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DEVELOPMENT OF A METHODOLOGY FOR INCREASING THE EFFICIENCY OF A WIND TURBINE

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Abstract. *Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness in the international arena. Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes wind power potentials.*

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors. It should be noted that today wind power competes with nuclear power in many countries. This is explained by the fact that the necessary costs for improving safety, reducing the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

The purpose of the work: to research and develop a methodology for choosing a wind turbine based on the assessment of the produced specific energy of the wind flow of the selected area;

Key words: *WPP, wind turbine power, wind turbine moment, turning moment coefficient, wind speed.*

I. INTRODUCTION

Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness on the international stage.

Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes the wind power potentials.

Positive factors that can offer the development of alternative energy in Armenia:
- ecologically clean and safe production of electricity;
- generating stations distributed over the territory;
- energy independent of imported fuel and international prices;
- no need to use water (for example, for reactor cooling systems) during electricity production;
- energy security and diversification of generating capacities.

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors.

It should be noted that today wind energy in many countries competes with nuclear energy. This is explained by the fact that the necessary costs for improving safety, reducing the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

II. LITERATURE ANALYSIS

1. Research of the method of selecting a wind installation

Let's consider the Raduga 1 wind turbine for this area as the distributed power of the wind flow over the entire height of the windmill and determine the possibility of increasing the efficiency of the wind turbine with a special system for adjusting the angles of installation of wind turbine blade blades.

All calculations will be carried out for the "Raduga 1" WPP, as the largest volume of available and necessary technical data is published in [1-4].

Currently, one wind turbine unit "Raduga 1" has been built, created with an asynchronous synchronous generator and with the possibility of adjusting the installation angle φ of the blades with the possibility of a special hydraulic drive. This ensured the operation of the wind turbine both in the mode with constant speed (z = const), and in the modes with a constant speed of rotation (nVK = const) of the wind turbine and constant power (PVEU = const). Such a system for adjusting the angle of installation φ of the blades provides, due to the specified adjustment, both self-starting and stopping of the turbine at a wind speed higher than the maximum permissible speed for wind turbines (25m/s).

The selection of wind turbines for this area is created in the following sequence:

1. We will estimate the resources of the wind potential of this area by statistical processing of a multi-year time series of wind speed values $V_0^{k=10}$, for example, from the "Ukrainian Hydrometeorological Center" [3] at the vane height h = 10m from the ground surface.
2. Recalculation of wind speed from the height of the axis of rotation, for example, a windmill (tower) $V_0^{k=10}$ Wind power generation is carried out according to a well-known formula:

$$V_0^{k=10} = \mathrm{V}_0^{\mathrm{h}=10} \cdot \left(\frac{h}{h_{10}} \right)^m , \tag{1}$$

where $m = 0{,}2$.

The height to the axis of rotation of the windmill of the wind turbine is 38 m, the radius of the windmill.

3. By converting the wind speed data to the height of the wind turbine, repeatability curves are calculated, for example, according to the Grynevich formula:

$$t(V) = 1.038 \cdot \frac{\Delta V}{V_{cp}} \cdot \left(\frac{V}{V_{cp}} \right)^{0.5} \cdot e^{-0.547 \cdot \left[\frac{V}{V_{cp}} \right]^2} \cdot 100 , \tag{2}$$

where V – current value of wind speed, m/s; V_a – average long-term wind speed, m/s; ΔV- calculation step (for example, 1m).

Repeatability curve graph $t = f(V)$ wind speed according to (2) in fig. 1.

4. There is also a graph of the known [4,5] dependence of specific annual energy $E_{уд} = f(V)$ per square meter of the area orthogonal to the wind flow, determined by the formula:

$$E_{уд} = \frac{\rho}{2}\sum_{i=1}^{i=25} V_i^3 \cdot t_i \cdot (V_i) \cdot 8760 = \sum_{i=1}^{i=25} P_{0i} \cdot t_i \cdot (V_i) \cdot 8760, \frac{Вт \cdot ч}{м^2 \cdot год}, \qquad (3)$$

where ρ – specific gravity of air; P_{0i} – specific power of a calm wind flow at the ith interval of wind speed gradation.

5. We are interested in formula (3) of the equation equal to $P_{уд} = f(V) = P_{0i} \cdot t_i(V_i), \frac{Вт}{м^2}$, the maximum of the characteristic coincides with the maximum of the characteristic $E_{уд} = f(V)$. According to the graph, it is reached at a wind speed of 13 m/s.

6. In fig. 1 graph of $P_{BEУ} = f(V)$ capacity of wind turbine "Raduga 1", from [2,6].

7. From fig. 1 shows that the wind speed of the nominal mode practically coincides with the wind speed of the maximum characteristic $E_{уд} = f(V)$, which testifies to the correctness of choosing a wind turbine for this area. In reality, the closer the original part of the characteristic is $P_{BEУ} = f(V)$ to the power characteristic of an ideal windmill, it is determined by the formula:

$$P_{ид} = \frac{\rho}{2} \cdot S \cdot V^2 \cdot C_p^{\max}, \qquad (4)$$

where S – the area of the windmill, $C_p^{\max} = 16/27$ – power factor of an ideal windmill (criterion Zhukovskoho-Bettsa).

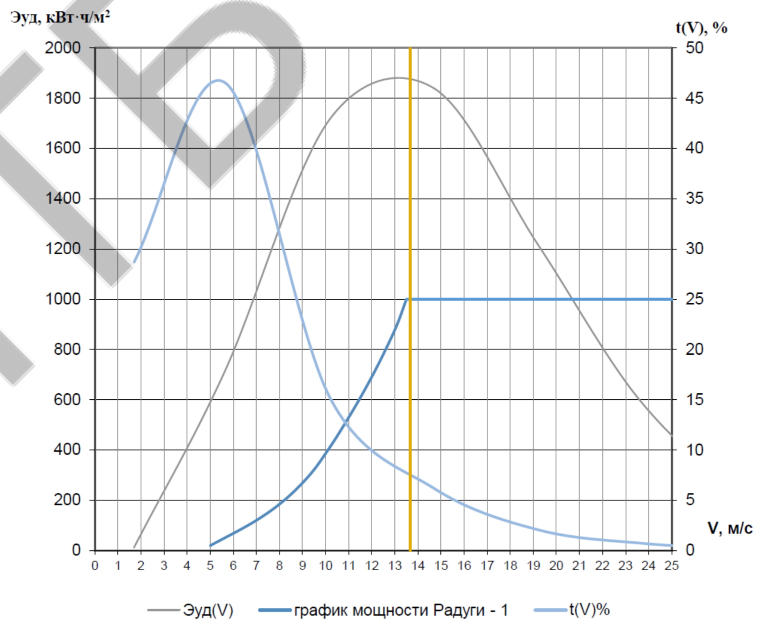

Fig. 1. Probable distribution of wind speed, specific wind energy potential of the wind flow at the height of the axis of rotation of the wind turbine wind turbine and power characteristics of the wind turbine "Raduga-1"

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Relevance of work. Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness in the international arena. Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes wind power potentials.

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors. It should be noted that today wind power competes with nuclear power in many countries. This is explained by the fact that the necessary costs for improving safety, reducing the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

The purpose of the work: to research and develop a methodology for choosing a wind turbine based on the assessment of the produced specific energy of the wind flow of the selected area;

The object of the study: wind power plant "Raduga".

The subject of the study: characteristics of capacities and moments of the windmill; characteristics of the power produced by wind turbines.

IV. RESULTS

2. Increasing the efficiency of the wind energy installation

2.1. Technical data of wind turbine "Raduga-1"

Wind power installations "Raduga - 1" are intended:

- for the production of electrical energy as part of wind power stations or independently for general energy systems or separate energy nodes;
- autonomous operation on the load during parallel operation with other wind turbines as part of wind power stations without connection to the power system.

Wind energy installations are equipped with systems that ensure convenient, efficient and safe operation.

WPP - propeller type with a horizontal axis of rotation, with a three-bladed wind wheel equipped with fully rotating blades.

As a generator, an asynchronous synchronous generator is used with rotor power from a thyristor frequency converter.

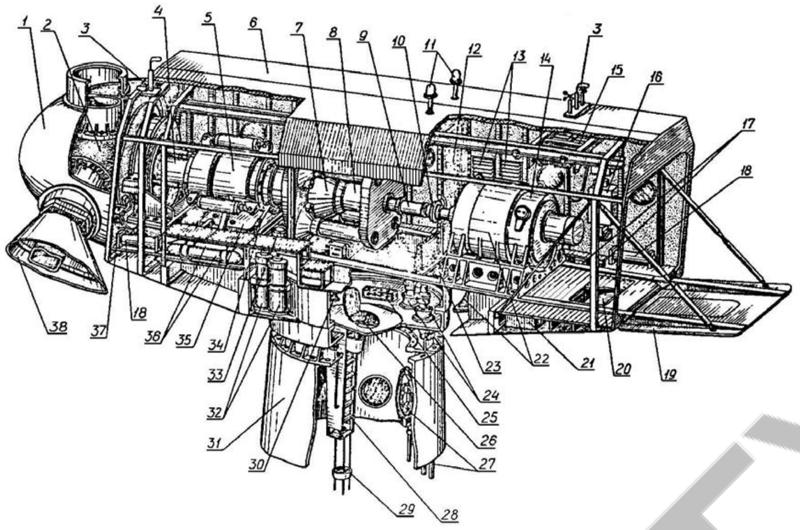

Fig. 2. Wind power plant "Raduga - 1": 1 - fairing; 2 - hub of the windmill; 3 - block of the system for measuring wind parameters; 4 - low-speed shaft; 5 - blade rotation mechanism; 6 - gondola; 7 - multiplier; 8 – circuit breaker; 9 - connecting shaft; 10 - compensation and safety clutch; 11 - blocking lights; 12 - insulating partition; 13 - louvers for air entering the nacelle; 14 - generator of asynchrony; 15 - crane device; 16 - control system units; 17 - blocks of electrical equipment; 18 - electric heater; 19 - folding platform; 20 - cargo hatch; 21 - block of the control system of the support-turning device; 22 - casing and duct for air removal from the generator; 23 - fire extinguisher; 24 - drive modules of the support-turning device; 25 - hydro remote control; 26 - brake; 27 - refueling pipelines and hoses; 28 - stairs; 29 - cable suspension device; 30 - electrohydraulic stopper; 32 - tower; 32 - pneumohydraulic accumulators; 33 - pump unit; 34 - brake stopper; 35 - oil tank; 36 - cylinders for emergency flapping of blades; 37 - brake; 38 - blade.

2.2. Increasing the efficiency of the wind turbine "Raduga - 1"

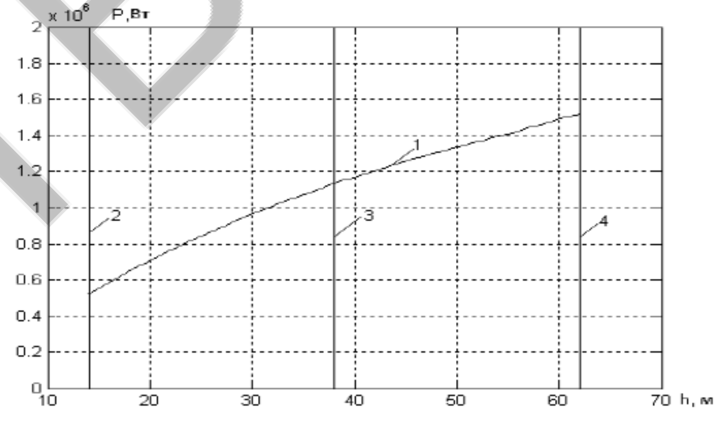

Fig. 3. Graph of the power developed by the wind flow taking into account the aerodynamic characteristics of the windmill by its height - 1; vertical lines 2, 3, 4 - respectively, the height of the lower limit (14 m), the axis of rotation (38 m) and the upper limit of the windmill (62 m)

The windmill model is represented by formulas [3,13]:

- speed:

$$z = \frac{n \cdot \pi \cdot R}{30 \cdot V}, \tag{5}$$

where n - speed of rotation of the windmill, rev/min; R – radius of the windmill, m;

- power factor of the windmill [7,8]:

$$C_p = z \cdot C_M, \tag{6}$$

where C_M - torque coefficient of the windmill;

- windmill power:

$$P = 0.5 \cdot \rho \cdot \pi \cdot R^2 \cdot V^3 \cdot C_p, \tag{7}$$

- torque of the windmill:

$$M = \frac{30 \cdot P}{\pi \cdot n}, \tag{8}$$

Since the wind speed over the height of the windmill is distributed significantly unevenly (see appendix), the power of the wind flow will also be unevenly distributed over the height of the windmill, fig. 3).

Equations (5) - (8) are implemented in the "Matlab Simulink" programming system in the form of a block diagram presented in Fig. 4 and the obtained characteristics of power and torque of wind turbine "Raduga-1" as a function of wind speed are presented in fig. 5 and 6.

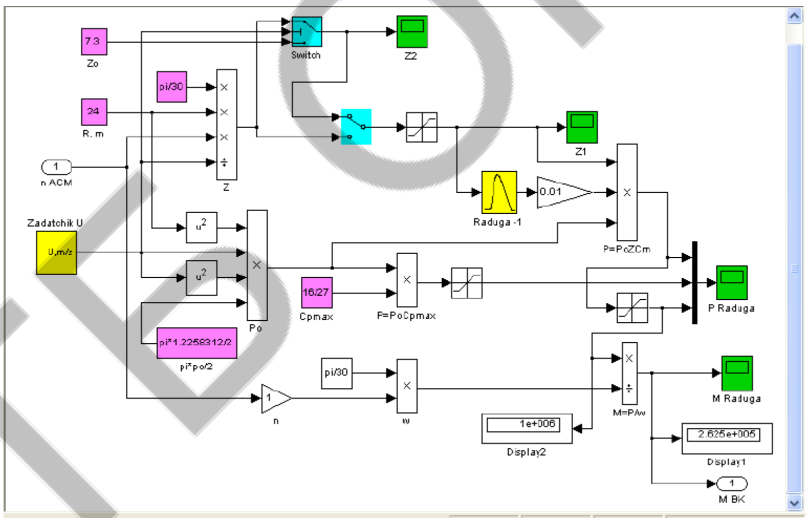

Fig. 4. Equations (5) - (7) implemented in the "Matlab Simulink" programming system in the form of a block diagram

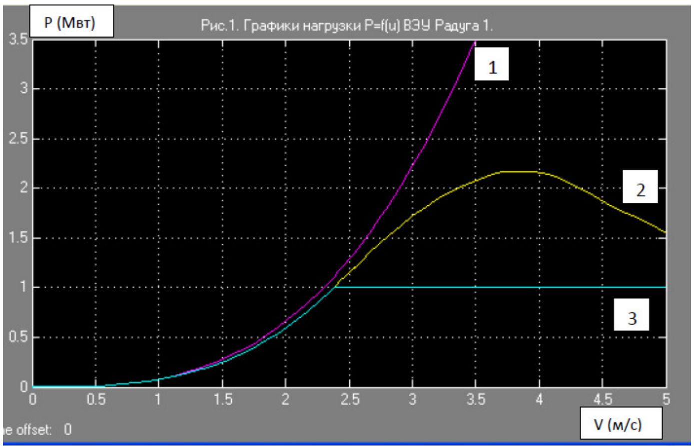

Fig. 5. Characteristics of wind turbine capacities as a function of wind speed: 1 - with an ideal wind turbine; 2 - at the "Raduga - 1" windmill; 3 - real characteristics of wind power plant "Raduga - 1" (speed scale 1:5)

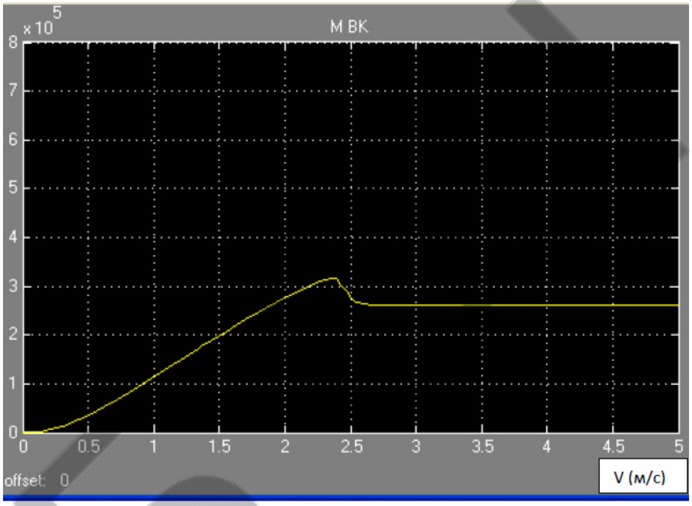

Fig. 6. Characteristics of the wind turbine moment "Raduga - 1" as a function of wind speed (scale of wind speed 1:5)

To construct a graph of real power distribution, let's divide the area of the windmill by its height into segments. The area of each i-th segment is determined by the formula [9]:

$$S_i = R^2 \cdot \left(\frac{\pi \cdot \alpha_i}{360^0} - 0.5 \cdot \sin \alpha_i \right), \qquad (9)$$

where $0 \le \alpha_i \le 360^0$ - the current value of the angle of the i-th component (the calculation is carried out in steps of 1 degree).

Next, we define elementary areas [10]:

$$\Delta S_i = S_{i+1} - S_i\,, \qquad (10)$$

Obviously, the condition [11] must be fulfilled:

$$\sum_{i=0}^{i=360} \Delta S_i = \pi \cdot R^2 = S_{BK}\,, \qquad (11)$$

where S_{BK} - the area blown by the windmill. For each elementary area, using equations (5) - (7), we calculate, taking into account (1) the height of the windmill of elementary power [12]:

$$\Delta P_i = \Delta S_i - P_i(h), \tag{12}$$

where $P_i(h)$ - power values according to the graph of fig. 6.

The graph of elementary capacities $\Delta P_i = f(h)$ by the height of the windmill is presented in fig. 7 (see appendix). From the graph of Fig. 7, it can be seen that during the rotation of the windmill, its blades in the position above the axis of rotation are overloaded compared to the lower position. According to fig. 7 overload is 16.6%. Let's consider, as mentioned above, the possibility of using a system for adjusting the angle of installation of the blades of the windmill to increase the efficiency of wind turbines. For this, a family of graphs of turning moment coefficients from speed Z at different angles φ of the installation of the blades of the windmill is used, presented in Fig. 8.

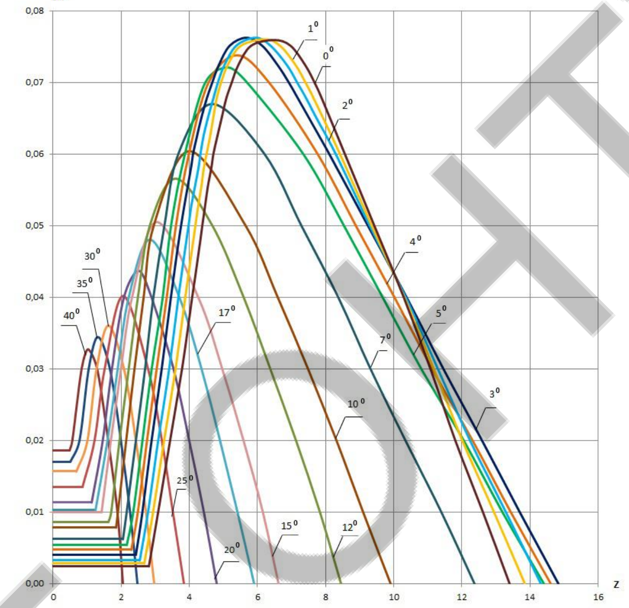

Fig. 8. Dependence of the turning moment coefficient on the speed $C_M = f(Z, \varphi)$ at different angles φ of the windmill blade installation

In relation to the characteristics according to equations (5) - (7), the characteristics of the power of the wind turbine as a function of the wind speed V at different angles φ were calculated and plotted for the three-blade wind turbine "Raduga 1" at the nominal rotation speed (n = 38 rpm) installation of blades (Fig. 9).

These characteristics are valid for simultaneous and joint adjustment of the installation angle φ common to all blades of the windmill. It can be seen from the family of wind power characteristics that if, for example, you draw a horizontal line at kW, then this mode can be ensured by the traditional method, namely by increasing the installation angle φ, common to all blades of the wind wheel. This is how the horizontal section shown in fig. 1 characteristics of the capacity of the Raduga 1 WPP.

If we draw a vertical line conditionally at a constant wind speed, for example, at V = 18 m/s, then the power graph at divides the power space into two zones: for modes whose power graphs pass above the power graph at , an increase in the angle leads to an increase in wind turbine power , and for modes whose power graphs pass below the power graph at

This feature of the modes of the windmill allows you to consider the possibility of adjusting the angle φ and setting each i-th blade separately and independently of other blades of the windmill as a function of the height of its position during each revolution of the windmill. It is worth noting that, for example, under the same conditions, the power characteristic of each i-th blade will have the same character, but, for example, for three-blade wind turbines (as in the Raduga 1 wind turbine), the amplitude will be three times smaller.

Taking into account the above, for a small range of adjustment of the installation angle (for example, $0^0 \le \varphi \le 3^0$), we construct the power characteristic for one blade at different angles of one revolution of the windmill. At the same time, in order not to construct characteristics similar to fig. 7, let's use the capacity graphs $P_{ВЕУ} = f(V,\varphi)$ in fig. 9. Since the range of wind speed changes over the entire height of the windmill is already known, each blade passes through all these values during one rotation of the windmill. At the same time, taking the power values from the graphs $P_{ВЕУ} = f(V,\varphi)$, for example at $\varphi = 0^0$, we construct a graph for the i-th blade using the formula [8]:

$$P_{лоп(\varphi=0)i} = \frac{P_{ВЕУ(\varphi=0)}}{3} = f(V), \qquad (13)$$

The resulting graph is shown in fig. 10. This graph shows similar graphs for other values of the angle φ for one revolution of the windmill (where ω is the angular frequency of rotation of the windmill, t is time), as well as the graph of the bypass of these characteristics, in fact, provides for the operation of the wind turbine according to the bypass characteristics, according to fig. 9, which ensures the maximum efficiency of wind turbines. The envelope curve in fig. 10 shows at what angles φ of the installation it is necessary to adjust the blade in order to obtain maximum power and, accordingly, increase the production of electricity. Let's assume that when the blade is in the lower position (below the axis of rotation of the windmill), and when - in the upper position.

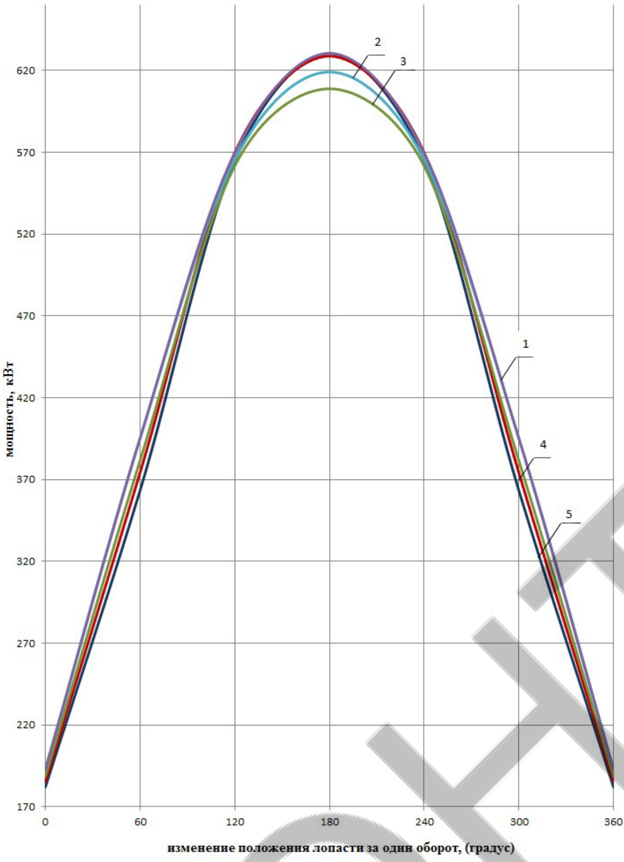

Fig. 10. Characteristics of the power produced by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 38 m) at different angles φ of the blades: 1 - bypassing all the characteristics; 2 - power characteristics of one blade at $\varphi=0^0$; 3- power characteristics with one blade at $\varphi=1^0$; 4- power characteristics with one blade at $\varphi=2^0$.

Next, we will consider options with three tower heights: 30, 38 and 50 m and determine the increase in production when using the system for adjusting the angle of installation of the blades. According to formula (6) – (7) and the characteristics in fig. 9. It is possible to calculate the power produced by the wind turbine at different angles φ of the blade installation.

The results of calculations for 30, 38 and 50 m are presented in Tables 1-3 (see appendix). According to these tables, it is possible to plot the characteristics of the power produced by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 30, 38 and 50 m) at different angles φ of the blade installation. In the graphic view for a height of 38 m, see fig. 10.

However, the windmill in our case has three blades shifted in space by 1200 relative to each other. Taking this into account, Fig. 11, three graphs (graphs 5, 6 and 7) of the power characteristics, similar to the one shown in fig. 10 bypass, also shifted in space by 1200 relative to each other. These three graphs are summarized. From fig. 11, it is obvious that the total graph (in Fig. 11, graph 2) of power clearly contains the third harmonic. The integral graph 3 of the total graph 2 and the integral graph 4 of the total graph calculated for the regime at $\varphi = 0°$ are also given there. From the comparison of these two graphs, it follows that with additional (to the main) adjustment of the installation angle in the range 0°≤φ≤ 2°, the increase in wind turbine power is ~ 1% [5].

At first glance, it seems that the percentage is too small for them to be seriously engaged. However, when creating the above-mentioned wind farm with a total capacity of 300 MW, where the installation of wind turbines of the company Vestas with a capacity of 3 MW is expected, the effect will conditionally be one additional unit. According to the generally accepted equation (7), the power was calculated under the same conditions, the graph of which is also shown in Fig. 11 (chart 1). From the comparison of graphs 1 and 3, it follows that for this wind turbine, equation (7) gives a result that is overestimated by ~ 15.3%.

For comparison, in fig. 12 and 13 show characteristics similar to fig. 11, but calculated for the heights of 50 m and 30 m of the axis of rotation of the same three-bladed windmill with a diameter of 48 m. At the same time, from the comparison of the integral graph 3 of the total graph 2 and the integral graph 4 of the total graph calculated for the regime at φ = 0 °, it follows that with additional (to the main) adjustment of the installation angle in the range, the increase in wind turbine power for heights of 50 and 30 m of the axis of rotation is ~ 2.3 and ~ 1%, respectively.

In addition, from the comparison of graph 1, calculated according to equation (7), and the specified graph 3, it follows that for such a wind turbine, equation (7) gives a result that is overestimated by ~ 12.3% and ~ 6.4%.

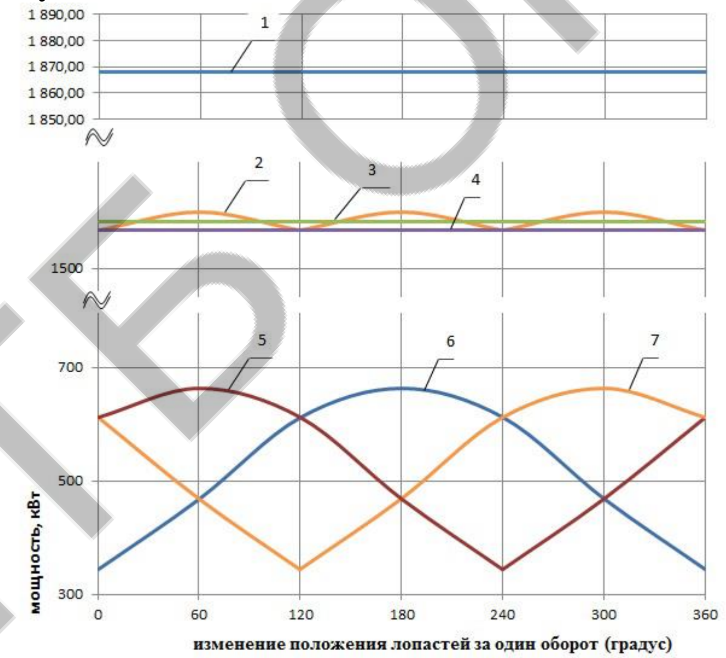

Fig. 11. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 38 m): 1 - the power of the wind turbine, calculated according to the formula (3.7); 2 - total power calculated for bypass; 3 - integral power for schedule 2; 5, 6, 7 - characteristics of the power of three blades of a windmill with an offset of 1200; 4 - integral power, calculated for the blade installation angle φ = 0 °

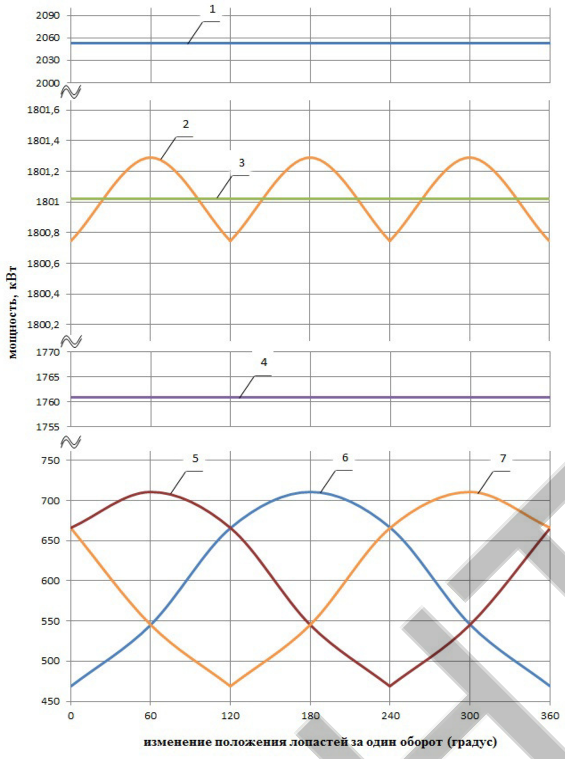

Fig. 12. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 50 m): 1 - the power of the wind turbine, calculated according to the formula (3.7); 2 - total power calculated for bypass; 3 - integrated total power calculated for bypass; 5, 6, 7 - rotation of the blades along the contour, consisting of angles φ of rotation of the blade 0°, 1°, 2°, 3°; 4 - integral power calculated for the angle φ = 0 of blade rotation

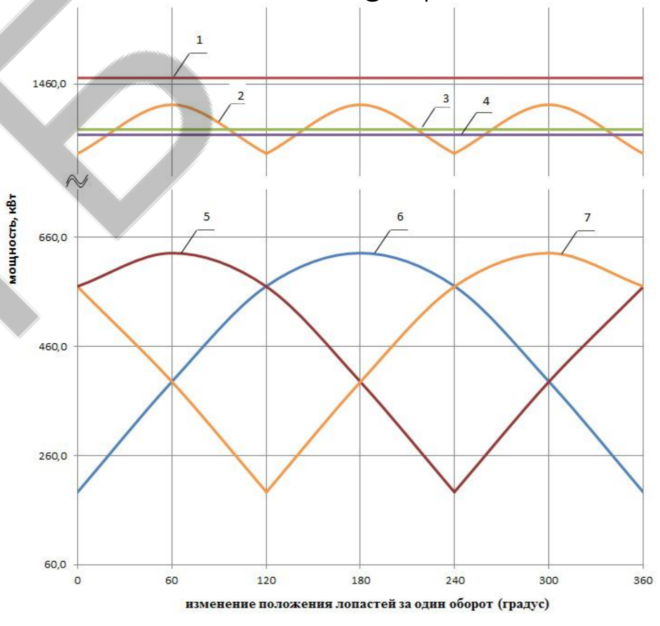

Fig. 13. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 30 m): 1 - the power of the wind turbine, calculated according to formula (7); 2 - total power calculated for bypass; 3 - integrated total power calculated for bypass; 5, 6, 7 - rotation of the blades along the contour, consisting of angles φ of rotation of the blade 0°, 1°, 2°, 3°; 4 - integral power calculated for the angle φ = 0 of blade rotation

By additional adjustment of the installation angle of each blade individually within the range of 0°≤φ≤ 3° during each rotation of the windmill so that when the blade passes from the position below the axis of rotation to the top, the angle changes from a larger value to a smaller value, the efficiency of the wind turbine increases.

For the "Raduga 1" wind turbine with the height of the axis of rotation of 38 m and the radius of the wind wheel of 24 m, the power increase is ~ 1%. With an increase in the height of the axis of rotation of the same windmill to 50 m, the power increase is ~ 2.3%. When calculating according to the generally accepted formula (7), we get an overestimated result.

3. Possible practical implementation options

In the article [2] it is indicated that in the "Raduga-1" VEU, a modified gearbox of the MI-26 helicopter is used as a multiplier. As an option for practical implementation of the system for adjusting the angle of installation of the blades during each revolution of the VC, it is possible to consider the use of an automatic skewing of the blades * helicopter propeller, the diagram of which is shown in fig. 14.

The main difficulties when using this system [9]:

- the blade should make several swings in one revolution, oriented in the direction of the wind;
- systems and devices for rotating the blades represent significant complexity and reduce the reliability of wind turbines;
- wind installation becomes more dependent on wind direction.

All these problems are removed when using the blade skew machine in the adjustment system.

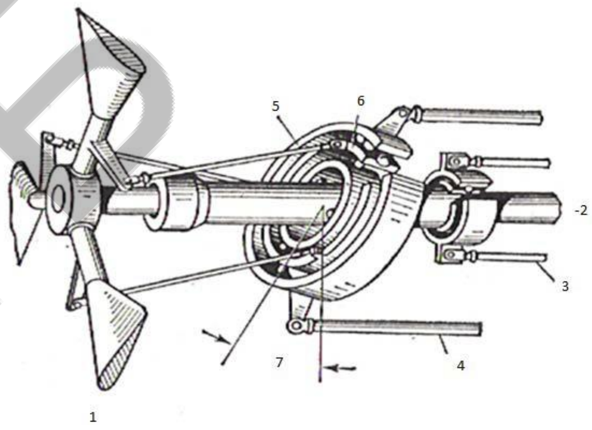

Fig. 14. Scheme of the automatic device for the angle of installation (automatic skewing) of the blades of the windmill: 1 - blade of the windmill; 2 - windmill shaft; 3. - control of the general pitch of the blades; 4 - control of the rings of the automatic blade installation angle; 5 - Does the ring of the blade installation angle machine not rotate; 7 - blade installation angle φ.

3.1. Statics

Blades 1 of the windmill with the possibility of turning around its longitudinal axis are connected to the common shaft 2, which is then connected, for example through a multiplier, to the shaft of the electric generator. There is a cylinder on shaft 2 that can be moved along shaft 2. There are three rings located coaxially above the cylinder. The cylinder, inner ring and ring 6 form a cardan1 transmission, so they rotate with the same angular speed. The rotating ring 6 and non-rotating ring 5 form a bearing. The outer ring 5 of the bearing is connected to three rods shifted in space by 120 degrees. The bearing ring 6 is hinged to the levers of the blades 1 through the rods according to the number of blades 1 of the windmill. The cylinder is rigidly connected to the inner ring of the second bearing, the outer ring of which is hinged to the rod 3. Rods 3 and rods 4 are connected to by the unit for controlling the angle φ of the blades 1 of the windmill. Elements 4-6 form a skew machine [6].

3.2. Dynamics

During the rotation of the windmill, control of the angle φ of its blades 1 is carried out by two independent processes: cyclic control of the pitch of the blades 1 and control of the joint pitch of the blades 1. Cyclic control of the pitch of the blades is performed by the automatic skew.

Under the action of control rods 4, all three rings of the tilting machine are tilted thanks to the cardan transmission, causing a sinusoidal change in the angles φ of the blades 1 in a given range through the rods that control the blades 1. In turn, this causes the appearance of a sinusoidal component in the turning moment, which, therefore, develops the power of the windmill.

V. CONCLUSIONS

1. The method of choosing a wind turbine based on the assessment of the produced specific annual energy of the wind flow of a given area has been developed and proposed;
2. It is based on the fact that by additional adjustment of the installation angle of each blade in some cases within the limits of $0^0 \le \varphi \le 3^0$ during each rotation of the wind wheel so that when the blade passes from the position below the axis of rotation to the top, the angle changes from a larger value to a smaller value, the efficiency of the wind turbine increases. For the "Raduga 1" wind turbine with the height of the axis of rotation of 38 m and the radius of the wind wheel of 24 m, the power increase is ~ 1%. As the height of the axis of rotation of the windmill increases, so does the power.
3. When calculating the power of a windmill according to the generally accepted formula, we get an overestimated result compared to the method used in the work.

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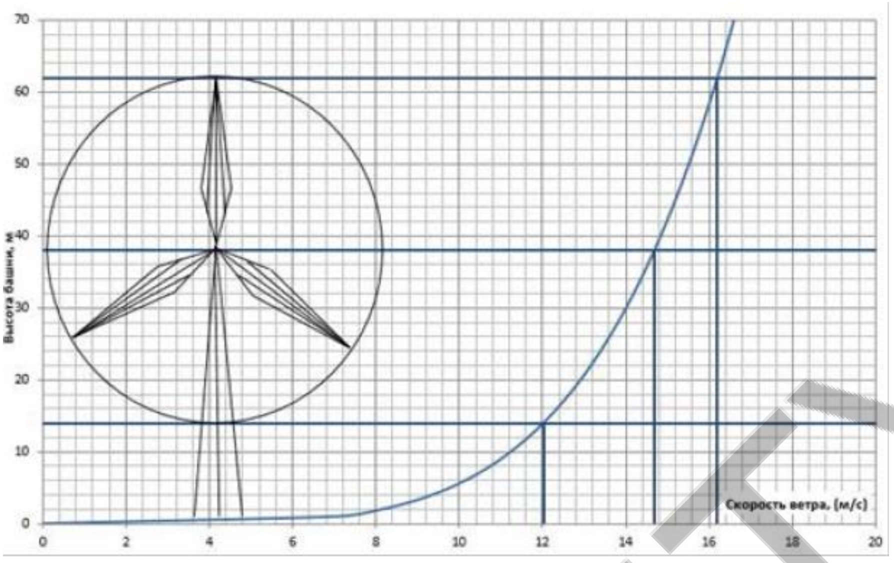
ADDITION



Graph of the change in wind speed along the entire height of the wind power plant (tower height = 38 meters)

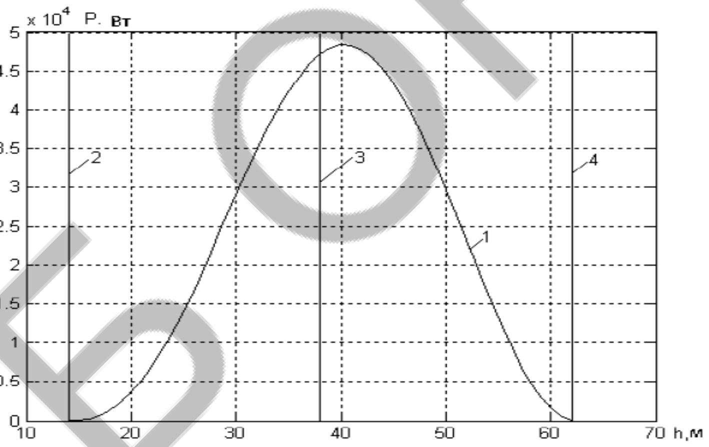


Fig. 7. Graph of distribution of the power developed by the windmill, taking into account its aerodynamic characteristics, by the area of the windmill and by its height - 1; vertical lines 2, 3, 4 - respectively, the height of the lower limit (14 m), the axis of rotation (38 m) and the upper limit of the windmill (62 m)

Table 1. - Characteristics of the power received by one blade for one rotation of the windmill (the height of the axis of its rotation of the windmill is 30 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0		Angle = 0^0	
				C_m	P, Вт	C_m	P, Вт			C_m	P, Вт
blade below	0^0	10,1	8,9	0,0529	182,1	0,0538	185,3	0,0548	188,7	0,0560	192,7
	60^0	12,6	7,2	0,0680	363,4	0,0700	374,2	0,0715	381,8	0,0740	395,2
	120^0	15,0	6,0	0,0754	565,0	0,0760	569,8	0,0749	561,9	0,0754	565,4
blade on top	180^0	15,7	5,7	0,0761	630,6	0,0758	628,8	0,0735	609,0	0,0747	619,0
	240^0	15,0	6,0	0,0754	565,0	0,0760	569,8	0,0749	561,9	0,0754	565,4
	300^0	12,6	7,2	0,0680	363,4	0,0700	374,2	0,0715	381,8	0,0740	395,2
blade below	360^0	10,1	8,9	0,0529	182,1	0,0538	185,3	0,0548	188,7	0,0560	192,7

Table 2. - Characteristics of the power received by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 38 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0	
				C_m	P, Вт	C_m	P, Вт		
blade below	0^0	12,0	7,5	0,066902	323,2	0,069458	335,6	0,071334	344,7
	60^0	13,6	6,6	0,073615	455,6	0,075191	465,4	0,075675	468,4
	120^0	15,5	5,8	0,076014	611,1	0,073901	594,1	0,075165	604,3
blade on top	180^0	16,2	56	0,075541	661,9	0,072672	636,7	0,073531	644,3
	240^0	15,5	5,8	0,076014	611,1	0,073901	594,1	0,075165	604,3
	300^0	13,6	6,6	0,073615	455,6	0,075191	465,4	0,075675	468,4
blade below	360^0	12,0	7,5	0,066902	323,2	0,069458	335,6	0,071334	344,7

Table 3. - Characteristics of the power received by one blade for one rotation of the windmill (the height of the axis of its rotation of the windmill is 50 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0		Angle = 0^0	
				C_m	P, Вт	C_m	P, Вт	C_m	P, Вт	C_m	P, Вт
blade below	0^0	13,6	6,6	0,0720	445,8	0,0736	455,8	0,0752	465,6	0,0765	468,6
	60^0	14,3	6,3	0,0739	502,6	0,0752	511,6	0,0758	515,7	0,0758	515,3
	120^0	15,0	6,0	0,0754	566,0	0,0760	570,7	0,0749	562,6	0,0754	566,3
blade on top	180^0	15,2	5,9	0,0756	586,6	0,0762	591,3	0,0744	577,4	0,0753	584,2
	240^0	15,0	6,0	0,0754	566,0	0,0760	570,7	0,0749	562,6	0,0754	566,3
	300^0	14,3	6,3	0,0739	502,6	0,0752	511,6	0,0758	515,7	0,0758	515,3
blade below	360^0	13,6	6,6	0,0720	445,8	0,0736	455,8	0,0752	465,6	0,0757	468,6