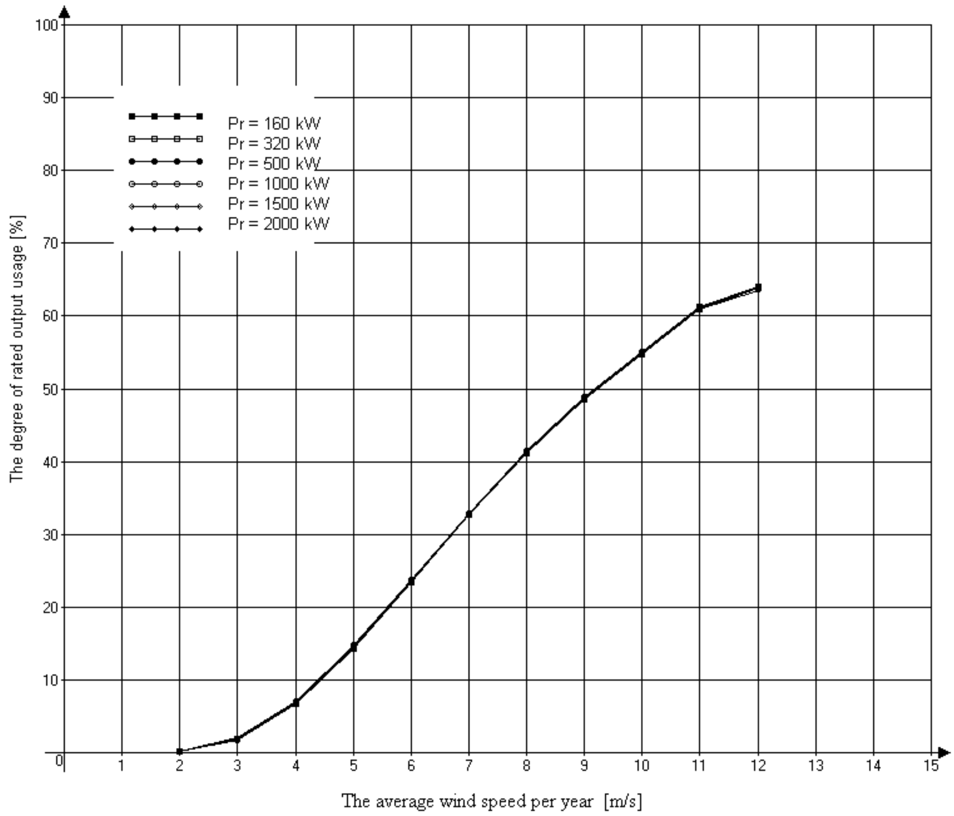

Figure 3: The influence of the rated output power of the wind turbine on the utilization degree of its power installed at the different average annual wind velocities.

be illustrated by the coordinate system. On the axis of coordinates the current balance value of expenditure and revenue is marked. The period of time during which the machine was performed is presented on the abscissa. The intersection of the timelines where the balance reaches zero determines the value of DBPT indicator, which means the number of years after which the reimbursement of expenses incurred for the investment is possible. Figure 4 shows the calculation results presenting how the rated output power value of the wind turbine influences the shaping of the NCF indicator and the value of DPBT at the local wind energy resources, defined with the average annual wind velocity equal to $V_{ave} = 5$ m/s.

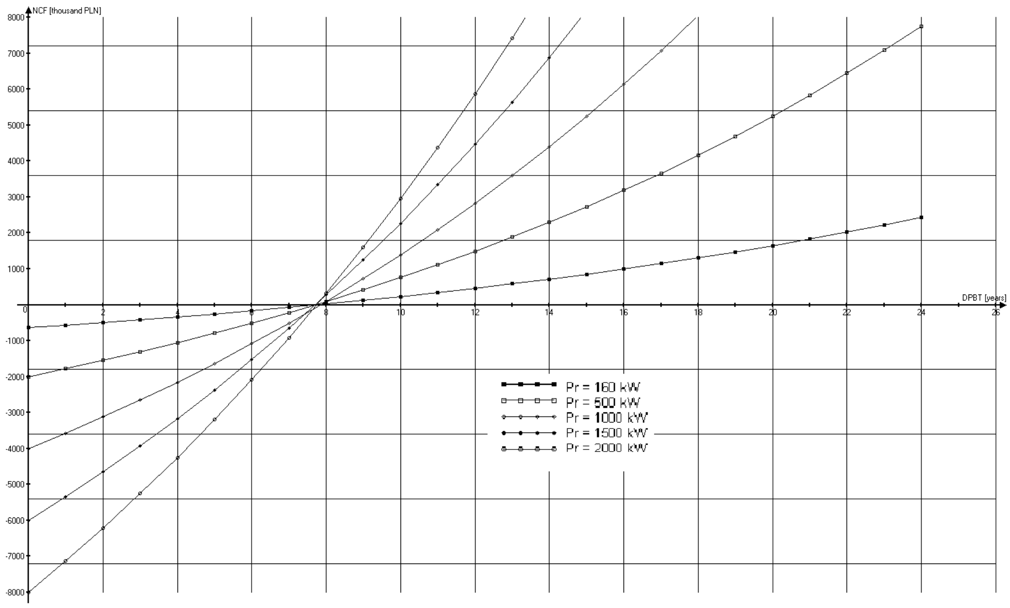

Figure 4: The influence of the rated output power of the wind turbine on the economic indicators of the electricity production at the average annual wind velocity $V_{ave} = 5$ m/s.

5 Influence of the rated output speed of the wind turbine on the performance and economic indicators of electricity production

As it was previously mentioned the performance indicator of the electricity production by the wind turbine is the utilization degree of its rated output power. It is the ratio of energy produced by the wind power plant during one year and maximum usable volume of electricity within one year which is expressed by the quotient of the rated output power and the number of hours.

In order to analyse the problem, the series of types of wind turbines were assumed which have the same rated output power 2 MW, the same cut-in speed 4 m/s but differing only in their rated output, V_r, speeds. These speeds were of the series of values 14, 13, 12, 11, and 10 m/s. The calculation results are presented in the graphic form in Fig. 5. The results indicate that the utilization of the rated output power in the wind power plant is greater if the rated output velocity is greater (the velocity at which the power plant reaches the rated output (nominal) nominal power). This relationship applies to all average annual wind velocities. For a frequently encountered average annual wind velocity of 5 m/s, the percentage level of power utilization in the power plant, at the rated output velocity of 10 m/s amounts 25%, whereas at the rated output velocity of 14 m/s only 15%.

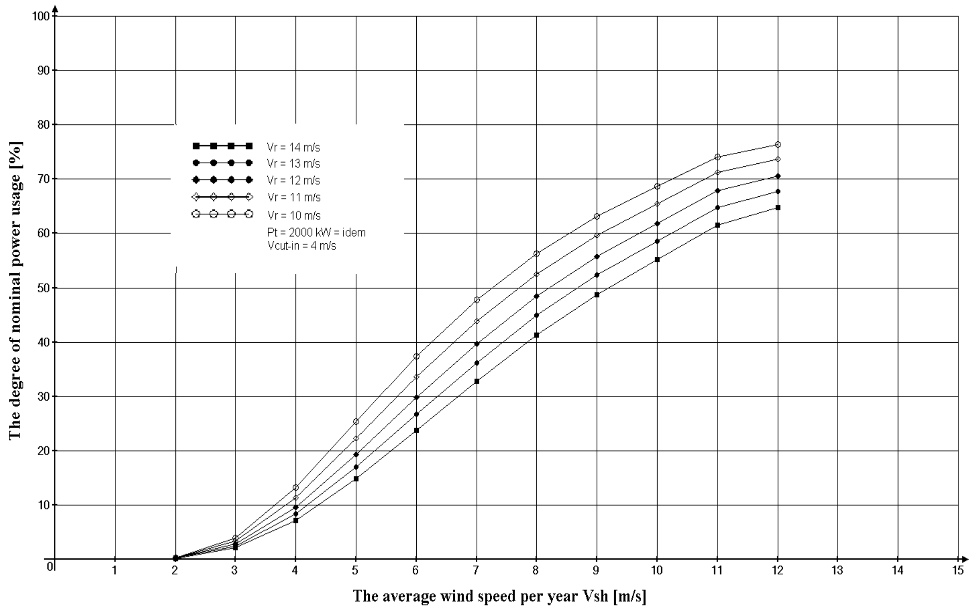

Figure 5: The influence of the rated output speed of the wind turbine on the utilization degree of its power installed at the different average annual wind velocities.

As it was mentioned the economic indicators of the electricity production are NCF and DPBT. Figure 6 shows the calculation results presenting how the rated output speed value of the wind turbine influences the shaping of the NCF indicator and the value of DPBT at the local wind energy resources defined with the average annual wind velocity equal to 5 m/s. from looking at the graph, it can be seen, the rated output velocity growth increases the discounted payback time for investment (DPBT). At the rated output speed of 10 m/s the dynamic payback time amounts less than 5 years, while at the rated output speed nearly 8 years. It can therefore be said that the lower the velocity at which the wind power plant reaches the rated output power is, the better utilization of power and shorter DPBT can be expected.

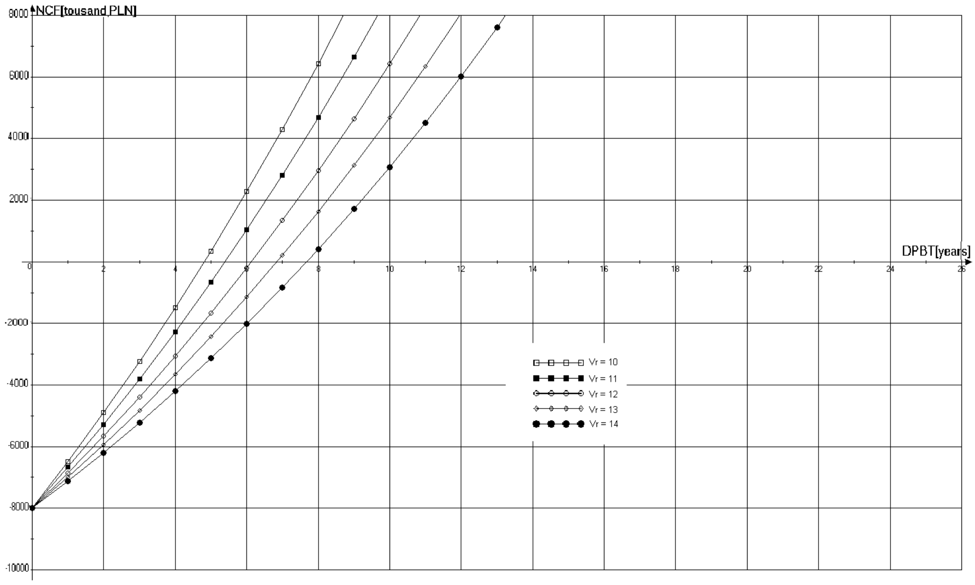

Figure 6: The influence of the nominal speed of the wind turbine on the economic indicators of the electricity production at the average annual wind velocity $V_{ave} = 5$ m/s.

6 Influence of the cut-in speed of the wind turbine on the performance and economic indicators of electricity production

In order to analyse the influence of the cut-in speed of the wind turbine on the performance and economic indicators, the series of types of wind turbines were assumed, which have the same rated output power $P_r = 2$ MW, the same rated output speed $V_r = 14$ m/s but differing only in their cut-in speeds, V_{cut-in}, which amounted to 2.5, 3, 3.5, and 4 m/s. The calculation results are presented in the graphic form in Fig. 7. These results indicate that the value of the cut-in velocity has a large impact on the percentage utilization degree of the rated output power of the wind turbine. At the local average annual wind velocity of 5 m/s, the percentage degree of utilization of the rated output power of wind turbine , whose cut-in velocity is 2.5 m/s, amounts 25% while for wind turbine the cut-in velocity of 4 m/s, amounts 15%.

The economic indicators of the electricity production by the wind turbine as it was mentioned are NCF and DPBT. Figure 8 illustrates, in the graphic form, the influence of the cut-in speed value of the wind turbine on the shaping of the

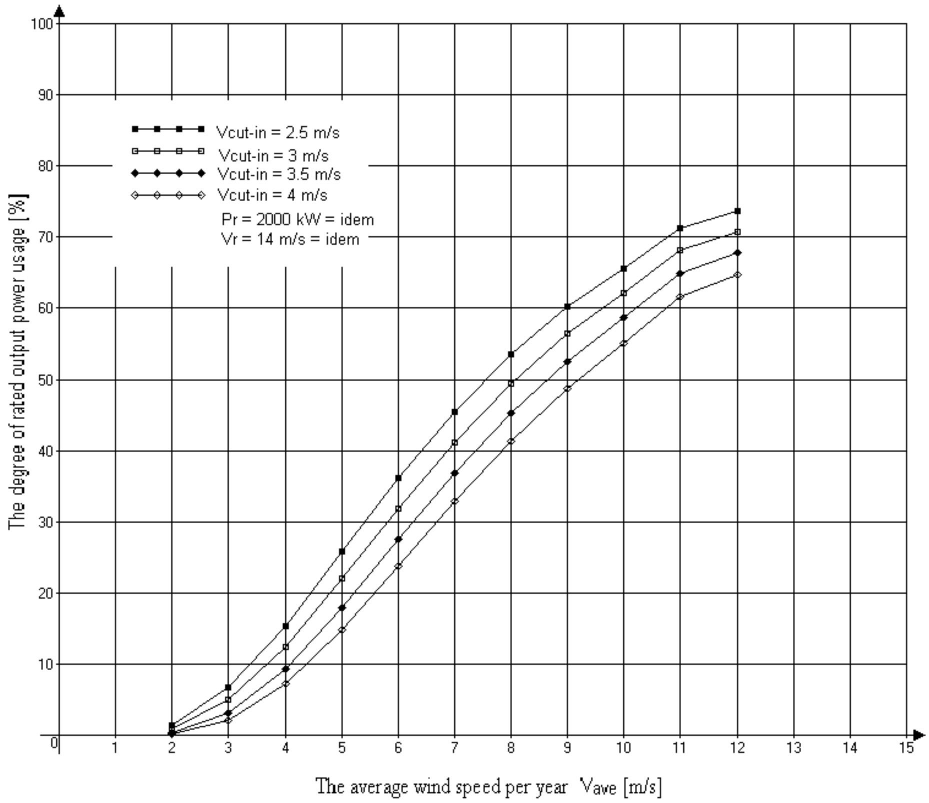

Figure 7: The influence of the cut-in speed of the wind turbine on the utilization degree of its power installed at the different average annual wind velocities.

NCF indicator and the value of DPBT. The dependence has been made for the local wind energy resources defined with the average annual wind velocity equal to 5 m/s. Presented results show a significant influence of the cut-in velocity value on the discount payback time for investment (DPBT). At cut-in velocity of 2.5 m/s DPBT is approx. 4.5 year, while at 4 m/s equals to approx. 7.5 year.

7 Summary

The influence of the parameters that determine the power characteristics of wind turbine on performance and economic indicators of electric energy production have been presented. The parameters that determine the characteristics of wind power plants are:

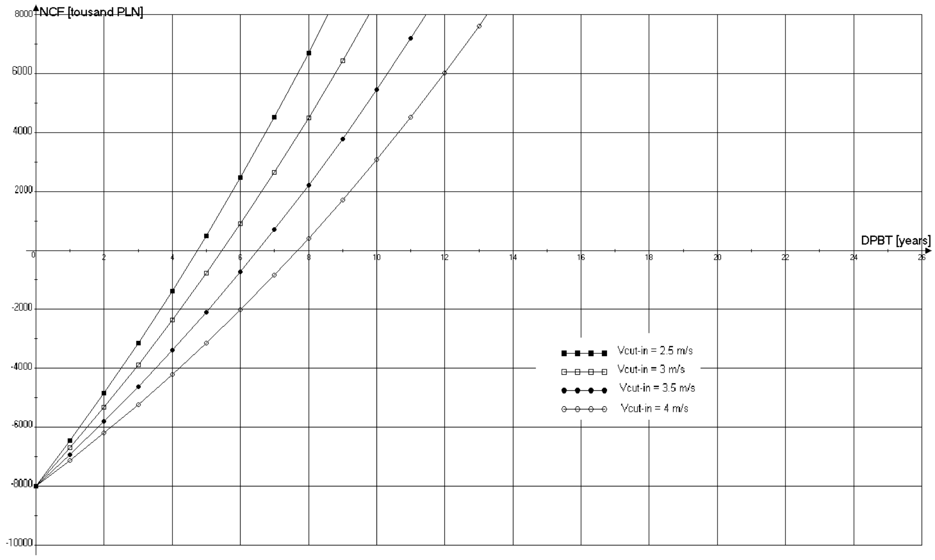

Figure 8: The influence of the cut-in speed of the wind turbine on the economic indicators of the electricity production at the average annual wind velocity $V_{ave} = 5$ m/s.

- the rated output power,
- the velocity at which the wind power plant reaches the rated output power,
- the cut-in velocity.

The degree of the rated output power utilization was taken as an performance indicator, i.e., is the ratio of energy produced by the wind turbine throughout the year to the energy that the wind turbine would produce while operating all year round with the rated output power.

The creation of expenses and revenues balance sheet associated with investment and operation of the power plant was taken as the economic indicator of its work (NCF). The time measured from the initiation of the power plant until its balance reaches zero determines the discount payback time for investment (DPBT).

The presented analysis shows that wind turbine differing only in the rated output power values and operating in places of the same resources, that is, at identical average annual wind velocity, have the same degree of the rated output power utilization and discount payback time for investment. Simultaneously, the analysis showed a strong dependence of rated output power utilization on the average annual wind velocity. With the average annual wind velocity of 4 m/s, which is considered as the lowest one worth investing in wind energy, the degree of the rated output power utilization is 6.5%. On the other hand, with the average annual wind velocity of 7 m/s, which is fairly common in distance of several meters above the ground, the degree of the rated output power utilization is approx. 33%.

The change of the rated output velocity value of the power plant, that is, the velocity at which the power plant reaches the rated output power, causes considerable changes in the degree of the rated output power utilization and discount payback time for investment. The rated output velocity growth decreases the degree of the rated output power utilization and extends the dynamic payback time. In the case when the average annual wind velocity is 5 m/s, the degree of power utilization of the wind power plant with the rated output velocity of 10 m/s is 25% and the dynamic payback time is less than 5 years. To contrast, the degree of power utilization of the power plant with the rated output velocity of 14 m/s is approx. 15%, while its discount payback time amounts nearly 8 years.

The cut-in velocity is of great significance both for the degree of the rated output power utilization in the wind power plant and for the discount payback time for investment. Decreasing the cut-in velocity increases the degree of the rated output power utilization and reduces the discount payback time for investment. With the average annual velocity of 5 m/s and the cut-in velocity of 2.5 m/s, the degree of the rated output power utilization amounts 25%, whereas the discount payback time is about 4 and a half years. On the other hand, at the same average annual wind velocity and the cut-in velocity of 4 m/s, the degree of the rated output power utilization is about 15%, whereas the process of the discount payback time is expected to take 7 and a half years.

Planning the investment in wind power engineering and assessing the effectiveness of the investment it is important to take into consideration the local wind energy resources as well as the design parameters and operating parameters of the wind turbine. Bearing in mind that the cut-in velocity has a great impact on the way the rated output power of the wind turbine is utilized, during the process of discount payback time, the reduction of the cut-in velocity should be considered. Starting up the wind turbine requires the overcome of resistance of the static friction of all the elements. The operation of the wind turbine requires the overcome of resistance of the kinetic friction which is much lower than the static friction. In this situation it is possible to decrease the cut-in velocity by a temporary (for the time of starting up) supply the power plant with the energy from the external power source. This energy will accelerate the start-up process by overcoming the static friction resistance.

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