ABSTRACT

of the dissertation for the scientific degree of Doctor of Philosophy (PhD)
in specialty 6D071800 – «Electric Power Engineering»

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RESEARCH AND SELECTION OF AN AUTOMATICALLY CONTROLLED WIND POWER PLANT PARAMETERS WITH A SWINGING INFLATABLE SAIL

The dissertation work is devoted to the selection and study of the parameters of the sail wind generator, which has an aerodynamic profile, with an automatically controlled area of achievement

Relevance of the work. The ability of wind sources of renewable energy to generate electric current at any point on the land surface and on the coast of water spaces makes wind power plants a promising segment of the world energy. The currently emerging trend of transition from energy sources based on hydrocarbons to renewable energy has further strengthened the community's desire to improve and introduce new renewable sources, in particular wind farms (WPPs). However, the centuries-old experience of using wind power plants shows that the efforts of scientists, designers and power engineers are focused mainly on increasing the efficiency of converting wind energy in the structures of turbine wind power plants. It is known that turbine WPPs are divided into WPPs with horizontal and vertical orientation of the turbine axis. Moreover, in a wind farm with a horizontal axis orientation, the turbine rotor blades move under the action of the lifting forces of the wind. The operation, independent of the change in the direction of the wind, distinguishes WPPs with a vertical orientation of the turbine axis, which mainly work due to the forces of resistance to the air flow. However, as studies and many years of operating experience show for turbine wind power plants of both types, the main problems are created by the unpredictability of the wind, the speed and strength of wind gusts, which often change in short periods of time. Another problem is that the lower limit of the wind speed range at which the turbine wind power plants operate with rated power is, as a rule, rather high - more than 10 m / s with a maximum efficiency of 0.3. In this regard, in vast areas with an average wind speed of 3 m / s, turbine wind farms can not be used. To solve the problems of improving turbine wind power plants, the search for optimal wind converters is underway, the designs of turbine wind power plants are constantly being modified.

The object of the study in operation is a wind power plant with a swinging working body consisting of an inflatable toroidal sail with an aerodynamic cross-section profile.

The purpose of the work is selection of parameters by means of research by analytical, computer and experimental methods of a new automatically controlled wind farm with a swinging inflatable sail (sails) designed to generate electrical energy in a wide range of wind speeds, starting from 2.5 m / s and regardless of an unpredictable change in wind direction.

The idea of the work is to create a sailing wind farm without a rotating turbine, similar to the Tunisian startup Saphon Energy [15]. To use a new technology for converting wind energy into electrical energy, which consists in the fact that the wind energy captured by the swinging sail is converted into the energy of the translational movement of six actuators of the parallel manipulator, the power take-off system converts the energy of the six actuators into electrical energy. Create a wind farm control automation system that adjusts the system parameters so that at any wind speed and direction, the wind farm operates with a given performance.

Scientific novelty:

- the substantiation of the sail parameters of the new wind farm is given by means of computer modeling and experimental research on a wind tunnel;
- a working demonstration model of a sailing wind farm with cyclically moving working elements has been created;
- for the selection and research of a sailing wind farm, a mathematical apparatus was developed based on the equations of state;
- as a result of calculations, it was obtained that the wind farm, due to the simultaneous action of the resistance force and the lifting force on the sail, more efficiently converts wind energy;
- an algorithm was obtained using a mathematical apparatus that allows you to select the parameters of the primary energy converter, as well as an active damping device controlled by changing the spring preload;
- formed a functional diagram of the ACS WPP, consisting of an information-measuring system, actuators and control PLC;
- investigated the energy characteristics of a sailing wind farm by analyzing the power transmitted by the power take-off system (PTS) to the generating system, depending on the wind speed;
- the substantiation of the structure of the PTS and the choice of an electric machine for generating electric current is given.

Research objectives:

- justification and selection of the sail parameter;
- confirmation of the functionality of a sailing wind farm by manufacturing a working prototype of a sailing wind farm;
- creation of an analytical apparatus for research and selection of parameters of a sailing wind farm with a swinging working body;
- development of an algorithm to determine the parameters of the primary manipulator transducer and damping system;
- formation of an automatic control system for a sailing wind farm composed of 4 subsystems:
    - sail control;
    - damping control;
    - control over the generation of electrical energy;
    - control in emergency situations;
- development of an algorithm for a sailing wind farm, which makes it possible to estimate the power of the wind force transmitted from the working body, which perceives the wind load through the SOM to the generator rotor shaft;

- study of the energy characteristics of a sailing wind farm by studying the power transmitted by the SOM to the generating system, depending on the wind speed;

- substantiation of the structure of SOM and systems for generating and storing electric energy of a sailing wind farm.

Basic scientific provisions and research results submitted to the defense:

- results of computer modeling and experimental studies of geometric and aerodynamic characteristics of the inflated sail;

- tests carried out using a working model, which confirmed the functionality of a sailing wind farm with a swinging working body;

- analytical apparatus obtained on the basis of the equations of state for the study and selection of the parameters of the sailing wind farm;

- algorithm for calculating and selecting parameters of the primary energy converter, as well as the active damping device;

- ACS of sailing wind farm, consisting of subsystems: sail control; damping control; control over the generation of electrical energy; management in emergency situations;

- methods of substantiating the structure of the PTS, systems for generating and storing electric energy of a sailing wind farm with a swinging inflatable sail.

Research methods. Scientific and practical results of the thesis were obtained using the analytical apparatus of the theory of nonlinear automatic control systems and energy balance equations. To solve the problems posed in the dissertation work, the following were also used: the method of making a demonstration sample; computer modeling using Autodesk Flow Design software: experimental studies on a wind tunnel; calculations using software MatLab and Mathcad; design of ACS using TIA Portal; modeling in WINCC.

Practical significance of the results consists in:

- creation of a renewable energy facility using wind energy - a low-power sailing wind farm, which allows converting wind energy more efficiently than turbine wind power plants;

- sailing wind farm, which allows to significantly expand the area of wind power plant application due to the ability to efficiently generate electric current at a wind speed of 2.5 m/s and can be used throughout Kazakhstan, because vast territories of Kazakhstan have an average annual wind speed of about 3 m/s.

Justification and reliability of the results and conclusions. The obtained analytical apparatus, the results of studies by computer modeling and experimental research, as well as calculations using applied software packages are reliable, since they were discussed by foreign reviewers when published in an international journal on renewable energy.

Volume and structure of the work. The work consists of the introduction, five chapters, the conclusion, 7 appendices. It contains 119 pages of the typewritten text, 49 figures, 5 tables, a list of sources used including 101 items.

Content of the work. The content of the work. The introduction substantiates the relevance of research and development of a sailing wind turbine with a toroidal cross-sectional profile. The purpose and objectives of the dissertation are formulated,

scientific novelty, scientific provisions and research results submitted for protection, the practical significance of research results are determined.

The first chapter sets out the state of the art and provides a review of literature sources and patents devoted to the development and research of all types of wind generators that have different methods of converting wind energy into electricity. The characteristics and design features of wind turbines are given. The existing technical solutions for the design of wind generators and methods of their energy conversion are considered. The goals and objectives of the study are formulated.

In the second chapter on the basis of a full-scale experiment on a wind tunnel and using the Autodesk Flow Design application, it allowed to justify the choice of a toroidal sail shape. As a result of an experimental study of sails of three geometric dimensions carried out on a wind tunnel at various angles of attack, experimental data were obtained, as a result of which processing graphs of changes in aerodynamic forces were built.

In the third chapter a mathematical apparatus based on the equations of state has been developed for the selection and study of a sailing wind farm. It is shown that the algorithm, built with the use of a mathematical apparatus, makes it possible to select the parameters of a parallel manipulator, as well as an active damping device, controlled by changing the preload of the springs.

In the fourth chapter, the structure of the control system of the sailing wind farm is formed. ACS wind farm is composed of 4 subsystems: sail control; damping control; control over the generation of electrical energy; control in emergency situations. The control system of one of the executive devices - the electromechanical blow-off valve used to control the windage is investigated.

In the fifth chapter an algorithm is obtained that makes it possible to estimate the power of wind forces in a sailing wind farm, transmitted from the working body, which perceives the wind load through the PTS to the generator rotor shaft. On the basis of calculations, the energy characteristics of a sailing wind farm were investigated by studying the power transmitted by the PTS to the generating system, depending on the wind speed.

In conclusion there are presented the research results.

Scope of use. The sailing wind farm will be used in remote pastures and Fazenda, where it is economically and technically impractical to lay traditional sources of electricity.

The personal contribution of the applicant is: to conduct a full-scale experiment on a wind tunnel; to conduct mathematical modeling on an application program; to design a demonstration model of a sailing wind farm; to calculate and select the primary energy Converter, power take-off systems, automatic control systems and power generation systems.

Testing the results of the dissertation and publications. The main provisions of the dissertation have been reported, discussed and approved:

The main provisions of the dissertation have been reported, discussed and approved:

- at scientific and technical seminars of KSTU;
- at 4 international conferences including 2 foreign:

1. Sholanov K.S., Kabanbayev A.B. Investigation of parameters of a wind power plant with a toroidal sail // VII scientific and technical conference with international participation «Science of the present and future» for students, graduate students and young scientists - St. Petersburg: Publishing House SPbSETU «LETI». 2019. - V .5 - P. 38-41;

2. Sholanov K.S., Kabanbayev A.B. Mathematical modeling of the aerodynamic characteristics of a toroidal sail // IX international scientific technical Internet Conf. of young scientists «Automation, mechatronics, information technologies». - Omsk: OmSTU, 2019. - P. 110-113;

3. Zhasakbaev A.D., Kabanbayev A.B. Wind power and prospects for the development of sailing wind generators // Scient. proceedings of the International scientific - practical conference «Integration of science, education and production - the basis for the implementation of the Nation's Plan» (Saginov's readings No.10). - Karaganda: KSTU, 2018. - Part 1. - P. 171-172;

4. Sholanov K.S., Imankarim R.K., Kabanbayev A.B. Justification of a portable sailing wind power plant parameters // Proceedings of the International scientific-practical conference «Integration of science, education and production - the basis for the implementation of the Nation's Plan» (Saginov's readings No.10). - Karaganda: KSTU, 2019. - Part 5. - P. 141-144;

- 1 article included in the information databases of Web of Science and Scopus, with the percentile of 64:

1. Sholanov K.S., Abzhaparov K.A., Kabanbayev A.B. Study and selection of parameters of an automatically controlled wind power station with swaying sails // International Journal of Renewable Energy Research (IJRER). – Turkey: GU, 2020. – V. 10, No. 2 – p. 768-779

- 3 articles in journals defined by the list of the Committee for Control in the Field of Education and Science of the Republic of Kazakhstan:

1. Sholanov K.S., Myrzabayev B., Sundet G.E., Kabanbayev A.B. Research of the state of sailing wind turbines in Kazakhstan // University Proceedings. 2019. - Karaganda: KSTU, 2019. - No. 2. - P. 115-121;

2. Sholanov K.S., Kabanbayev A.B. Investigation of aerodynamic characteristics of a sail-type wind power plant // University Proceedings. 2019. - Karaganda: KSTU, 2019. - No. 3. - P. 131-137;

3. Sholanov K.S., Abzhaparov K.A., Kabanbayev A.B. Selection and calculation of parameters of a wind power plant with an automatically controlled steam working body // Bulletin of KazNTU. - Almaty: KazNRTU, 2018. – No. 4 - P. 19-21;

- 1 patent of the Republic of Kazakhstan:

1. RK patent No. 5431. Wind power station with a sails system (useful model) // Abildayev A.A., Kabanbayev A.B. No. 2020/0379.1; applied 04/17/2020; publ. 09/10/2020. Bull. No. 10.

- 1 certificate of intellectual property:

1. Zhasakbaev A.D., Kabanbaev A.B. Information and measuring program for a sail-type wind power plant (computer program) // Certificate of state registration of rights to the copyright object. Record in the register No. 2310 of 03/15/2019. Ministry of Justice of the Republic of Kazakhstan.

The results of the work have been introduced into the educational process of the M.Kh.Dulati Taraz Regional University at the Department of «Automation and Telecommunications ».