

## ANALYSIS OF THE OUTPUT PARAMETERS OF A LOW-SPEED ELECTRIC GENERATOR USING ANALYTICAL AND COMPUTER MODELING

*Nasullo Sadullaev*<sup>\*1</sup>, *Shukhrat Nematov*<sup>2</sup>, *Farid Sayliev*<sup>3</sup>, *Abubakir Atoyev*<sup>4</sup>, *Firdavs Muzaffarov*<sup>5</sup> and *Jasur Hojimurodov*<sup>6</sup>  
*Bukhara engineering technological institute, Bukhara, Uzbekistan*  
*mrshuxa@mail.ru*

### ARTICLE INFO

#### Article history:

Received 19 Dec 2024  
Accepted 14 Jan 2025  
Available online 13 May 2025

#### Keywords:

*Power, wind power plant, water power plant, axial flux synchronous generator, radial flux, synchronous generator, voltage, current, frequency, rotor, stator, counter rotating synchronous generator, Permanent magnet synchronous generator.*

### ABSTRACT

This article proposes a generator that operates efficiently in low-pressure water streams and low-speed wind flows. The article considers it relevant not to use gearboxes and generators with excitation windings in micro hydroelectric power plants and wind power plants. The proposed generator consists of multipolar permanent magnets with a low rotation speed. To further reduce the rotation speed of the generator, counter-rotation of the rotor and stator is ensured. In order to evaluate the technical and economic indicators of the proposed generator, a computer model was created and analyzed in the Ansys Electronics Desktop program. The research work is relevant for the design and production of generators that are used to generate electricity from low-speed flows.

© 2024 International Journal of Advanced Research in Science and Technology (IJARST).

All rights reserved.

### Introduction:

Energy efficiency is a set of processes aimed at efficient, that is, rational use of energy resources. Achieving the desired result at the cost of consuming less energy for the energy supply of consumers or production processes is also an indicator of efficiency. At the current level of technical and technological development, achieving economically based efficiency in the use of fuel and energy resources, as well as compliance with the requirements of environmental protection, are among them [1].

All electrical devices have optimal operating conditions. Any change in these conditions can lead to a decrease in the efficiency of the equipment. Electric generators are no exception. The parameters of the generator are not a fixed value - it depends on several factors. These omms are affected by manufacturing variations, environmental and structural parameters and it is essential to ensure these parameters to ensure optimum performance [2]. Therefore, the analysis of analytical and computer models in the design of electric generators is of urgent importance.

### Literature review:

The use of axial-flux generators in wind turbines without the use of a gearbox resulted in an increase in wind energy utilization coefficient and energy density, as well as a decrease in generator weight [3]. When comparing axial (SGPM-5-150A) and radial (SGPM-5-150T) flux generators, the axial flux generator has a 2.1% higher efficiency, 2.2 times less commutation, and many other advantages [4]. The voltage of the two-rotor axial generator was recorded at 219-402 rpm, and the

frequency was 333 rpm at 50 Hz [5]. The energy density of the two-rotor and three-rotor axial flux generators, and the energy density of the two-rotor and single-stator axial flux generators was recorded as 283.6 W/kg and 195.3 W/kg, respectively. However, the large number of magnets required for the manufacture of this type of generator increases the cost of the generator [6]. Radial current generators are currently used in many large-capacity hydroelectric power plants. The generator used in these hydroelectric power plants is multi-polar, has a low rotation speed. The difference in voltage between each phase of a radial flux generator with a power of 10 kW and a rotation speed of 214.3 rpm was observed to be 0.3%-1.3%, and the difference between practical and theoretical experiments was 5% [7]. Other research studies have shown that the use of radial flux generators for wind flows with low potential energy efficiency gives good results. When the flow speed is 3 m/s-5 m/s, the generator speed can reach 100 rpm-500 rpm [8]

### Materials and methods:

Based on the values obtained using a mathematical model used in the design of a multi-polar, low-speed electric generator, a computer model was constructed in the ansys electronics desktop program. Based on the computer model, the output voltages, torques, and losses of the electric generator were analyzed. Twenty-two different electric generator designs were analyzed on the computer model. Radial-axis synchronous generator consisting of permanent magnets has 48 magnetic poles and 36 coils, the conductor type and cross-sectional surface, the number of windings were selected as in the axial-axis electric generator. 12 computer models were created by

changing the type of stator and rotor materials and structural structure. In order to reduce the time spent on the design, the models were created in the form of two-dimensional models.

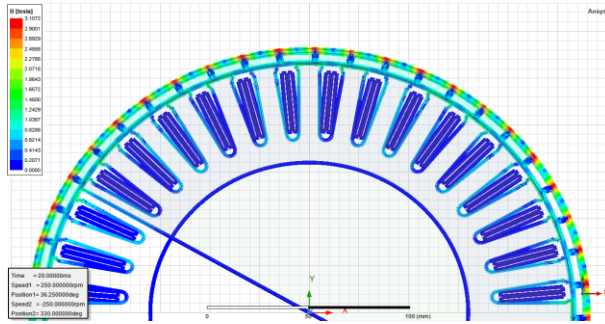


Fig. 1. Magnetic field distribution of generator with stator and rotor cast steel

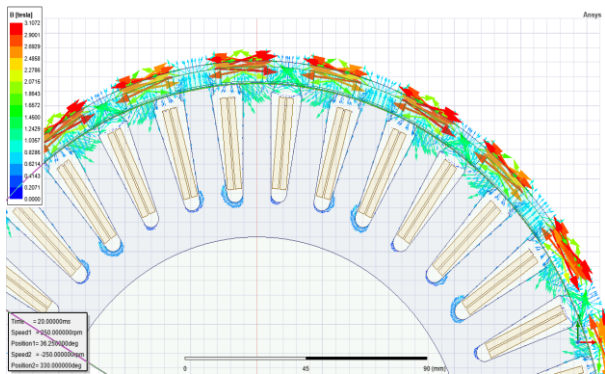


Fig. 1b. The direction of the magnetic force vectors of a cast steel generator with stator and rotor

Taking into account that the initial results of the designed model are at the required level, we can conclude that the generator is designed correctly [9]. Fig. 1 shows a graphical representation of some values from computer models of designed radial axis electric generators

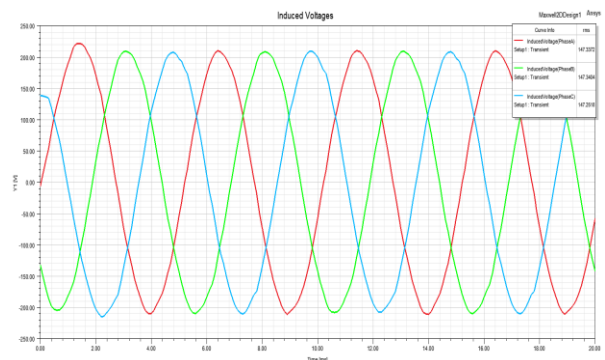


Fig. 2. EMF in the generator stator with stator and rotor cast steel

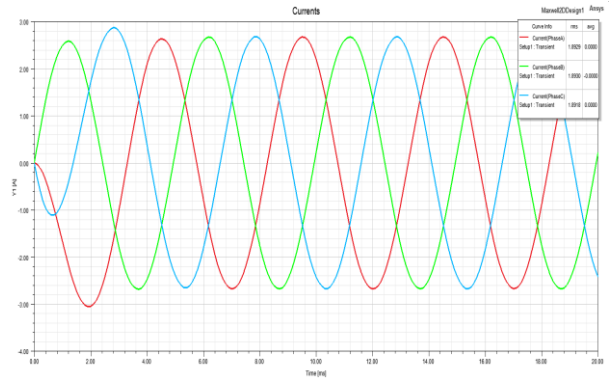


Fig. 2b. Induction current in the stator of a generator with a cast steel stator and rotor.

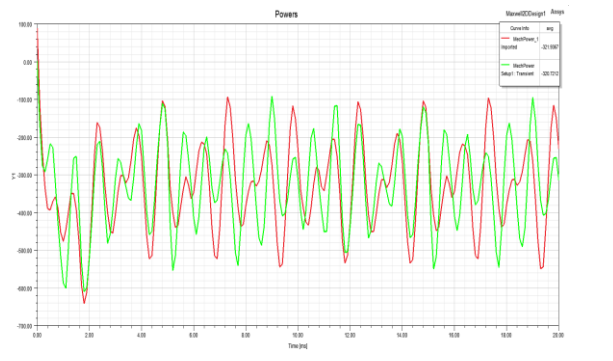


Fig. 3. The mechanical power used to rotate the generator stator and rotor

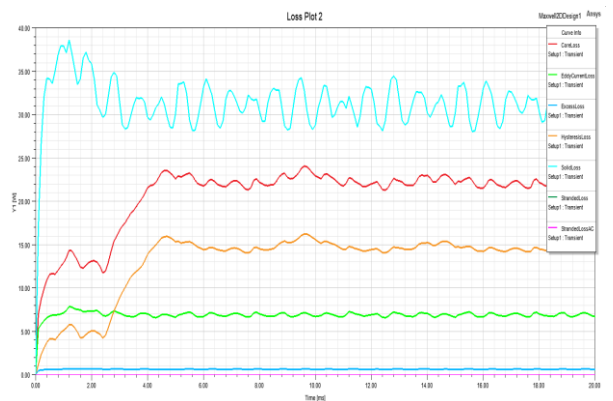
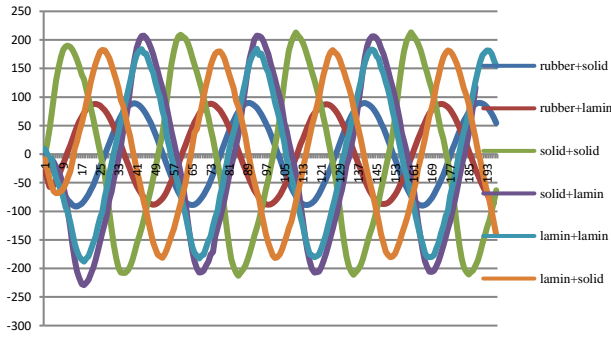


Fig. 3b. Losses in a two-rotor electric generator with solid rubber stator

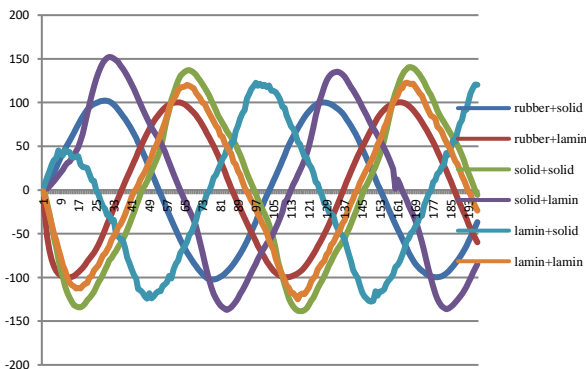
**The obtained results of experimental studies:**

Axial-flow, single-rotor electric generators conductive forces were compared in the studies carried out on the computer model in the Ansys Electronics Desktop 2022 program (Fig. 3). Values in different phases were selected so that the lines representing the indicators in the graph do not overlap with each other [10].



**Fig. 4. Single-rotor, axial flux electric generators computer model results in Ansys Electronics Desktop.**

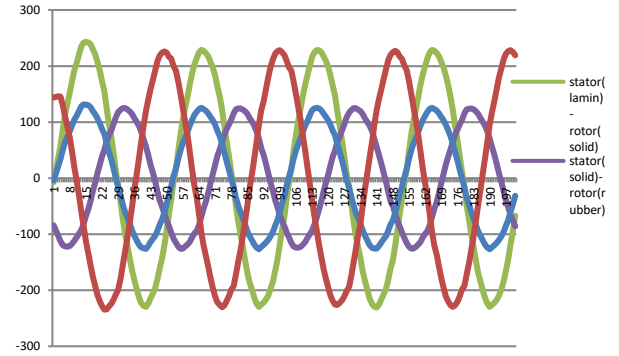
According to the results of the model, the lowest indicators were observed in generators with solid rubber rotors. Further analyzes focused on the comparison of 4 steel-based models [11]. Relatively high values were found in the model with a solid steel structure, but because of the high dissipation of cumulative currents in this model, the three models were continued to be compared. In the remaining three models, the values of electric driving force are approximately the same, but the radius of the generator with such a design increases dramatically and causes an increase in the value of the moment of inertia in the rotational movement. For this reason, further research was conducted on two-rotor, axial-flow electric generators based on the same number of magnets and conductors. Fig. 4 shows the results of the two-rotor axial flux electric generator. As can be seen from the graph, here too, the electric power value of the electric generator with solid rubber stator is lower compared to the generators with steel base. In the general case, the values are lower than the results of single-rotor axial flux generator models [12]. For example, in electric generators with a solid steel base, the EMF value is 46% lower in the two-rotor construction than in the one-rotor construction, and in the stator generators made of pressed thin steel plates, the two-rotor construction is 48% lower than in the one-rotor construction. For this reason, a comparison of radial flux electric generators was also determined.



**Fig. 5. Results of a computer model in Ansys Electronics Desktop software of a two-rotor axial-flux electric generator**

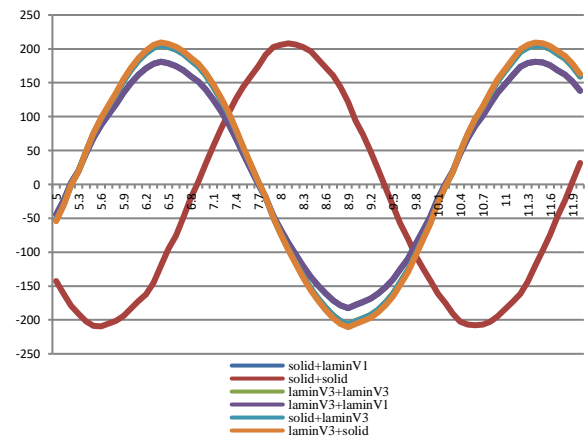
Fig. 5 compares the results obtained by the computer model of radial flux electric generators based on different materials. In the results, 82.4% lower EMF value was

recorded in hard rubber stator constructions compared to steel base constructions.



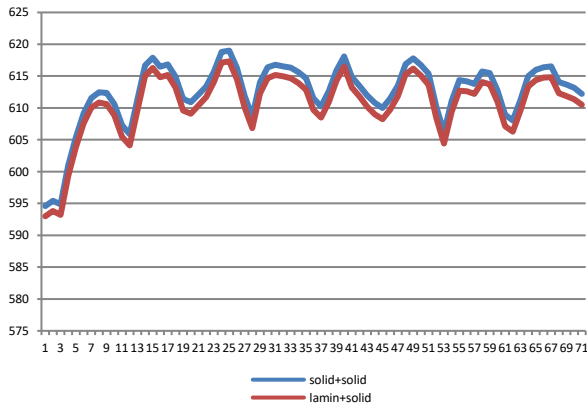
**Fig. 6. EMF in the phases of electric generator with radial flux of different designs.**

The maximum value in the design with radial flux is 7.2% more than the maximum value of EIUK in the single-rotor design with axial flux [13]. Due to the fact that the EMF value is relatively high in generators consisting of a steel-based stator among all constructions, further research was continued on these constructions. That is, the generators of the four selected constructions are additionally based on waste and steel plates pressing direction was also analyzed by modification [14]. That is, the effect of pressing the stator made of thin plates along the y-axis and x-axis on the EMF generated in the generator was evaluated (Fig. 6).



**Fig. 7. EMF in the phases of a radial flux electric generator pressed in different directions with a thin plate.**

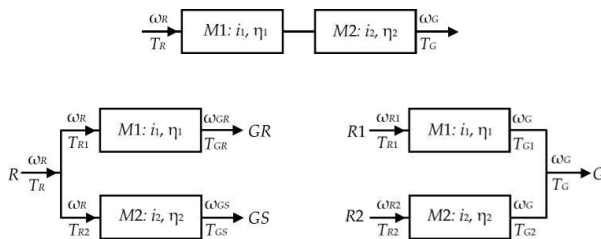
It can also be seen in Fig.7 that the best results of EMF in the phases were recorded in the structure with the stator and rotor made of solid steel and the stator with a thin plate pressed along the x-axis and with a solid steel rotor. At the next stage of the research, losses were evaluated in structures with stator and rotor made of solid steel and stator with thin plates pressed along the x-axis and with solid steel rotor. Fig. 10 shows the breakdown of active power losses in two selected electric generators.



**Fig. 10. Active power losses in structures with stator and rotor made of solid steel and stator with thin plate and rotor made of solid steel**

In the Fig., the performance of an electric generator with a stator and a rotor made of solid steel is shown in blue, and the results of a construction with a stator and a thin plate pressed along the x-axis and a solid steel rotor are shown in red. Based on the results, active power dissipation is higher in electric generator with stator and rotor made of steel.

Knowing the mechanical systems that transmit power in parallel and in series, parallel transmission systems have been proven to be more efficient than series transmission systems. The same system can be applied to two counter-rotating wind and hydro turbines, or to two counter-rotating wind and hydro turbines driving a counter-rotating electric generator [15]. To transfer power to the generator, a system consisting of two mechanisms providing a series transmission with torques M1 and M2 (Fig. 12) or two counter-rotating mechanisms from one turbine (R) in parallel transmission (It has an electric generator with GR and GS) and a standard electric generator (G) from two counter-rotating turbines (R1 and R2) (or a counter-rotating generator with rotor rotation (GR) and stator rotation (GS)) systems were selected. Here  $i_1$  and  $i_2$  are kinematic ratios, as well as  $\eta_1$  and  $\eta_2$  are characterized by the efficiency of mechanisms. A motion with an angular velocity  $\omega_x$  and a torque  $T_x$  is transmitted to each shaft x.



**Fig. 12. Series and parallel power transmission schemes of mechanisms with a degree of freedom equal to one.**

For Case 1 in Fig. 12, i.e., with one input (R) and one output (G), the angular velocity is calculated as:

$$\omega_G = \frac{\omega \cdot R}{i_1 \cdot i_2} \tag{1}$$

$$T_G = -i_1 \cdot i_2 \cdot \eta_1 \cdot \eta_2 \cdot T_R \tag{2}$$

efficiency for the same system:

$$\eta_A = \frac{-P_G}{P_R} = \frac{-T_G \cdot \omega_G}{T_R \cdot \omega_R} = \eta_1 \cdot \eta_2 \tag{3}$$

In case 2 of Fig. 12, speed change with one input (R) and two outputs (GR and GS):

$$\omega_{GR} = \frac{\omega_R}{i_1} \tag{4}$$

$$\omega_{GS} = \frac{\omega_R}{i_2} \quad \omega_G = \omega_{GR} - \omega_{GS} = \frac{i_2 - i_1}{i_2 \cdot i_1} \cdot \omega_r \tag{4}$$

$$T_{R1} = -\frac{T_{GR}}{i_1 \eta_1} \tag{5}$$

$$T_{R2} = -\frac{T_{GS}}{i_2 \eta_2} \tag{6}$$

$$T_{R1} + T_{R2} = T_R \tag{7}$$

Knowing that the torques transmitted from the turbine to the moving stator or rotor of the electric generator are equal but opposite in sign ( $T_{GS} = -T_{GR}$ ), assuming that the torque  $T_G = T_{GR}$  and the mechanical power  $T_G \omega_G$  transmitted to the electric generator are equal:

$$T_G = T_R \frac{i_1 \cdot i_2 \cdot \eta_1 \cdot \eta_2}{i_1 \cdot \eta_1 - i_2 \cdot \eta_2} \tag{8}$$

$$T_G \cdot \omega_G = \eta_1 \cdot \eta_2 \cdot T_R \cdot \omega_r \frac{i_2 - i_1}{i_1 \eta_1 - i_2 \eta_2} \tag{9}$$

It allows you to calculate the transmission efficiency for the beam B as follows:

$$\eta_B = \frac{-P_G}{P_R} = \frac{-T_G \cdot \omega_G}{T_R \cdot \omega_R} = \eta_1 \cdot \eta_2 \cdot \frac{i_2 - i_1}{i_1 \eta_1 - i_2 \eta_2} \tag{10}$$

**Conclusion:**

As a general conclusion, it has been confirmed that parallel power transmission has higher efficiency than serial transmission based on the above equations and research conducted by foreign scientists [16]. Good efficiency was evaluated as a system summing the input and output power for the case of H1 (Fig. 12). The second most efficient case is case H2 with two inputs and one output (Fig. 12). The next efficiency is for case H3 with single-turn and counter-rotating electric generator. The least efficient option was found in the case of H4 in the serial transmission of mechanical power. Thus, it can be concluded that the transmission of two parallel input systems into one output system, or the transmission of one input power as two parallel output power, is highly efficient in the efficient use of tidal and wind energy.

**References:**

1. Sadullayev, NN, Safarov, AB, Nematov, SN et al. Opportunities and Prospects for the Using Renewable Energy Sources in Bukhara Region. Appl. Left. Energy 56, 291–300 (2020). <https://doi.org/10.3103/S0003701X20040106>
2. Sadullayev, NN, Safarov, AB, Nematov, SN et al. Statistical Analysis of Wind Energy Potential in Uzbekistan's Bukhara Region Using Weibull Distribution. Appl. Left. Energy 55, 126–132 (2019). <https://doi.org/10.3103/S0003701X19020105>
3. D Ahmed and A Ahmad. An optimal design of coreless direct-drive axial flux permanent magnet generator for wind turbine. Journal of Physics: Conference Series Volume 439, 6th Vacuum and Surface Sciences Conference of Asia and Australia (VASSCAA-6) 9–13 October 2012, Islamabad, Pakistan. Doi: 10.1088/1742-6596/439/1/012039
4. 10. A N Antipov, A D Grozov and A V Ivanova.

- Design and analysis of a new axial flux permanent magnet synchronous generator for wind IOP Conference Series: Materials Science and Engineering, Volume 643, International Scientific Electric Power Conference 23–24 May 2019, Saint Petersburg, Russian Federation
5. I M W Kastawan, Rusmana. Voltage Generation of Three-Phase Double Sided Internal Stator Axial Flux Permanent Magnet (AFPM) Generator IOP Conference Series: Materials Science and Engineering, Volume 180, 1st Annual Applied Science and Engineering Conference (AASEC), in conjunction with The International Conference on Sport Science, Health, and Physical Education (ICSSHPE) 16–18 November 2016, Bandung, Indonesia
  6. M Tadjuddin, I Hasanuddin, Z Fuadi, A Mukminin, M R Arief. Power density comparison of multi-air gap axial flux permanent magnet motor for electric vehicle, IOP Conference Series: Materials Science and Engineering, Volume 931, International Conference on Experimental and Computational Mechanics in Engineering (ICECME) 2019 18-19 September 2019, Banda Aceh, Indonesia
  7. Ashraf, Muhammad Mansoor and Tahir Nadeem Malik. “Design of a three-phase multistage axial flux permanent magnet generator for wind turbine applications.” *Turkish J. Electr. Eng. Comput. Sci.* 25 (2017): 520-538.
  8. Reza Yazdanpanah, Abdolkarim Afroozeh, Mahdiyeh Eslami, Analytical design of a radial-flux PM generator for direct-drive wind turbine renewable energy application, *Energy Reports*, Volume 8, 2022, Pages 3011-3017, ISSN 2352-4847, <https://doi.org/10.1016/j.egy.2022.01.121>.
  9. Tadjiev, UA, Kiseleva, EI, Tadjiev, MU et al. Estimated technical and economic indicators of wind power installations that convert wind energy of surface layers of the atmosphere in the plains of Uzbekistan. *Appl. Left. Energy* 49, 105–109 (2013). <https://doi.org/10.3103/S0003701X1204010X>
  10. Bahrami, A., Teimourian, A., Okoye, CO, & Shiri, H. (2019). Technical and economic analysis of wind energy potential in Uzbekistan. *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2019.03.140
  11. Sadullaev, N & Safarov, A & Mamedov, R & Kodirov, D. (2020). Assessment of wind and hydropower potential of Bukhara region. IOP Conference Series: Earth and Environmental Science. 614. 012036. doi:10.1088/1755-1315/614/1/012036.
  12. Muzaffarov F. Development and experimental research of a vertical axis wind turbine // *International journal of advanced research in science, engineering and technology* Vol. 10, Issue 8, August 2023. p.
  13. Sadullaev N., Nematov Sh., Muzaffarov F., and Bafoyeva G. // *Mathematical modeling of vertical axis wind turbines*. E3S Web of Conferences 417, 03008 (2023). GEOTECH-2023. (Scopus, DOI:<https://doi.org/10.1051/e3sconf/202341703008>)
  14. Nasullo Sadullaev, Shukhrat Nematov, Farid Sayliev. Analysis of multipolar generators operating efficiently in low-speed water and wind flows using ANSYS MAXWELL program. *E3S Web Conf.* 288, 01057 (2021), doi: 10.1051/e3sconf/202128801057
  15. Nasullo Sadullaev, Shukhrat Nematov, Mukhiba Gafurova. Increase the reliability of power supply by using mechanical energy storage devices for low-power consumers. *E3S Web Conf.* 288 01060 (2021), doi: 10.1051/e3sconf/202128801060
  16. N.N. Sadullaev, SH.N.Nematov and F.O. Sayliev. Evaluation of the technical parameters of the generator for efficient electricity generation in low-speed wind and water flows. *Journal of Physics: Conference Series*, Volume 2388, IV International Conference on Applied Physics, Information Technologies and Engineering 2022 (APITECH-IV 2022), Bukhara, Uzbekistan. DOI: 10.1088/1742-6596/2388/1/012142.