

ABSTRACT

of the dissertation submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) under the Educational Program 8D07101 – Electrical Power Engineering (specialty 6D071800 – Electrical Power Engineering)

TALGAT NURLANOVICH AGIMOV

on the topic:

“Development and Investigation of a Valve Generator with a Wide Rotational Speed Range and Stable Output Voltage for Small Wind Power Plants”

Relevance of the dissertation research.

Kazakhstan has numerous regions with an average annual wind speed of 8–10 m/s, representing significant wind energy resources. A distinctive feature of the wind regime in these regions is the continuous variation in wind direction and speed, with wind speed ranging from 2–3 m/s to storm-level values of 30–40 m/s within tens of seconds. Under such wind conditions, Vertical-Axis Wind Turbines (VAWTs) are particularly effective because of their high starting torque, low noise levels, and ability to start operating at minimum wind speeds of 2–3 m/s without requiring additional start-up intervention.

Kazakhstani researchers have proposed a number of wind turbine designs, particularly low-power vertical-axis wind turbines. The installations developed by N.S. Buktukov, A.V. Bolotov, Sh.A. Yershin, and other researchers are capable of operating regardless of wind direction and within a wind speed range from 3 m/s to 60–80 m/s for 300–330 days per year.

A distinctive feature of VAWTs is their ability to operate at relatively low rotational speeds and their practical advantages in operation. Their design incorporates fewer mechanisms and components, thereby improving the operational reliability of the wind turbine.

VAWTs commonly used in Kazakhstan are equipped with alternating-current generators rated at 2–5 kW. These generators operate within a limited wind speed range of approximately 5–12 m/s because their rated output voltage and frequency must be maintained within the manufacturer's specified limits.

An analysis of existing wind generator types has shown that developing an electric generator capable of operating over a wide range of rotational speeds presents considerable technical challenges. As the range of magnetic flux density regulation increases, the size, weight, and cost of the generator increase, while its overload capacity decreases. At the same time, its external characteristic becomes less stiff because of the increased armature reaction of the generator.

Utilizing the available mechanical power reserve of VAWTs at different wind speeds provides an opportunity to increase their Capacity Factor (CF) through the development of fundamentally new Wide-Range Valve Generators (WRVGs) capable of maintaining a stable output voltage under varying wind speed conditions.

The aim of the research is to develop a new Wide-Range Valve Generator with a stable output voltage and to investigate its operation in conjunction with a VAWT.

Research objectives. To achieve the stated aim, the following objectives were established:

- to identify, based on a review of the relevant literature and a patent search, new approaches to the efficient utilization of VAWT power for electricity generation;
- to develop new connection configurations and a calculation methodology for the armature winding of the WRVG to provide discrete stabilization of the generated voltage;
- to develop a simulation model of the WRVG in the MATLAB/Simulink environment for the theoretical investigation of various operating modes;
- to develop an experimental test bench and conduct experimental studies of the coupled operation of the VAWT and WRVG under various operating conditions;
- to compare the calculated and experimental results and develop recommendations for the operation of the WRVG.

The scientific novelty of the research is as follows:

1. An effective approach to utilizing the available mechanical power reserve of VAWTs for electricity generation through the development and application of a WRVG has been identified.
2. A combined stepwise and continuous method for stabilizing the WRVG output voltage has been developed. The method is based on switching groups of parallel branches of the armature winding combined with continuous regulation of the excitation current.
3. New theoretical and experimental results have been obtained regarding the coupled operation of the VAWT and WRVG over a wide range of rotational speeds, demonstrating the effectiveness of the proposed WRVG design and its operational performance.

Based on the work performed and the research conducted, the following principal scientific contributions and results are presented for defense:

1. The concept of efficient utilization of the mechanical power available from VAWTs for electricity generation through the application of a WRVG.
2. Connection configurations for forming new groups of parallel branches of the WRVG armature winding and a methodology for calculating their technical parameters.
3. A method for stabilizing the WRVG output voltage by stepwise switching of groups of parallel armature-winding branches combined with continuous regulation of the excitation current.
4. The results of theoretical and experimental investigations into the stabilization of the WRVG output voltage at different rotational speeds of the VAWT.
5. The results of the development of a new WRVG with improved key characteristics that enhance its technical and economic performance.

The practical significance of the research is as follows:

- the developed and investigated WRVG can be successfully used with VAWTs and other types of wind turbines to provide autonomous power supply to remote off-grid facilities;
- VAWTs equipped with WRVGs can be used to charge battery storage systems serving as power sources for autonomous consumers at remote facilities, as well as for small electric vehicles, drones, and unmanned aerial vehicles operating in hard-to-reach areas;
- the research findings can be applied by small enterprises to manufacture WRVGs based on new, used, or decommissioned synchronous generators from various types of vehicles;
- the materials of the dissertation can be used in the educational process for courses addressing variable-speed electric generators, including those used in wind power systems, hydroelectric generating units, and similar applications.

Reliability and validity of the research results. The reliability and validity of the results obtained in the dissertation were ensured by:

- the use of modern high-precision measuring instruments in the experiments to measure voltage, current, and the temperature rise of the WRVG armature-winding branches, including a UT181A digital multimeter with True RMS functionality, UT33B+ digital multimeters, a UT371 UNI-T digital tachometer, and a UTD1025 UNI-T digital oscilloscope multimeter;
- comparative analysis of the theoretical and experimental results and documentation of the parameters of the WRVG external and regulation characteristics;

- conducting the research under grant-funded project AP19679469 of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan for 2023–2025, “Development of a Valve Generator with a Wide Rotational Speed Range and Stable Output Voltage for Small Wind Power Plants.”

Presentation and dissemination of the research results. The principal results of the research were presented and discussed at the XIII International Scientific and Technical Conference “Energy, Infocommunication Technologies and Higher Education,” dedicated to the 50th anniversary of the Almaty University of Power Engineering and Telecommunications (Almaty, 2025); the VI International Scientific Congress “Agricultural Machinery,” Volume 1: “Agricultural Machines. Research and Testing. New Machine Designs” (Burgas, Bulgaria, 2018); the 2018 14th International Scientific-Technical Conference on Actual Problems of Electronic Instrument Engineering (APEIE) (Novosibirsk, 2018); the International Scientific and Practical Conference “Current Issues of Transport and Energy: Ways of Their Innovative Solution” (Astana, 2017); the Republican Scientific and Practical Conference of Young Scientists and Students “Priority Areas for the Development of the Agro-Industrial Complex: Global Challenges and Scientific and Technical Potential” (Almaty, 2017); and the International Scientific and Practical Conference “Innovations in Science, Education and Production of Kazakhstan” (Almaty, 2016).

Publications. The results of the dissertation research have been published in 2 articles in journals indexed in Scopus, 5 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and 5 papers in the proceedings of international scientific conferences. Two utility model patents have also been obtained.

The author's personal contribution includes:

- conducting the literature review and patent search and performing theoretical studies, including the development of a MATLAB/Simulink simulation model;
- developing the experimental test bench, conducting experiments, processing the experimental data, and publishing research articles in scientific and technical journals;
- preparing utility model patent applications and presenting the research results at scientific conferences;
- identifying the principal directions of the research with the participation of the academic supervisor and foreign scientific consultant.

Scope and structure of the dissertation. The dissertation consists of an introduction, four chapters, a conclusion, a list of references, and appendices. The dissertation comprises 133 pages, 43 figures, and 11 tables.

The Introduction outlines the problems identified within the research area and substantiates the relevance of the selected topic. A review of the relevant literature and a patent search were conducted. The Introduction presents the aim and objectives of the research, its scientific novelty, practical significance, reliability and validity of the results, the author's personal contribution, publications, and presentation and dissemination of the research results.

Chapter 1 presents analytical and computational studies of the power output of existing wind turbines at different wind speeds. The available mechanical power potential of VAWTs that can be utilized to increase their Capacity Factor (CF) and generate additional electrical energy is identified. The design features of electric generators used in various wind power plants are analyzed, together with the principles of stabilizing their generated voltage under varying wind speed conditions. The advantages and disadvantages of existing wind turbine generators are presented. The type and rated capacity of the WRVG are substantiated for typical electrical loads of remote agricultural facilities, and the fundamentals of automatic generator excitation control as a function of wind speed are presented.

Chapter 2 presents the prerequisites for the development of Wide-Range Valve Generators (WRVGs) capable of maintaining the output voltage within specified limits under varying wind speed conditions. Based on the results of a patent search, connection schemes for groups of parallel branches of the WRVG armature winding were developed to provide discrete stabilization of the output voltage. A WRVG model with a reduced number of switching contacts for the groups of parallel branches is presented, in which the diode bridges are switched between parallel and series connections. A methodology for calculating the WRVG parameters after rewinding its armature winding was developed. Simulation studies of the WRVG were carried out using the MATLAB/Simulink software package.

Chapter 3 presents the electrical schematic diagram and a description of the experimental test bench incorporating physical models of the Vertical-Axis Wind Turbine (VAWT) and the WRVG. A methodology for conducting the experimental investigations was developed. The specifications and characteristics of the measuring instruments, including a digital tachometer and a UT181A digital multimeter with True RMS functionality, are provided. The general view of the WRVG and its stator with the armature winding rewound to form groups of parallel branches are also presented.

Chapter 4 presents the results of experimental investigations conducted under various operating modes of the newly developed WRVG. The results of the

approximation of experimental data for the special no-load characteristic of the WRVG using MATLAB are presented. The WRVG efficiency values at different angular velocities are indicated on its regulation characteristic. A comparative analysis of the experimental and calculated performance characteristics of the WRVG was carried out.

The Conclusion provides detailed research results and findings demonstrating the significance of the study for the development of WRVGs for wind energy systems. Particular emphasis is placed on the ability of the WRVG to maintain the generated voltage at a specified level over a wide range of wind speeds.

The Appendices contain copies of utility model patents of the Republic of Kazakhstan, a certificate confirming the implementation of the dissertation research results in the educational process and in production by LLP “Research and Production Company ‘Talgat Renewable Energy’”, a list of scientific publications related to the dissertation topic, and photographs of the experimental laboratory.

The present research is aimed at addressing an important scientific and engineering problem associated with increasing the Capacity Factor (CF) of small wind power plants. The practical implementation of the developed solutions will contribute to the advancement of Kazakhstan's wind energy technologies, increase the localization of electrical equipment manufacturing, and facilitate further improvement of autonomous power supply systems in the Republic of Kazakhstan.