Review of Russian research in the field of wind energy

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Abstract. The use of renewable energy sources is becoming a priority for states due to growing environmental problems. Wind is one of the most sustainable renewable energy sources. In Russia, interest in wind energy has been growing in recent years. This paper is a review of the research on wind in Russia, the main objective is to show the level of development of the scientific base, as well as to consider the main topics, articles, research groups and completed projects, and make a comparison with world scientific works.

1. Introduction
Environmental problems make us pay attention to the current situation in the global energy industry. The increase in energy demand and consumption is the result of technological progress and is considered as the most important factor in accelerating climate and environmental change [1]. World energy consumption will increase by 40% in 2040 compared with 2017 [2]. The use of renewable energy sources (RES) is becoming a priority for states due to growing environmental problems and the security of fossil fuel supply [3]. Progress in the development of technologies for the efficient use of renewable energy in recent decades has led to the public understanding that without the use of solar energy, wind energy, biomass and other environmentally friendly natural renewable energy sources, it will be difficult to ensure long-term, sustainable and safe energy development. However, in many regions of the world, in particular in our country, renewable energy sources are still very limited in use.

Wind is one of the most sustainable renewable energy sources [4]. This type of energy provides the best ratio of investment costs and productivity [5]. In recent years, wind power has strengthened its position in the production of electricity throughout the world. 2015 was the year when more than 40% of the electricity generated by Denmark was obtained from wind energy resources (the highest rate in the world in all time), while Ireland, Portugal and Spain produced about 20% of their electricity using wind [6]. China, the United States and Germany continue to lead in total wind power capacity. China established 37% of new global capacity in 2017, the United States – 13% and Germany – 12%. Global wind power increased by 53 GW during 2017, for a total of 539 GW. A record number of new offshore capacities was installed worldwide — 4.3 GW, which increased the total offshore capacity by 31%, to 18.8 GW. Wind power continues to be the largest non-hydro renewable energy source in terms of installed capacity. The energy generated by the wind covered about 5.6% of global demand in 2017 [7].
This paper is a review of the research on wind in Russia, the main objective is to show level of development of the scientific base, as well as to consider the main topics, articles, research groups and completed projects, and make a comparison with world scientific works.

2. Bibliometric analysis

Bibliometrics is a powerful and widely used tool for evaluating research conducted. In paper [8], a bibliometric analysis of articles devoted to estimating the cost of wind energy is performed. The study [9] uses the Scopus database to demonstrate a growing number of scientific publications on the problems of wind turbine optimization. The article [10] assesses both quantitatively and qualitatively global scientific research on low-carbon electricity.

In this paper, a bibliometric analysis of wind power research was carried out using the ScienceDirect. Analysis was conducted to confirm the relevance and growing interest in wind power. Figure 1 shows the graphs of changes in the number of publications on wind energy topics.

![Figure 1. Articles on the topic of wind energy.](image)

As the results show, there is a positive trend in the number of published works for the year. The annual number of publications in almost all topics over the past decade has increased more than 2 times, which confirms the increased interest and development of wind power in recent years.

To compare Russian and world publication activity, a study on the number of publications on the topic of wind energy and related countries was conducted. The results of study with the distribution by year are presented in Figure 2.

![Figure 2. Analysis of search queries by country.](image)

Leading positions are occupied by China, Germany and the United States, which is not surprising. These countries are the world leaders in total wind power capacity, as noted above. In addition, China’s chart is
highlighted among others in the figure. The number of annually published articles, related to wind energy and China, has increased more than 4.5 times over the past 10 years. This explains the accelerated development of wind power in China in recent years. The number of articles on request related to Russia is much less than the world leaders at the moment, although it has a positive growth trend. This may indicate an insufficient development of the Russian scientific base in the field of wind energy.

3. Review of Russian wind energy research and comparison with global research

Some scientific groups in countries with developed wind energy research were reviewed for comparison with Russian scientific groups. A research team from Germany study and model the geometry of wind turbines and their blades. In particular, the work [11] is a study of various methods for calculating the angle of attack and the base velocity on wind turbine blades using data obtained using three-dimensional computational fluid dynamics. The study was conducted for two standard wind turbines with a capacity of 10 MW. The article [12] presents a tool for high-precision design of wind turbine rotors. The developed tool combines the open source Computational Fluid Dynamics (CFD) code OpenFOAM and the BeamFOAM internal solver and allows to analyze flexible of wind turbines blades by means of CFD. To demonstrate the work of the solver, modeling was performed using the NREL 5 MW standard wind turbine, and a comparison with the results of other authors was made.

In Norway, scientists pay much attention to the icing of wind turbines. In order to optimize the performance of large wind turbines in cold regions exposed to ice, it is important to understand the physics of ice accretion and its effect on aerodynamic performance and power production losses. An article [13] describes a study of the icing of the DU96-W-180 airfoil, which is used for blades of large wind turbines, such as the NREL 5 MW. The analysis was carried out using experimental data obtained in a laboratory setup, and a numerical approach based on multiphase CFD. Numerical results were compared with the experimental data, where a good agreement was found. In the article [14], a numerical study of the ice accretion process and the resulting flow characteristics was carried out for the wind turbine blade profile NACA 64618 in order to understand the effects that atmospheric temperature and droplet size variations have on the rate and shape of ice growth. Aerodynamic characteristics of the blade profile were analyzed at different angles of attack in the range from -10 ° to +20 °. The results showed an increase in the growth rate of ice with an increase in the size of the droplets, while a change in air temperature significantly affects the shape of the accreted ice.

A number of review articles on the methods of de-icing of wind turbines have been published by Canadian researchers [15-16]. Icing control methods are divided into passive and active. Passive methods are used to prevent the formation of ice without additional energy costs. Any control systems are not used to keep the blades free of ice, therefore operating costs are reduced. The application of a hydrophobic coating that prevents water from sticking to the surface of the blade and freezing is one of the most popular passive methods. Another passive method is the use of black blades. The sun heats the dark surface of the blade faster, causing the ice to melt. Also, passive methods include a temporary stop of wind turbines as soon as the icing begins. Active methods of de-icing the blades of wind turbines require additional energy. One of such methods is chemical treatment of the surface of the blade. These fluids are often used in the treatment of aircraft wings. There are a number of mechanical methods for removing ice. They include the physical destruction of ice using scrapers, vibration or movement of the structure. Pneumatic, ultrasonic and electromagnetic pulses are used to create vibrations. A proven way to prevent the formation of ice is to maintain the temperature of the surface above the freezing point. The method of supplying hot air to the surface adjacent to the area of icing is used in the wings of aircraft. It was adapted for wind turbines by Enercon in 2009. Another thermal method for de-icing is the installation of resistive heaters. Also, surface heating can be carried out using microwave and infrared radiation.

Interest in renewable energy sources in Russia is growing both among scientists and power engineers. At the moment, government decisions have been taken to stimulate a more rapid development of renewable energy, despite the fact that Russia has huge reserves of fossil fuels. And
although power plants based on renewable energy sources are not used everywhere in Russia, it is obvious that these technologies will be developed in the near future. This will cause an increased need for scientific research that can accelerate this development.

A number of books, devoted to renewable energy sources, already published in Russia. In the book of prof. A.B. Alkhasov, the director of the Institute of Geothermal Problems of the Dagestan Scientific Center of the Russian Academy of Sciences, [17] reviewed the current state and prospects for the use of renewable energy sources, their energy, economic and environmental characteristics, given technological schemes of power plants, the principles of their work. In the book of prof. N.N. Baranov [18] considered methods for converting energy from renewable sources (wind, solar, biomass, ocean, hydrogen, geothermal energy). Physical and thermodynamic principles of energy conversion in photo and wind power installations are considered in the book of prof. A. da Rosa [19]. The book [20], written by the professor of the St. Petersburg Polytechnic University V.V. Yelistratov, covers the issues of storage of energy from renewable sources, as well as the operation of renewable energy facilities in grid and distributed generation. The book of O.S. Popel and V.E. Fortov, the Deputy Director and Director of the Institute for High Temperatures RAS respectively, [21] systematically examines all the most promising technologies for using renewable energy sources and the state of their development in the world.

Also, some articles on the topic of wind were published by Russian scientists. The articles [22‒23] analyze systems that can solve the problem of energy storage produced by wind turbines. Based on the simulation of autonomous wind turbine, it is shown that due to differences in the production and consumption of electricity, from 40 to 80% of the electricity generated by wind turbine is not used by the consumer. In order to improve the efficiency of using wind energy, it is proposed to accumulate excess electricity in a solid-phase heat accumulator, which will help provide the consumer with not only electricity, but also heat.

Article [24] is devoted to the selection of optimal characteristics of a hybrid power plant for an isolated settlement. The work develops approaches to optimize power plants based on renewable energy sources and diesel generator sets. The power ratio of the RES unit and a diesel generator set is selected as a criterion for such optimization, which allows equalizing capital and operating costs for a diesel generator set and a hybrid power plant.

Scientists at the Peter the Great St. Petersburg Polytechnic University are engaged in the study and development of designs of wind power plants. In article [25], a review and analysis of engineering structures used in the design of wind power plants was carried out. It is shown that it is necessary to divide the system into a number of subsystems in the design of wind power stations depending on the climatic factors. The results of calculations of the wind turbines foundation of the Anadyr wind farm on permafrost soils are presented. The article [26] presents a description of the new wind power plant, its design and principle of operation. The methods of aerodynamic and energy research of this power plant is described, the results and their analysis are presented. Also, a number of patents for inventions and utility models have been obtained by scientists from St. Petersburg.

4. Completed wind projects in Russia

Already in Russia there are projects in the field of wind energy. However, most of them are implemented with the help of foreign companies that have many years of experience, developed technical and scientific base, in which Russian companies have a big disadvantage.

Since January 2018 the wind power station Fortum in Ulyanovsk has started to work. The wind farm with an installed capacity of 35 MW consists of 14 wind turbines. The first wind farm project in Ulyanovsk was successful, so the second project was implemented after it. A wind farm with an installed capacity of 50 MW began supplying energy to the market in January 2019. It consists of 14 power plants manufactured by Vestas with a capacity of 3.6 MW each. There are other implemented projects:

– wind-diesel complex based on two Vergnet wind turbines with a unit capacity of 275 kW, Bering island, Kamchatka region;
wind-diesel complex based on GHRepower wind turbine with a capacity of 30 kW, the Republic of Tatarstan;
- Micon wind turbine with a capacity of 250 kW in permafrost conditions, Labytnangi, Yamalo-Nenets Autonomous region;
- Vergnet wind turbine with a capacity of 275 kW, Ust-Kamchatsk settlement, Kamchatka region;
- Komai wind turbine with a capacity of 300 kW, Ust-Kamchatsk settlement, Kamchatka region;
- wind-diesel complex based on two Vestas wind turbines with a unit capacity of 225 kW, Novikovo settlement, Sakhalin.
- a wind-diesel complex based on three Komai wind turbines with a unit capacity of 300 kW, Ust-Kamchatsk settlement, Kamchatka region.

The project of a wind-diesel complex consisting of three wind turbines with a total capacity of 900 kW, three diesel generators with a total capacity of 3 MW and an energy storage system is implemented in the Tiksi settlement. The construction of the wind park in the Arctic zone will allow testing equipment in conditions of extremely low temperatures (up to -40 °C) and strong winds (up to 60 m/s). In November 2018, the wind park began supplying the isolated Tiksi settlement with a population of over 4.6 thousand people with clean energy. Due to the start of wind energy generation, the consumption of imported diesel fuel can be reduced to 500 tons per year. Completion of the project and the construction of a diesel power station is planned for 2019.

Construction of the currently largest wind farm in Russia is carried out in the Republic of Adygea. A wind farm with an installed capacity of 150 MW will consist of 60 wind turbines with a capacity of 2.5 MW each. The planned annual energy production of the wind farm will be 354 million kWh per year. A large wind farm will reduce the energy deficit of the Republic of Adygea by 20%. The capacity of this wind park is enough for full energy supply of the capital of the republic – Maikop city.

5. Conclusions
As a result of the study of publication activity, the main trends and directions of wind power development were identified: the study and modeling of the geometry of wind turbine blades, the physics of ice formation on the blades and methods of de-icing, energy storage, hybrid power plants, etc. It was found that the scientific base in Russia is insufficiently developed: there is a lag behind the leading countries in the number of articles in the field of wind power, there is no major scientific research on the icing of wind turbine blades, which is extremely important in northern conditions. In addition, there are not enough articles on the assessment of the wind energy potential of the Russian territories. Any territory has unique ecological and economic conditions. Therefore, each case can be unique and requires individual complex study. Analysis of wind energy potential can contribute to the successful implementation of the project and prevent mistakes at the design stage.

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