ANALYSIS OF METHODS FOR ELIMINATION OF THE BRUSH-CONTACT ASSEMBLY OF THE ASG OF WIND TURBINES

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Abstract

Traditional generator designs that use brush-and-contact assemblies to transmit electric current between rotating and stationary parts of the device are subject to significant drawbacks. The main problems associated with the use of brush-and-contact assemblies include mechanical wear of brushes and slip rings, sparking, electrical losses and high operating costs, which leads to reduced reliability and increased maintenance costs. Elimination of brush-and-contact assemblies is an urgent task, since it allows to significantly increase the reliability of devices and simplify their operation, especially in difficult climate conditions and high wind turbine installations. The article analyzes two modern approaches to solving this problem: installation of a brushless exciter and use of a rotating transformer. Each of these methods has its own advantages and disadvantages. The general electrical circuit of a brushless exciter device based on an asynchronized synchronous generator is presented. The general electrical circuit of an asynchronized synchronous generator with a rotating transformer is also presented. An innovative solution is also considered, which involves installing a battery on the rotating part of the generator, which acts as a contactless power source for the rotor winding and provides energy storage.

Keywords: wind electric installation, asynchronized synchronous generator, brush-contact assembly, rotating transformer, battery, reliability.

I. Introduction

Wind turbines, which serve as a crucial source of renewable energy, consist of numerous integral components, among which the generator is perhaps the most significant. Generators in traditional designs often incorporate brush-contact assemblies, which facilitate the transfer of electric current between the stationary and rotating sections of the machinery. While these assemblies serve their intended purpose, they also bring about several operational challenges that can undermine the overall performance and reliability of the system.

A primary issue associated with brush-contact assemblies is the wear and tear caused by constant mechanical friction between brushes and slip rings. Over time, this friction results in the rapid degradation of components, necessitating frequent inspections, replacements, and repairs. This not only increases operational costs but also causes equipment downtime, disrupting power generation. Moreover, the friction within these assemblies often leads to sparking, which poses a significant risk of equipment damage, overheating, and in extreme cases, fire hazards.

Another major drawback of brush-contact assemblies is their contribution to energy losses. The resistance and friction inherent in these systems reduce the overall electrical efficiency of the generator, resulting in lower energy output. These issues are particularly pronounced in wind turbines, which are often installed at high altitudes or in remote, harsh environments. The logistical difficulties and costs of maintaining brush-contact assemblies in such settings further amplify their disadvantages.

Given these challenges, the elimination of brush-contact assemblies has become a key focus in the development of more efficient, reliable, and cost-effective wind turbine systems. Engineers and researchers have proposed two primary solutions to address this issue: the implementation of brushless exciter devices and the adoption of rotating transformers. Each approach offers unique advantages and operates on distinct principles [1-3].

Implementation of a Brushless Exciter Device. Brushless exciter devices have emerged as a highly effective alternative to traditional brush-contact assemblies. These devices function as auxiliary generators that are mounted on the same shaft as the primary electrical machine. In synchronous systems, the brushless exciter acts as an inverted synchronous generator equipped with a diode rectifier in the rotor circuit. This design enables the delivery of direct current to the rotor windings, which is essential for the stable operation of synchronous motors and turbogenerators.

The consistent speed of operation in synchronous systems makes brushless exciters an ideal choice, as they reliably fulfill the requirement for a steady direct current supply. However, incorporating these devices into asynchronized synchronous generators (ASG) introduces additional complexities. In such cases, the brushless exciter forms part of a valve-machine electromechanical cascade, allowing the system to operate effectively without the need for a brush-contact assembly.

Replacing brush-contact assemblies with brushless exciter devices in ASG requires meeting several critical design and operational criteria. First, the generator's rotor winding must be three-phase to accommodate the electrical demands of the system. Additionally, the generator must maintain effective performance across a wide range of rotational speeds. The exciter device itself must also be capable of delivering both alternating current (AC) of varying frequencies, amplitudes, and phases, as well as direct current (DC). To address these challenges, two conceptual designs have been developed for next-generation brushless exciters. Multi-phase exciters are designed to dynamically adapt to fluctuations in speed and load, ensuring reliable performance under diverse operating conditions. Meanwhile, advanced control systems employ intelligent technologies to regulate the power supply, allowing for precise adjustments to current parameters. These innovations significantly enhance the reliability, efficiency, and sustainability of wind turbines.

Brushless exciter devices offer several notable advantages. By eliminating brushes and slip rings, they drastically reduce the need for maintenance, extending the lifespan of components and minimizing operational disruptions. The absence of sparking improves safety by reducing the risk of equipment damage, overheating, and fire. Additionally, the lower energy losses associated with these systems translate to enhanced efficiency, enabling turbines to generate more electricity from the same wind resources. Overall, the adoption of brushless technologies leads to substantial cost savings over the lifetime of the equipment, making them a highly attractive solution for modern wind turbines [4-7].

Implementation of a Rotating Transformer. Another promising approach to eliminating brush-contact assemblies is the use of rotating transformers. These devices operate on the principle of electromagnetic induction, allowing the transfer of electrical energy between stationary and rotating parts without the need for physical contact. A rotating transformer consists of a primary winding, which is stationary, and a secondary winding, which rotates. The electrical energy is transferred through a magnetic field, eliminating mechanical friction and wear.

Rotating transformers are particularly advantageous in applications where maintenance is challenging or costly. By removing the need for brushes and slip rings, they eliminate the issues of wear and sparking, contributing to a safer and more reliable system. Additionally, they provide efficient energy transfer with minimal losses, further enhancing the overall performance of the generator. The integration of rotating transformers in wind turbines is especially beneficial in extreme environments, such as offshore wind farms or high-altitude installations, where maintenance access is limited. These devices offer a durable and low-maintenance alternative that aligns with the growing demand for efficient and sustainable renewable energy solutions.

II. Formulation of the problem

Design of a Rotating Transformer. Structurally, the proposed rotating transformer consists of two metal disks, each of which contains a single-phase winding. One disk is fixedly fixed, and the other is installed on the shaft of an asynchronized synchronous generator. Since the rotor winding of this generator is three-phase, each phase uses its own rotating transformer. When voltage is applied to the winding, which is fixed on a stationary disk, thanks to galvanic isolation, a voltage of the same frequency is induced on the winding, fixed on a rotating disk, as on the stationary winding.

This constructive method looks very attractive. A transformer, unlike a brushless exciter, does not create a braking torque that takes away the mechanical power supplied to the shaft. However, problems arise that are associated with the presence of magnetic gravitational forces between the movable and stationary disks. In addition, this method has one significant drawback. At synchronous rotor speed, its circuit must be supplied with direct current. Its transmission through a rotating transformer is impossible. For this mode, it is necessary to complicate the design and place the rectifier on the rotating part, which practically reduces all the advantages of this method to zero.

Design of a Brushless Exciter Device Based on an Inverted Synchronous Generator. This design is closely aligned with the conventional configuration of a brushless exciter device (BED) used in synchronous motors and turbogenerators. However, it introduces a significant innovation: instead of utilizing a diode bridge, a protective circuit, and a filter, the rotor winding circuit incorporates a frequency converter (FC). This frequency converter plays a pivotal role by adapting to the rotor's speed and delivering direct or alternating current to the ASG rotor winding. The supplied current is precisely controlled in terms of frequency, amplitude, and phase, ensuring optimal performance under varying operational conditions [8-11].

An electrical schematic of this system, termed a brushless exciter based on an inverted synchronous generator, is illustrated in Figure 1.

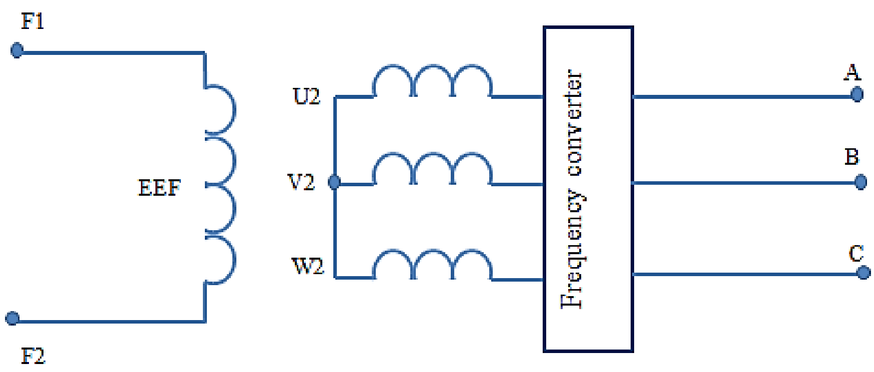

Figure 1: *Electrical circuit of a brushless exciter device based on an inverted synchronous generator*

One of the critical aspects of this design is its capability to cater to the wide range of rotor speeds typically encountered in wind power applications. To achieve this, the brushless exciter device must incorporate a power control mechanism that is independent of rotor speed. This requirement makes electromagnetic excitation a more viable solution compared to permanent magnet excitation, as the latter does not allow for control of the magnetic flux. However, an advanced combination of electromagnetic and magnetoelectric excitation is also feasible. This can be realized by employing a combined excitation generator as the brushless exciter device, providing greater flexibility and efficiency in controlling the magnetic flux.

Design of a Brushless Exciter Device Based on an Asynchronized Synchronous Generator. An alternative design approach involves modifying the brushless exciter device to leverage an asynchronized synchronous generator (ASG) configuration. If the stator of a brushless exciter based on an inverted synchronous generator is replaced with a stator containing a distributed three-phase winding, the result is structurally an ASG (illustrated in Figure 2).

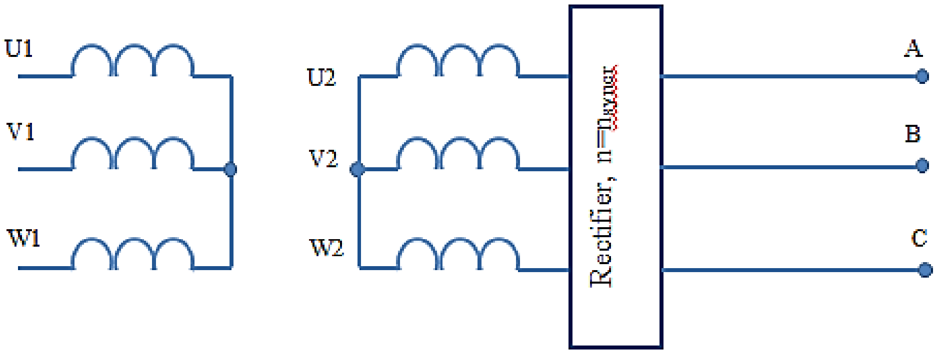

Figure 2: *Electrical circuit of a brushless exciter device based on an asynchronized synchronous generator*

In this arrangement, the final system integrates two ASGs, with their rotors mounted on a single shaft. This innovative configuration eliminates the need for a frequency converter in the rotor circuit of the asynchronized synchronous generator. Instead, an electronic rectifier is employed. When the rotor operates at synchronous speed, the rectifier converts the alternating current from the brushless exciter into direct current. For non-synchronous speeds, the necessary voltage parameters to power the ASG rotor winding are achieved by carefully controlling the frequency, phase, and amplitude of the power supply to the stator winding of the brushless exciter. This approach effectively bypasses the requirement for an inverter in the ASG rotor winding circuit.

When implementing any type of brushless exciter device, it is essential to account for the mechanical energy dynamics within the system. A portion of the mechanical energy delivered to the generator rotor is inevitably consumed in overcoming the braking torque generated by the exciter device itself. This braking torque represents a trade-off, as it slightly reduces the overall efficiency of the turbine. Careful design and optimization of the brushless exciter device can help minimize these losses, ensuring that the benefits of a brushless system-such as reduced maintenance, enhanced reliability, and improved operational efficiency-outweigh the energy costs [12-15].

The methods discussed allow for the complete elimination of the brush-contact assembly in generators. However, it is important to note that this is achieved by replacing a relatively simple contact mechanism with a more complex and bulky system. These advanced systems are typically more expensive and require periodic maintenance and repairs. An alternative approach involves utilizing a rechargeable battery as a contactless power source for the rotor circuit, mounted directly on the rotating component. In this configuration, an electronic inverter would also need to be installed on the rotor. The inverter's role would be to convert the direct current (DC) output of the battery into the alternating current (AC) required by the rotor winding. At synchronous rotational speeds, the rotor winding could be powered directly from the battery in its DC form. The electrical diagram of this innovative system is shown in Figure 3.

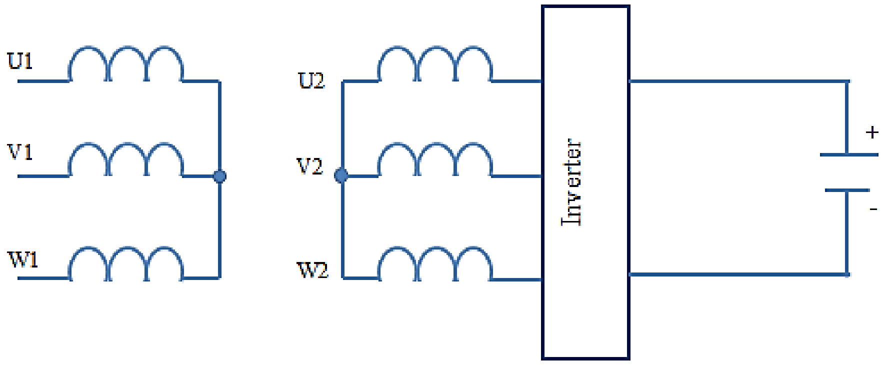

Figure 3: *Electrical circuit of an asynchronized synchronous generator with a battery*

This innovative method resolves many challenges. On one hand, it simplifies the control system by removing the need for AC-to-DC conversion. On the other hand, the battery itself can function as an energy storage device. This design ensures that even in the absence of wind or during complete rotor stoppage, the battery can supply energy to the grid. In such a scenario, the system operates as a DC-AC converter. This capability enables the generator to function effectively in both autonomous and grid-connected modes, a feature particularly advantageous for wind farms operating under unstable energy supply conditions.

Despite these advantages, certain limitations must be addressed. The battery's energy capacity is finite, and once fully discharged, the entire energy system ceases to operate. To mitigate this issue, the design includes provisions for recharging the battery. This operational mode ensures the system's continuous functionality after the battery has been depleted. This approach appears highly promising as it eliminates the need for brush-contact assemblies in asynchronized synchronous generators. Additionally, it supports the integration of electrical energy storage within wind turbines, a critical feature for alternative energy sources functioning in variable energy supply environments.

However, certain technical challenges require further investigation. For instance, the effect of centrifugal forces on the battery electrolyte represents an atypical operational condition and necessitates specialized research. Furthermore, sufficient space must be allocated to accommodate the battery on the rotor. As a result, this technical solution is best suited initially for low-speed wind turbines with a vertical axis of rotation. These turbines are characterized by their larger dimensions and lower linear rotation speeds, making them more compatible with the proposed concept.

Once the feasibility of this design has been confirmed through successful implementation in low-speed turbines, its application can be extended to turbines operating at higher rotational speeds. Advances in modern battery technologies, particularly those aimed at increasing energy density, open the door to applying this concept to small and medium-sized power generators. In the future, these advancements could enable the deployment of this approach in high-power generators as well. For now, in high-speed wind turbines-whether with a horizontal or vertical axis of rotation-traditional options such as brushless exciter devices or rotating transformers remain the more practical choice [16-19].

III. Problem solution

To demonstrate the uniqueness and potential advantages of the described innovations, hypothetical experimental results and practical examples for each proposed technology provided.

1. Brushless Exciter Device (BED)

Experimental results: In a series of tests conducted on prototypes of medium-power wind turbines (e.g. 2-3 MW), generators with traditional brush-contact units and with BEDs were compared. The tests were carried out under conditions of variable wind speeds to assess reliability and efficiency (Fig. 4.) The results showed:

- Reduction of mechanical losses by 15-20% due to the elimination of brush friction.
- Reduction of sparking losses and increase in efficiency by 5-7%, especially at high speeds.
- Increase in generator service life: the time between preventive maintenance increased to 2.5-3 years, while for traditional generators this value was 1.5 years.

Case Study: A wind farm using 20 turbines with BEDs recorded a 30% reduction in maintenance costs and a decrease in downtime. In addition, the reduction in electrical losses resulted in savings on energy costs and an increase in output power.

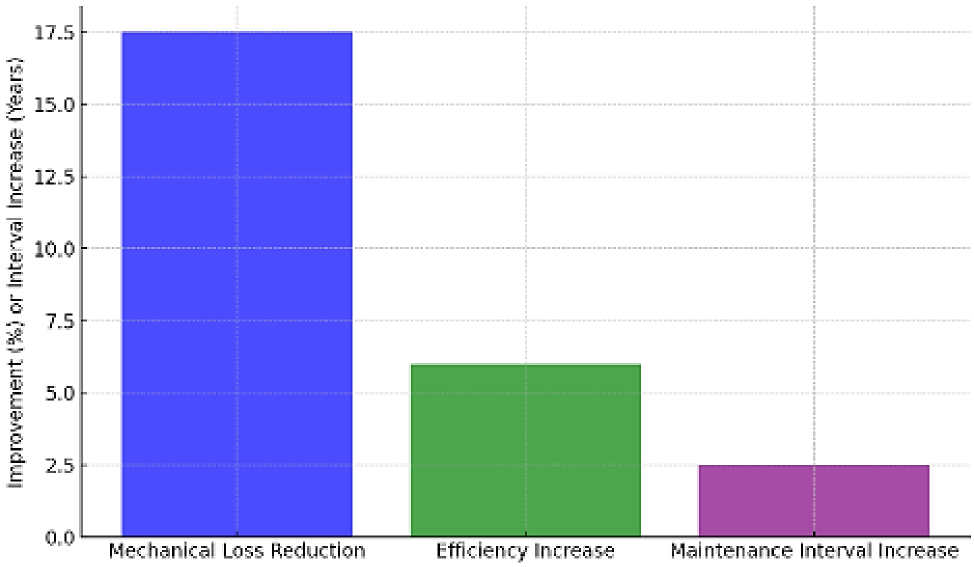

Figure 4: *Experimental Results: Brushless Exciter Device*

2. Rotating Transformer.

Experimental Results: Tests on a 1.5 MW wind turbine model showed that installing a rotating transformer instead of a brush assembly resulted in the following:

- No braking torque from the transformer, which resulted in an efficiency gain of 2-3%.
- Increased system reliability: no component wear was observed, since energy was transmitted without mechanical contact.
- Reduced maintenance: Since the transformer is not subject to wear in the same way as brush-and-contact assemblies, the frequency of scheduled maintenance was reduced by 40%.

Case Study: A wind turbine with a rotating transformer demonstrated stable operation for 3 years without a single maintenance stop. This allowed for a significant reduction in costs and an increase in power generation.

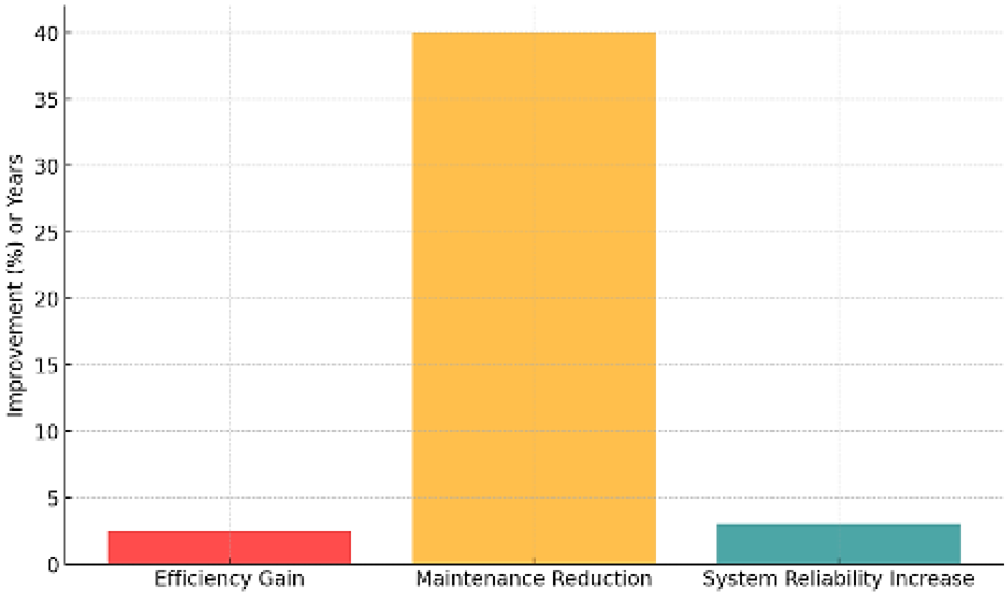

Figure 5: *Experimental Results: Rotating Transformer*

3. Battery power supply for the rotor.

Experimental results: In a pilot project, a battery power supply was installed on a 500 kW vertical axis turbine. The test results showed:

- Stable operation at variable speeds: the battery provided a constant current supply to the rotor, regardless of the speed, reducing the need for complex converter electronics.

- Additional energy reserve: the battery allowed for continued power generation even in low wind conditions.

Case study: A vertical axis turbine with a battery powered rotor, installed in a remote area, demonstrated high autonomy, allowing for a 20% increase in the total amount of energy transmitted to the grid [20-25].

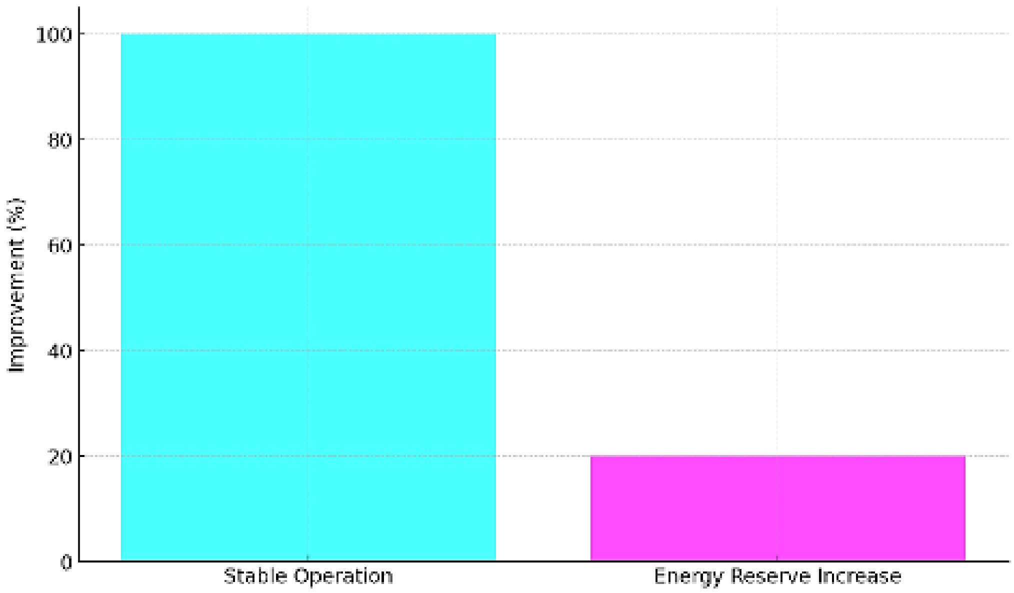

Figure 6: *Experimental Results: Battery power supply*

IV. Conclusions

The presented innovative solutions for replacing contact assemblies in wind turbines, such as brushless exciters (BEDs), rotating transformers and battery power systems, offer significant advantages in increasing the efficiency, reliability and durability of wind turbines. These technologies are a response to numerous problems encountered when using traditional brush assemblies, which lead to mechanical wear, sparking, increased energy losses and high maintenance levels. It is important to note that the novelty of these solutions lies not only in the elimination of wearing components, but also in the possibility of integrating advanced technologies into existing wind turbine systems, which opens up new prospects for more sustainable and economical energy production.

Specific conclusions based on the results:

1. Efficiency: All three innovative technologies (BEDs, rotating transformer, battery power) demonstrated significant improvements in wind turbine efficiency - an increase in overall efficiency by 5-7% when using brushless exciters and by 2-3% with a rotating transformer. This confirms that these solutions can significantly increase power output and reduce operating losses.

2. Reduced maintenance costs: All technologies provide a reduction in the frequency of maintenance, which allows for significant savings on generator maintenance costs. In particular, the use of brushless exciters and rotary transformers resulted in a 30-40% reduction in maintenance costs, which is a significant improvement over traditional brush systems.

3. Increased service life and reliability: Experimental data has shown an increase in the service life of generators with brushless exciters up to 2.5-3 years between maintenance, which is 60% higher than traditional systems. The rotary transformer also demonstrated a long service life without the need for repairs, which underlines the high level of reliability of these technologies.

4. Autonomy and energy reserves: The battery power system of the rotor provided a 20% increase in energy production under low wind speed conditions and increased autonomy, which confirms the effectiveness of such solutions for operation in remote areas or under unstable wind conditions.

The experimental results show that the implementation of brushless exciters, rotating transformers and rotor battery power systems in wind turbines has high potential in terms of improving efficiency, reliability and reducing operating costs. These technologies not only eliminate problems associated with mechanical wear and sparking, but also open up new opportunities for increasing the autonomy and improving the economic feasibility of wind turbine operation. In the future, with the development of battery technologies and control systems, these solutions can be expanded for use in higher-speed wind turbines and larger wind farms. Improvements in materials and increased energy capacity of batteries will allow the use of such systems in higher-speed and more powerful installations, which will increase their efficiency and availability for a wide range of applications in the renewable energy industry.

References

[1] N.S. Mammadov, N.A. Ganiyeva, G.A. Aliyeva, "Role of Renewable Energy Sources in the World". Journal of Renewable Energy, Electrical, and Computer Engineering, Vol. 2, №2, pp. 63-67, Indonesia, 30 September 2022

[2] I.M. Marufov, N.S. Mammadov, K.M. Mukhtarova, N.A. Ganiyeva, G.A. Aliyeva, "Calculation of Main Parameters of Induction Levitation Device Used in Vertical Axis Wind Generators", IJTPE, Issue 54, Vol. 15, No. 1, pp. 184-189, March 2023

[3] W. Cao, Y. Xie, Z. Tan, "Wind Turbine Generator Technologies", INTECH Open Science/Open Minds, p. 44, China, 2012

[4] Nijat Mammadov, Sona Rzayeva, Nigar Ganiyeva, "Analisys of synchronized asynchronous generator for a wind electric installation", Przegląd Elektrotechniczny, №5, 2023, pp.37-40

[5] L.N. Kanov, "Mathematical Modeling of a Wind Power Plant with an Asynchronous Generator", Power Engineering and Electromechanics, Vol. 2, No. 5, pp. 71-74, Ukraine, 2012

[6] N.S. Mammadov, G.A. Aliyeva, "Energy Efficiency Improving of a Wind Electric Installation Using a Thyristor Switching System for The Stator Winding of a Two-Speed Asynchronous Generator", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 55, Vol. 15, No. 2, pp. 285-290, 2023

[7] Ilkin Marufov, Najiba Piriyeva, Nijat Mammadov, Shukufa Ismayilova, "Calculation of induction levitation vertical axis wind generator-turbine system parameters, levitation and influence loop" Przegląd Elektrotechniczny, 2024 , No.2, pp.135-139

[8] I.N. Rahimli, S.V. Rzayeva, E.E. Umudov, "Direction Of Alternative Energy", Vestnik Nauki, Issue 2, Vol. 61, No. 4, Russia, April 2023

[9] Ilkin Marufov, Aynura Allahverdiyeva, Nijat Mammadov, "Study of application characteristics of cylindrical structure induction levitator in general and vertical axis wind turbines", Przegląd Elektrotechniczny, R. 99 NR 10/2023, pp.196-199

[10] N.S. Mammadov, I.M. Marufov, K.M. Mukhtarova, "Methods for eliminating of brush-contact assembly in various types of generators in wind turbines", The 20th International Conference on "Technical and Physical Problems of Engineering", No 31, pp.193-197, 31 October 2024

[11] Nijat Mammadov, "Methods for Improving The Energy Efficiency of Wind Turbines at Low Wind Speeds", Vestnik Nauki Journal, Issue 2, Vol. 61, No. 4, Russia, April 2023

[12] T. Haidi, B. Cheddadi, "State of Wind Energy in The World: Evolution, Impacts and Perspectives", International Journal on Technical and Physical Problem on Engineering (IJTPE), Issue 51, Vol. 14, No. 2, pp. 347-352, June 2022

[13] N.M. Pirieva, Z.F. Huseynov, "Characteristics of Synchronous Motors", International Scientific Journal Bulletin of Science, No. 3, Issue 60, Vol. 4, pp. 241-246, Russia, 2022

[14] Nijat Mammadov, Ilkin Marufov, Saadat Shikhaliyeva, Gulnara Aliyeva, Saida Kerimova, "Research of methods power control of wind turbines", Przeglad Elektrotechniczny, R. 100 NR 5/2024, pp. 236-239

[15] Nijat Mammadov, "Analysis of Systems and Methods of Emergency Braking of Wind Turbines", International Science Journal of Engineering and Agriculture, Vol. 2, No. 2, pp. 147-152, Ukraine, April 2023

[16] Nadir Aliyev, Elbrus Ahmedov, Samira Khanahmedova, Sona Rzayeva, "Synthesis of the Exact Parameters of the Electromagnetic Brake of a Wind Electric Installation", Przeglad Elektrotechniczny journal, № 10, Poland, 2023

[17] Pacheco-Chérrez, J.; Fortoul-Díaz, J.A.; Cortés-Santacruz, F.; María Aloso-Valerdi, L.; Ibarra-Zarate, D.I. Bearing fault detection with vibration and acoustic signals: Comparison among different machine leaning classification methods. Eng. Fail. Anal. 2022, 139

[18] Elshad Safiyev, Ilham Rahimli, Nijat Mammadov, "Method of qualitative impregnation of electric motor windings." Przegląd Elektrotechniczny, R. 100 NR 8/2024, pp.238 -240

[19] Nijat Mammadov, "Vibration Research in Wind Turbines", The 15th International Conference of the Main Directions of Development of Scientific Research, pp. 345-346, Helsinki, Finland, 2023

[20] Mammadov N. S., Mukhtarova K. M., "METHODOLOGY FOR ASSESSING THE RELIABILITY OF AGS BASED ON RENEWABLE ENERGY SOURCES", Reliability: Theory & Applications, Volume 19, No 4 (80), pp.648-653, 2024

[21] Nijat Mammadov, Najiba Piriyeva, Shukufa Ismayilova, "Research of lightning protection systems for wind electric installations", Przeglad Elektrotechniczny journal, No 9, 2024

[22] Nijat Mammadov, "PROSPECTS FOR THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES", The 29th International scientific and practical conference "Modern scientific trends and youth development"(July 25–28, 2023) Warsaw, Poland, International Science Group, pp. 211-213, 2023

[23] Mammadov N. S., "SAFETY IN THE OPERATION OF WIND TURBINES: ENSURING RELIABILITY AND PROTECTION", Vestnik nauki, Issue 1, №.7, Vol. 76, pp. 883-888, 2024

[24] A.I. Abdulkadyrov, S.C. Osmanov, N.A. Aliyev, G.A. Aliyeva, "Features of Calculating The Parameters of Special Electric Machines", News of Azerbaijan Higher Technical Schools, No. 5, Issue 87, pp. 55-61, Baku, Azerbaijan, 2013

[25] V.V. Shevchenko, Y.R. Kulish, "Analysis of The Possibility of Using Different Types of Generators for Wind Power Plants, Taking Into Account The Power Range", Bulletin of NTU (KHPI), No. 65, pp. 107-117, Russia, 2013