E3S Web of Conferences **474**, 01050 (2024) https://doi.org/10.1051/e3sconf/202447401050
ICITE 2023

Numerical simulation and experimental data blade investigation of horizontal wind turbine

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Abstract. The article presents the results of numerical simulation of a wind turbine blade. The fundamental formulas of the theory of aerodynamics, on which the calculations are based, are presented. Computer models of air movement near the blade are shown. Data on the distribution of speed have been obtained. The coefficient of wind energy utilization depends on the parameters of both the oncoming flow and the blade profile. This coefficient is different for vertical and horizontal wind turbines. To improve the operation of the wind turbine, it is proposed to use non-network algorithms. The neural network should collect data on the received errors in the system of mechanization and automatic control. Errors in control systems are analyzed, individual parameters are weighted to stabilize the operation of the wind turbine as a whole.

1 Introduction

Wind turbines acquire the properties of individual power plants. A standard power plant is characterized by reliable operation on electric power networks. The power grids must operate continuously. Increasing the load negatively affects the stability of the power system. A sharp decrease in load also negatively affects the stable supply of electricity to consumers.

A distinctive feature of wind turbines is the instability of electricity generation, although modern installations are equipped with stabilizers. Instability lies in the fact that the wind, although stable, but not a constant phenomenon. There are moments when the blades stop due to the lack of even a minimal opportunity for rotational movement. At the same time, there is a moment of emergency stop of the blades due to squally gusts of wind. Here, first of all, wind turbine designers care about safety and reliability. An important role is occupied by such an indicator as the service life, as well as the overhaul period [1, 2].

At present, prices for fossil fuels for industrial enterprises are such that separate generation of electricity by standard methods becomes unprofitable for small-scale energy. On the scale of a large energy industry, industrialists of the industry made this conclusion a long time ago. For small-scale power generation, with power generation by units up to 5 MW, such conclusions began to flow from theory into practice. For example, for micro wind

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turbines, electricity generation is comparable to mini thermal power plants based on installations using fossil fuels. However, in both cases there are operating features that should be considered when choosing equipment [3, 4].

The advantage of wind turbines is a wide choice of designs and a large range of speed, and consequently, a quick commissioning and shutdown of equipment. The disadvantage is the low efficiency in comparison with conventional mini thermal power plants, as well as the complexity of manufacturing, repair and service.

Let's take as a basis - the construction of a wind turbine on the territory of an industrial enterprise. The use of a wind turbine must necessarily be in terms of redundant power generation by standard methods. In this case, the reliability of the power supply of the industrial enterprise is increased [5, 6].

2 Materials and methods. Fundamental dependencies and methods for building a computer model

Let's write down the basic formulas for organizing the calculation of a wind turbine.

If we assume that the wind speed behind the blade becomes equal to zero, then the formula is applicable:

$$v_1 = 0.5\left(v_0 + v_2\right) = 0.5 v_0 \tag{1}$$

The flow stagnation factor can be calculated as follows:

$$a = \left(v_0 - v_1\right) / v_0 \tag{2}$$

Thus, we can write the formula for the wind power factor:

$$C_p = 4a(1-a)^2 \tag{3}$$

It should be noted that the maximum coefficient can be determined as follows:

$$C_{p\max} = 0.593 \tag{4}$$

This coefficient is sometimes called the Betz coefficient [7, 8]. At the same time, one should not forget about the maximum possible wind speeds, this value can be up to 25 m/s.

Let's write an equation for our case of a horizontal wind turbine [9, 10].

$$P_0 / \rho_0 + g + z_1 + v_0^2 / 2 = P_2 / \rho_2 + g + z_2 + v_2^2 / 2 \tag{5}$$

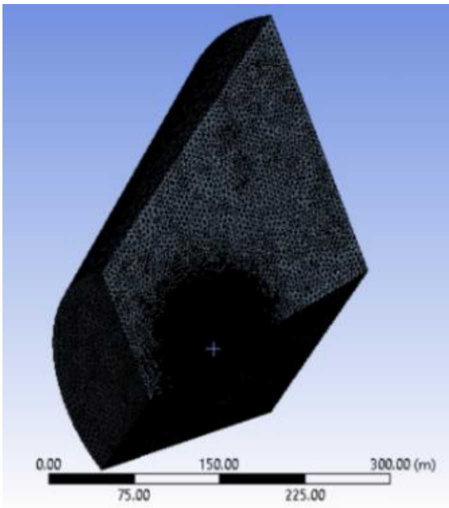
In this case, the load on the blades will look like this [11, 12].

$$F_{A\max} = pA_1 \cdot v_0^2 / 2 \tag{6}$$

The drag coefficient can be found by the formula.

$$C_F = 4a(1-a) \tag{7}$$

If we talk about methods for constructing a numerical model, then we will show the solid model grid in Figure 1.



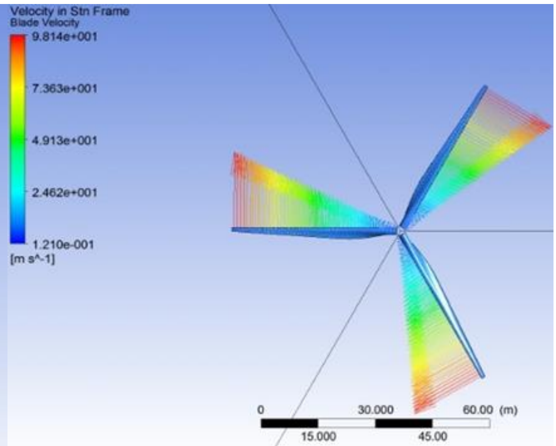


Fig. 1. The grid of model.

Fig. 2. Speed of blades.

The mesh of the model describes in sufficient detail the accuracy required for the movement of air flow without significant heating as shown in Figure 1.

3 Results. Post-processing of a computer model and results of experimental studies

We present the results in the form of a model of air flow around the blades of a wind turbine in figure 2 and 3.

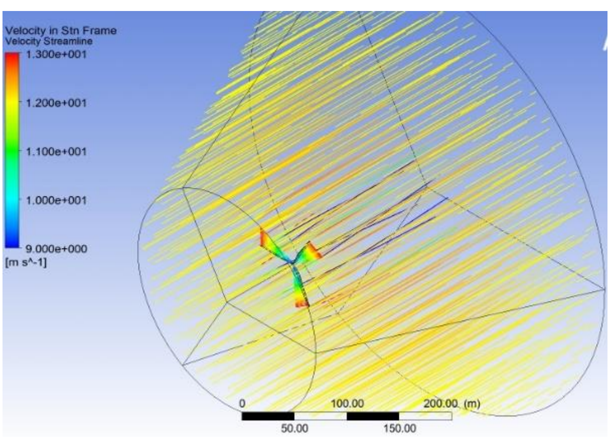


Fig. 3. Streams of speed.

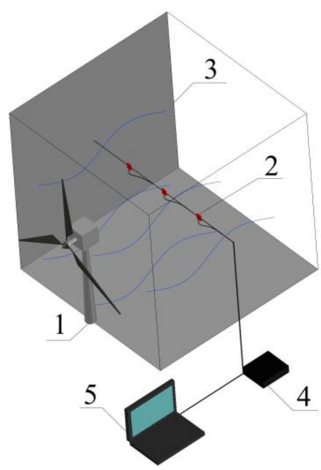


Fig. 4. Experimental installation:
1 - wind turbine, 2 - tape sensors,
3 - measuring channel, 4 - controller,
5 – laptop.

The experimental installation assumes the existence of a special channel for air flow and measuring devices in figure 4.

The obtained results fit into the permissible measurement errors. Thus, the dependence of the air flow parameters on the mathematical model description is justified. The need for new methodological approaches to the theory of wind turbines is theoretically confirmed.

The results of experimental studies allowed us to plot the speeds and showed dependence according to Table 1.

Table 1. Dependence of streams of speeds and deviation.

Velosity (v), m/s	Deviation (δ), m/s
1.3	0.03
1.5	0.06
1.8	0.10

4 Discussion. Possibilities of using neural networks in control systems

Wind power depends on the average annual or average speed for the period and the frequency of various wind speeds. It is estimated by the amount of energy that can be obtained with the help of a wind turbine in a given area. Modern designs and methods for regulating the speed and power of wind turbines ensure their reliable operation at storm wind speeds and limiting the developed power in such a way that the maximum power usually exceeds the established value by no more than 15-20%. To reduce power fluctuations or avoid them, wind energy is accumulated during periods when there is excess power [13, 14]. There are no special obstacles for modern legislation in the field of energy, not only for the construction of wind turbines, but also for the generation of electricity for the load of large energy networks. That is, there is no need to reduce the load, it is only necessary to warn the large electric power industry in time about the upcoming supply of surplus electricity in a certain amount [15, 16].

Energy as a branch of the national economy is being transformed in accordance with the needs of the electricity and heat sales market. The construction of wind turbines at industrial enterprises is possible not only to cover their own needs, but also to sell products on the electricity and heat market in the field of large-scale energy [17, 18].

Changes in the dynamics of the behaviour of the model, or in this case the model of a wind turbine blade, are characterized by an adaptation parameter. Training takes place on the collected data. The database is constantly updated. Thus, it is an ongoing process.

For a neural network, time series are important. Denote x - time series in the form of the ratio $x = r + d$, then r is a component determined by a random process that affects subsequent members of the time series, and d is a component obtained in a non-auto correlated process that affects only the synchronous value of the series.

When constructing a predictive model, a hypothesis is put forward about the dynamics of the function of the value d from the time argument. The models under consideration are endowed with adaptive properties, the ability to correct the original hypothesis or to replace it with another one that is more adequate in terms of forecast accuracy.

It is necessary to create an author's methodology that allows determining the required rotation time of the wind turbine blades according to wind parameters, analysis of the control system and errors. The best option would be to create a software algorithm capable of calculating the necessary impact and making adjustments, as well as collecting and systematizing data on the calculated and real effect with the construction of predictive characteristics. In addition, the creation of a neural network regulation algorithm that will learn from the collected data and adapt to a specific blade profile when using mechanization elements.

5 Conclusion

Summing up the results of the work carried out, we can say that in this study the efficiency of wind turbine blades was studied. In this case, computer modeling and data from a physical experiment were used. The results of numerical modeling methods are compared with experimental data. Numerical methods are consistent with experimental data and can be used to optimize blade mechanization elements.

The introduction of predictive methods will reduce the number of hours of wind turbine downtime due to an emergency, as a result of which the control system, according to a given algorithm, decides to suspend operation.

Based on the results of numerical modeling of the wind turbine blades, the main results on the speeds of the wind and the blades themselves, the main formulas of the theory of air movement are shown. Numerical models of air movement over the wind turbine area are presented. Wind power utilization factor and its dependencies are shown. This coefficient is calculated for horizontal wind turbines. To optimize the operation of a wind turbine, it is proposed to use neural networks that collect data on errors in the mechanization and automatic control system. Further, the analysis is carried out, and individual parameters receive weight coefficients. Based on these coefficients, further improvement of the wind turbine operation model is carried out; in particular, the option of controlling the elements of mechanization of the blade is possible.

The study was supported by the Russian Science Foundation grant No. 23-11-20016, https://rscf.ru/en/project/23-11-20016/

References

1. S. Perzhabinsky, D. Karamov, A. Achitaev, Journal of Siberian Federal University. Engineering and Technologies **1** (2021).
2. H. Qin, G. Li, En. Chye, V. Voronin, V. Ivanov, Bulletin of the Pacific State University **2(57)**, 9-16 (2020).
3. A. Kirsanova, *Mathematical modeling of processes and systems* (Russia, 2022).
4. A. Valentova, E. Budylina, Intellect, Idea, Innovation **2(2)**, 220-224 (2017).
5. N. Voropaev, Challenges and prospects **2**, 112-117 (2019).
6. I. Popova, V. Kravtsov, E. Kamelina, Young researcher of the Don **1(28)**, 2-9 (2021).
7. D. Pashegorov, A. Izhevsky, *Materials of the IX International Scientific and practical conference* (Russia, 2018).
8. M. Kondratyuk, My professional career **14**, 22-24 (2020).
9. B. Lukutin, E. Sarsikeev, Scientific and Technical Bulletin of the Volga region **1**, 140-143 (2011).
10. V. Antipov, A. Grozov, A. Ivanova Electrical engineering **6**, 42-47 (2020).
11. M. Galimov, V. Golubev, Bulletin of the Magistracy **12(1)**, 98-100 (2014).
12. K. R. Ishenaliev, My professional career **8**, 138-141 (2020).
13. I. Al-Bahadly, *Proceedings of Int. Conf. on Circuits, Systems, Signal and Telecommunications* (Gold Coast, Australia, 2007).

14. V. Khramshin, D. Blagodarov, R. Khramshin, V. Zhilina, I. Barankova, *Proceedings of the Conference: IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering* (St. Petersburg, Russia, 2017).
15. A. Hughes, *Electric motors and drives: fundamentals, types and applications* (Newnes, Oxford, 2006).
16. J. E. Sierra-Garcia, M. Santos, Neural Comput & Applic **34**, 10503-10517 (2022).
17. K. Osintsev, S. Aliukov, A. Shishkov Energies **14**, 3085 (2021).
18. C. Phelps, J. Singleton, *Wind turbine blade design* (Ithaca, NY, USA, 2013).