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The Ukrainian Scientific and Practical Conference "Scientific Research Methodology – 2024"

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Address (Organizing Committee)

Ukraine, 18006, Cherkasy,
Shevchenko Blvd., 460,
Cherkasy State Technological University (ChSTU),
IMCT Department
SRM-2024 Organizing Committee

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CONTENTS

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Valerii Starikov, *post-graduate student at the Department of Instrumentation, Mechatronics and Computerized Technologies, Cherkasy State Technological University, e-mail: v.o.starikov.fetam23@chdtu.edu.ua*
Vyacheslav Tuz, *Cand.Tech.Sc., Associate Professor, Associate Professor at the Department of Instrumentation, Mechatronics and Computerized Technologies, Cherkasy State Technological University, e-mail: v.tuz@chdtu.edu.ua*
Volodymyr Tychkov, *Cand.Tech.Sc., Associate Professor, Associate Professor at the Department of Instrumentation, Mechatronics, and Computerized Technologies, Cherkasy State Technological University, e-mail: v.tychkov@chdtu.edu.ua*

IMPROVEMENT OF THE WIND TURBINE CONTROL SYSTEM

Abstract. *This study explores methods to improve the energy efficiency of autonomous wind energy converters using brushless DC machines (BDC). The work focuses on developing a control system and a mathematical model that maintain high efficiency in varying wind conditions. By addressing challenges in power generation and optimizing control strategies, the proposed methods aim to enhance reliability and sustainability for applications in remote areas.*

Key words*: wind energy converter, energy efficiency, brushless DC machine, autonomous systems, MPPT.*

Introduction. Remote and sparsely populated areas face significant energy supply challenges due to the high costs associated with integrating these locations into centralized power grids. Diesel generators are a common solution but come with substantial disadvantages, such as high fuel transport costs, frequent maintenance needs, and increased environmental impact. As a result, renewable energy sources like wind energy are an attractive alternative. Autonomous wind energy converters, particularly those using BDC machines, are suitable for such conditions, as they combine the efficiency of renewable energy with the simplicity and reliability of brushless systems. However, harnessing wind energy efficiently in areas with low average wind speeds requires advanced control strategies to maximize energy capture and conversion. This research addresses the pressing need for autonomous systems that can operate reliably and efficiently, even in challenging environments.

The primary goal of this study is to develop control strategies that enhance the efficiency of wind energy converters based on brushless DC machines. Specific objectives include analyzing sources of energy loss in the "wind turbine-BDC machine-static energy converter" system, identifying methods to maximize wind energy utilization, and developing control laws to optimize energy efficiency. The research also seeks to implement an automatic power regulation system that adjusts the converter's output according to fluctuating wind speeds, thereby ensuring consistent energy supply. In addition, this study aims to create a detailed mathematical model of the BDC-based wind converter system in MATLAB/Simulink. This model includes real-world variables such as wind speed variation, converter losses, and mechanical constraints to accurately simulate and evaluate the performance of the proposed control methods under various operating conditions.

Methods and materials. The research methodology centers on the development of a mathematical model for a horizontal-axis wind turbine coupled with a BDC machine. This model simulates the aerodynamic properties of the turbine and the electrical characteristics of the BDC machine, incorporating factors such as magnetic and electrical losses that affect efficiency. To maximize energy capture, a maximum power point tracking (MPPT) algorithm is employed, which dynamically adjusts the system to operate at optimal points across a range of wind speeds.

The control system developed in this study consists of two main components: speed regulation and power regulation. Speed regulation is achieved by adjusting the turbine's rotational speed to maintain the optimal tip speed ratio, which maximizes energy extraction from the wind.

Power regulation involves modulating the output of the BDC machine to ensure stable power delivery, compensating for fluctuations in wind speed. This dual-loop control structure—speed control as the outer loop and power control as the inner loop—ensures that the system responds swiftly to changes in wind conditions, thereby reducing energy losses. Simulations are conducted in MATLAB/Simulink, which provides an integrated environment for developing and testing control algorithms. This setup allows for comprehensive testing of the system's performance under simulated real-world conditions, including variable wind speeds and diverse environmental factors that can affect energy conversion efficiency.

The simulation results indicate that the proposed control strategies significantly improve the energy efficiency of the autonomous wind energy converter. The MPPT algorithm demonstrates high effectiveness in tracking the maximum power point, allowing the system to capture a greater proportion of available wind energy compared to traditional methods. Through optimized speed and power regulation, the system maintains high energy efficiency across a broad spectrum of wind speeds, even under rapidly changing wind conditions.

The BDC-based system achieves a 15% increase in energy capture in low-wind conditions compared to standard configurations. The dual-loop control system minimizes losses by maintaining precise control over the BDC machine's output, allowing the turbine to operate near its optimal performance range consistently. This performance improvement is attributed to the system's ability to adjust quickly to fluctuations in wind speed, thereby enhancing the coefficient of power utilization (CP) for the wind turbine. Additionally, the system achieves stable energy output with minimal fluctuations, making it a reliable source of energy for off-grid applications. The control model developed in MATLAB/Simulink provides a useful tool for analyzing various operational scenarios and further refining the control algorithms to optimize performance.

Conclusions. The findings of this study underscore the potential of advanced control strategies to enhance the efficiency and reliability of autonomous wind energy converters based on brushless DC machines. The dual-loop control structure, combined with an optimized MPPT algorithm, effectively addresses the challenges posed by variable wind conditions, enabling the system to achieve higher energy efficiency and operational stability. The mathematical model and simulation framework developed in this research offer a valuable foundation for further studies and practical implementation in small-scale, autonomous wind energy systems.

The successful application of these methods could lead to more reliable and sustainable energy solutions for remote regions, where conventional grid connections are often impractical. By increasing energy capture and minimizing losses, this study contributes to the advancement of renewable energy technologies, specifically for off-grid and isolated applications. Future research will focus on field testing of the proposed control system to assess its real-world performance. Additionally, further refinements to the control algorithms will be explored, including adaptive adjustments to respond to diverse environmental conditions and incorporating additional variables such as wind turbulence and temperature variations.

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