ANNOTATION

dissertation for the degree of Doctor of Philosophy (PhD) in the specialty «6D072300 – Technical Physics»

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Technical-technological solution to the starting problems of a vertical-axis wind turbine

General description of work. This dissertation presents an experimental and numerical investigation into the aerodynamic performance of a Darrieus-type vertical-axis wind turbine (VAWT) equipped with asymmetrical blades. The main goal is to improve turbine efficiency under low wind speed conditions.

Relevance of the Research Topic

The modern development of renewable energy sources (RES) is driven by the need to enhance energy independence, promote sustainable development, and minimize environmental impact. In this context, wind energy is one of the key areas, especially in regions with limited and variable wind potential. Small-scale wind energy systems (WES), designed for autonomous energy supply in remote and rural areas, are gaining particular importance. Among them, vertical-axis wind turbines (VAWTs) are considered especially promising due to their advantages such as independence from wind direction, simple design, low noise levels, and the ability to operate efficiently at low wind speeds. This highlights the relevance of developing and improving rotor designs with enhanced aerodynamic characteristics, including Darrieus-type rotors with asymmetrical blades.

Kazakhstan is actively developing its renewable energy sector as part of a national strategy to achieve carbon neutrality by 2060. As of 2025, the country operates more than 25 industrial wind energy installations with a total capacity exceeding 800 MW, which is more than double the figure in 2020. According to national targets, the share of RES in the country's energy balance is expected to reach 15% by 2030 and 50% by 2050. Favorable natural and climatic conditions, especially in the southern and western regions with wind speeds of 5–7 m/s and above, create strong preconditions for the further development of wind energy.

Thus, in 2025, Kazakhstan is entering a phase of active implementation of new solutions in wind energy, where scientific research aimed at improving the efficiency of WES at low wind speeds is in high demand and holds strategic importance.

While Kazakhstan holds considerable potential in renewable energy – including hydropower, solar, and wind – wind energy stands out due to its environmental cleanliness, accessibility, and suitability for local generation.

However, much of the country's territory experiences modest average wind speeds (below 5 m/s), which limits the effectiveness of many existing turbine designs. A critical issue is the self-starting capability of the rotor from a stationary state. Many current Darrieus rotor designs fail to generate sufficient torque for self-

starting at low wind speeds, necessitating auxiliary starting mechanisms or design modifications.

Vertical-axis wind turbines have recently garnered increased interest due to their simple design, compactness, and independence from wind direction. Among these, the Darrieus rotor with aerodynamic drive exhibits a higher power coefficient compared to traditional rotors like the Savonius type. Nevertheless, the self-starting issue remains a significant challenge, limiting their widespread application in low wind potential conditions.

Therefore, the development and optimization of vertical-axis wind turbines with asymmetrical blade shapes that operate efficiently under low average wind speeds represent a crucial scientific and technical task. Addressing the self-starting problem directly impacts the energy efficiency, reliability, and broader applicability of such installations. Research in this area aligns with the priority directions of scientific and energy development in the Republic of Kazakhstan.

The dissertation work aims the objective of this dissertation is to investigate the aerodynamic characteristics of a Darrieus rotor with asymmetrical blades, aiming to enhance the efficiency of vertical-axis wind turbines.

Research Tasks

1. Investigation of the aerodynamic characteristics of an asymmetrical blade used as a working blade in a vertical-axis wind turbine;

2. Study of the pressure field distribution and velocity vectors around a single blade and the entire rotor at various angles of attack and incoming flow velocities; identification of flow separation zones and determination of regions with maximum aerodynamic impact.

3. Analysis and generalization of the results of experimental research on the aerodynamic characteristics of a Darrieus rotor with various structural elements.

The objects of research the objects of the research are Darrieus rotors equipped with asymmetrical blades designed to enhance lift and improve self-starting performance. The study encompasses configurations both with and without horizontal guide vanes, investigated through both numerical simulations and experimental methods.

Subject of Research

The subject of this research is the determination of the aerodynamic characteristics of an asymmetrical airfoil blade interacting with the wind flow.

Research Methods

Experimental studies were conducted in the working section of the T-1-M wind tunnel using aerodynamic balances to investigate the aerodynamic characteristics of turbine models.

Additionally, numerical methods (CFD – computational fluid dynamics) were employed using the ANSYS Fluent environment, enabling the analysis of unsteady flow and assessment of the aerodynamic characteristics of the Darrieus rotor with asymmetrical blades.

Relation of the Topic to Research Program Plans

This work was carried out within the framework of the grant funding competition for research projects by young scientists under the "Zhas Galym"

program for 2024 – 2026, conducted by the Ministry of Science and Higher Education of the Republic of Kazakhstan, for which the author expresses gratitude. Project IRN: AP22685893 "Investigation of the aerodynamic characteristics of asymmetrical blades used in wind energy installations to enhance turbine efficiency."

Scientific Novelty

1. A novel asymmetrical blade profile was developed and implemented for the first time in a Darrieus-type rotor, specifically targeting self-start capability at low wind speeds.

2. The influence of additional structural components – horizontal flow deflectors – on startup behavior and power coefficient was quantified.

3. CFD-based analysis of pressure and velocity distributions around asymmetrical blades was conducted for the first time in this context..

Key Provisions Submitted for Defense

1. The original geometry (shape) of the asymmetrical blade contributes to an increase in lift force and a reduction in starting torque, enabling the self-starting capability of the rotor at wind speeds starting from 3 m/s.

2. The inclusion of horizontal guide plates in the rotor design contributes to the improvement of its starting and energy performance. At a wind speed of 3 m/s, the rotational speed increases from 25 rpm (without plates) to 40 rpm (with plates), and at 12 m/s – from 158 to 200 rpm, respectively. Moreover, the design with plates provides a higher power coefficient: at a wind speed of 9 m/s, the Cp value reaches 0.34, which is 23% higher than that of the rotor without plates (0.276).

3. The proposed asymmetrical blade shape of the vertical-axis wind turbine rotor provides improved starting performance in critical azimuthal zones (0 – 120° and 300 – 360°), reducing start-up time and ensuring stable self-starting at low wind speeds. Despite a localized increase in start-up time in the 180 – 210° range, the obtained results confirm the effectiveness of the geometric modification and its applicability for optimizing the performance of wind energy systems under real operating conditions.

Practical Value

The practical value of this work lies in enhancing the efficiency of small-scale wind energy installations through the use of asymmetrical blades and guide plates. The obtained results can be utilized in designing turbines for regions with low wind speeds, ensuring better self-starting capabilities and increased turbine power output.

Reliability and validity of the data are confirmed by direct physical experiments and numerical modeling, the use of standard data processing methods and computer software. Furthermore, the reliability of the results is supported by publications in high-impact international scientific journals, as well as in journals recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan (CQASHE MSHE RK), and in the proceedings of international scientific conferences both near and far abroad.

Publications

Based on the materials of the dissertation, 5 publications have been issued, including 2 articles in journals indexed in the Scopus and Web of Science databases, 2 articles in journals recommended by CQASHE MSHE RK, and 1 paper in the proceedings of international scientific conferences.

Approbation of the dissertation work

Articles with impact factor included in the international scientific databases Scopus and Web of Science:

– Isataev, M.; Manatbayev, R.; **Seydulla, Z.;** Bektibai, B.; Kalassov, N. Study of Aerodynamic Characteristics of Asymmetrical Blades and a Wind-Driven Power Plant with a Vertical Axis of Rotation. *Appl. Sci.* 2024, 14, 11654. https://doi.org/10.3390/app142411654. (Q1, 79%).

– Isataev, M.; Manatbayev, R.; **Seydulla, Z.;** Kalassov, N.; Yershina, A.; Baizhuma, Z. Experimental and Computational Study of the Aerodynamic Characteristics of a Darrieus Rotor with Asymmetrical Blades to Increase Turbine Efficiency Under LowWind Velocity Conditions. *Appl. Syst. Innov.* 2025, 8, 49. https://doi.org/10.3390/asi8020049. (Q2, 82%).

Articles in publications recommended by the CQAFSHE MSHE RK:

– Isatayev M.S., Ershina A.K., Manatbayev R.K., **Seidulla Zh.K.** Experimental Study of the Characteristics of a VAWT with Asymmetrical Blades in a Wind Tunnel // Bulletin of Almaty University of Power Engineering and Telecommunications. – No. 1 (68). – 2025. – P. 80–90.

– **Seidulla Zh.K.,** Isatayev M.S., Manatbayev R.K., Ershina A.K., Dodayev S. Aerodynamic Study of Asymmetrical Blades for Vertical-Axis Wind Turbines // Bulletin of Toraygirov University. Energy Series. – No. 1. – 2025. – P. 330–343.

Publications in the proceedings of international scientific conferences

– CFD Analysis of the Aerodynamic Behavior of a Darrieus Rotor with Asymmetrical Blades at Low Flow Velocity // International Scientific Conference of Students and Young Scientists «Farabi Alemi2 – Almaty, Kazakhstan, – 2025. – P. 255.

Certificate of Authorship

– **Seidulla Zh.K.,** Isatayev M.S., Manatbayev R.K. Darrieus Wind Turbine with Asymmetrical Blades. Ministry of Justice of the Republic of Kazakhstan, "National Institute of Intellectual Property", 2025, Certificate of Authorship No. 53576.

Author’s Contribution

The author’s personal contribution includes the formulation of the research objectives and tasks, the development of the rotor geometry and the design of experimental models, the execution of experimental studies in a wind tunnel, and the implementation of numerical simulations using ANSYS Fluent. The author also performed data processing and analysis, formulated conclusions, and synthesized the research findings. The author was directly involved in all stages of the study, including the preparation of publications and the presentation of results at scientific conferences.

Scope and Structure of the Dissertation

The dissertation consists of an introduction, three main chapters, a conclusion, a list of references, and appendices. The total volume of the dissertation is 91 pages of core text and includes 46 figures, 24 equations, 2 tables, and 100 references in the bibliography.