ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

Analysis of Micro Hydrokinetik Power Plants Adapted For Efficient Operation in a Free-Flow Water Course

Mamedov Rasul Akif-ogli, Fazliddinova Sevinch Fazliddinovna

Docent of the Department of Electrical and energy engineering, Bukhara State Technical University, Bukhara, Uzbekistan
Student of the Department of Electrical and energy engineering, Bukhara State Technical University, Bukhara, Uzbekistan

ABSTRACT: The article presents an analysis of the hydropower potential of irrigation canals in the Bukhara region, with an emphasis on the possibility of using kinetic turbines in free-flowing low-pressure watercourses with a flow rate of 0.5 to 5 m / s. Particular attention is paid to the design of a micro hydroelectric power plant on a floating pontoon foundation, which allows compensating for changes in the water level, typical for irrigation systems. The irrigation system of the Amu-Bukhara Canal, whose gross hydropower potential, according to calculations, is 202.4 GW h, was chosen as the object of study. The presented installation is focused on sustainable energy supply to rural and remote consumers not connected to centralized power grids, which makes it an important tool for improving the quality of life and developing the socio-economic infrastructure of the region.

I.INTRODUCTION

Currently, the rapid increase in electricity consumption worldwide, associated with the growth of the planet's population, has caused the depletion of natural fuel resources, as well as global climate change associated with carbon dioxide emissions into the atmosphere due to the combustion of fuel resources for the production of electricity [1]. To solve these problems, it is necessary to increase the share of electricity production from environmentally friendly, renewable energy sources [2].

Between 2010 and 2023, the share of renewable energy sources in the global energy balance increased by 10 percent and currently amounts to about 30%, while in 2022 the share of renewable energy sources increased by 1.5 percent [3]. Figure 1 shows the share of renewable energy sources as of 2022.

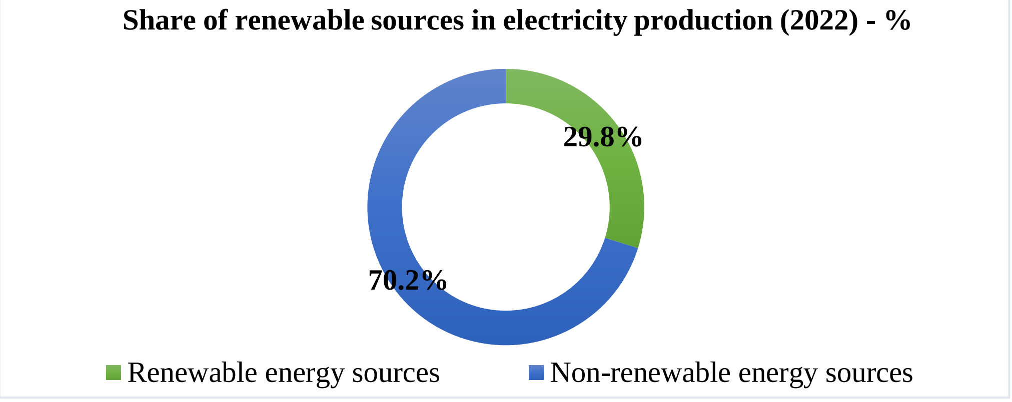

Fig. 1. Share of renewable energy sources as of 2022

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

In the global energy balance, the share of renewable energy sources is traditionally high in countries with huge hydropower potential, such as Brazil, Colombia, Canada, New Zealand, Sweden and Norway, which account for more than 2/3 of the generated electricity (Fig. 2) [4].

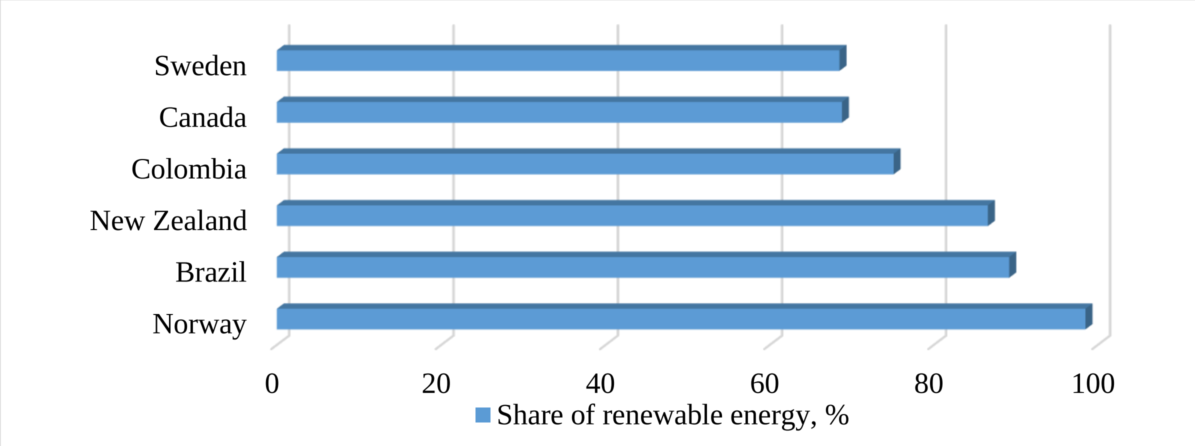

Fig. 2. Share of renewable energy sources in countries with huge hydropower potential.

In other countries, the reduction in electricity production costs and a significant increase in the share of renewable energy sources is achieved through solar and wind power plants. For example, in Europe, the share of renewable energy sources increased by 18 percent between 2010 and 2022, reaching 43%, with strong growth in the UK (+36 percent to 43%), the Netherlands (+30 percent to 40%), Germany (+27 percent to 44%) and Turkey (+15 percent to 42%). Significant growth in the share of renewable energy sources is also observed in Australia by 22 percent to 31%, by 14 percent in Chile to 55%, by 12 percent in the USA (up to 22%), China (up to 31%), Japan (up to 22%) and Thailand (up to 18%) and by 8 percent in South Africa (up to 10%). Figure 3 shows the growth trend of the share of renewable energy sources worldwide in the period 2000-2022 [4].

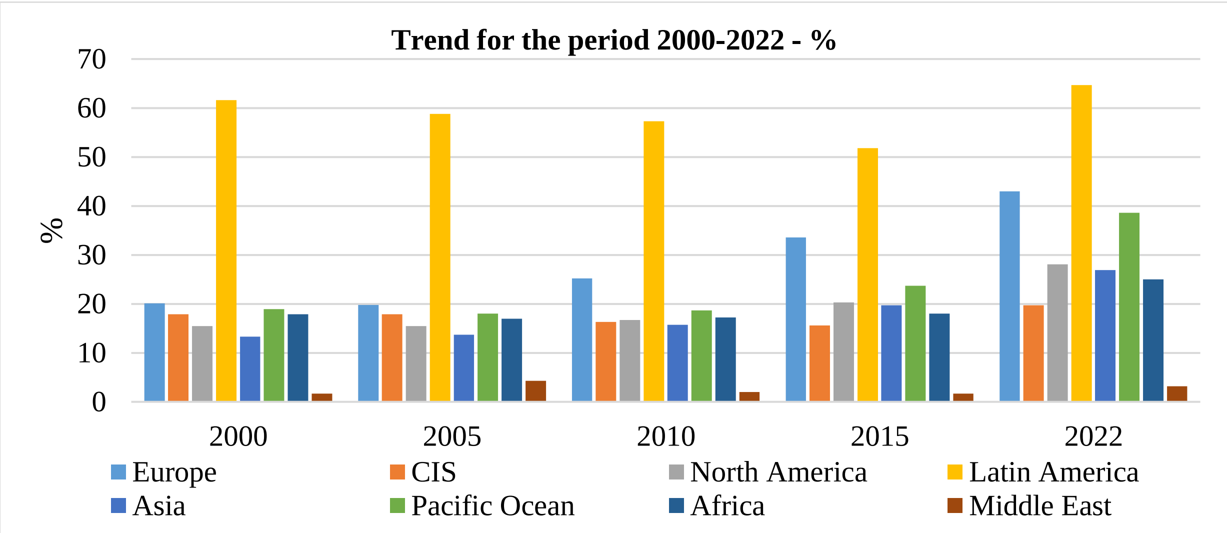

Fig. 3. The growth trend of the share of renewable energy sources in the world in the period 2000-2022

According to the world organization International Hydropower Association (IHA), as of 2022, the top five leaders in terms of installed capacity were China with an installed capacity of 415 GW, Brazil with 110 GW, the USA 102 GW, Canada 83 GW and Russia 56 GW, and our republic accounted for 2081 MW of installed capacity in the hydropower sector [5]. Among the important complexes in the hydropower sector of the Republic of Uzbekistan is the irrigation system of the Amu-Bukhara Canal, planned on the territory of the Bukhara region. The irrigation system of the

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

Amu-Bukhara Canal is one of the branches of the Amu Darya River passing through the territory of the Republic of Turkmenistan and demonstrates one of the most important complexes in the territory of Uzbekistan, intended for water supply to the Bukhara and part of the Navain regions, starting at the inlet hydroelectric complex "Dvoynik". For the effective use of micro hydroelectric power plants, it is first necessary to assess the resources of the gross hydropower potential and the properties of the energy of the water flow in the study area. The gross hydropower potential of the Amu-Bukhara Canal was first estimated in scientific studies by employees of the Bukhara Engineering and Technology Institute, amounting to 200.2 GW h. Also, during the assessment of the hydropower potential, a diagram (Fig. 4) of the location of the main and inter-farm canals of the Bukhara region was constructed using a linear diagram taken from the management of the Amu-Bukhara machine canal, as well as information obtained using satellite data based on the Google Earth Pro application [6].

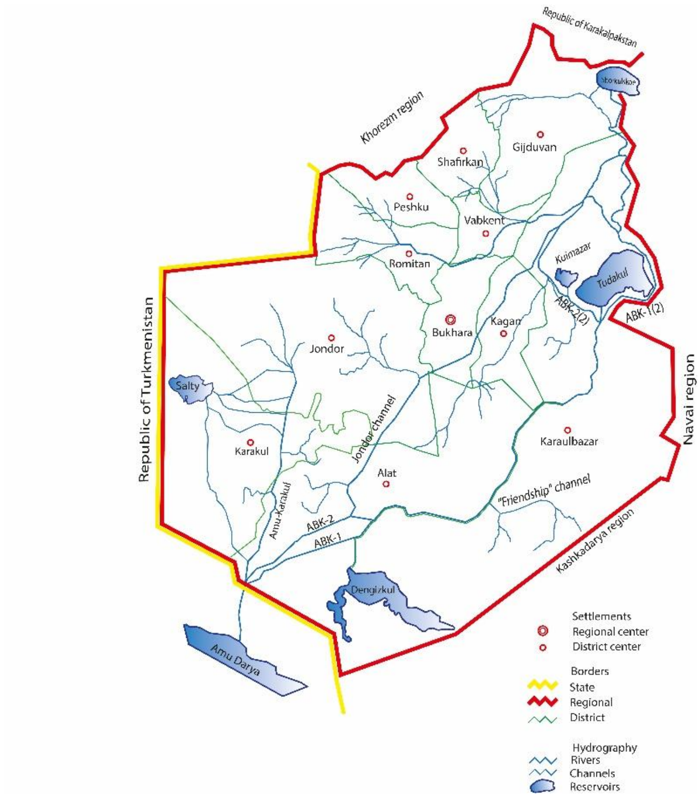

Fig. 4. Layout of the main trunk and inter-farm canals of the Bukhara region

Literature review. It is known that to ensure the efficient operation of hydroturbines, their runners play an important role. Hydroturbines are divided into active, reaction, Archimedes screws and kinetic hydroturbines.

The power of a hydroturbine is characterized by the flow rate of water flowing through the turbine and the working pressure. Figure 5 shows a graph showing the area of application of various types of turbines, which should be taken into account if it is necessary to improve the output power and economic indicators of hydropower with very low pressure. From the graph it is clear that, for efficient operation in free-flowing watercourses (rivers, irrigation canals), bottom-flow water wheels, which belong to the class of kinetic hydraulic turbines, are widely used [7].

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

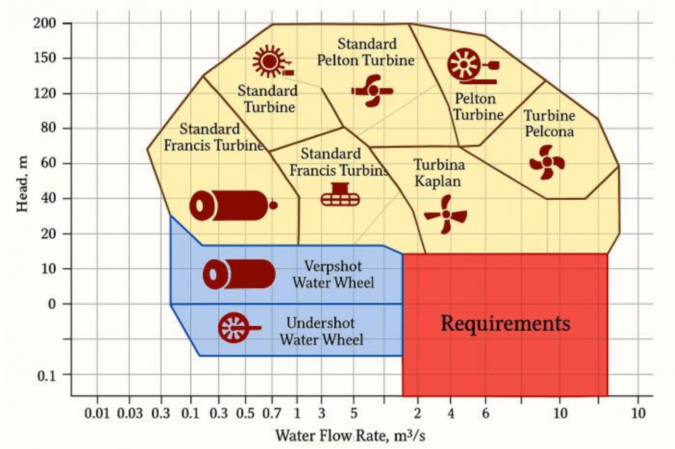

Fig. 5. Application areas of different types of turbines

This analysis presents scientific research conducted both in world practice and in our republic, dedicated to the development of micro hydroelectric power plants with kinetic hydroturbines.

In the work of J.R. Gandhi et al., a hydroelectric power plant is described in which a kinetic hydroturbine is placed on a floating base. This design uses a low-speed electric generator, which ensures the efficient operation of the hydroelectric power plant in conditions of low water flow pressure. [8]. G. Müller et al. devoted their research to the issues of the efficiency of floating water wheels and their impact on the environment, as well as ways to improve this situation. The main disadvantages of the hydroelectric power plant are low efficiency and low rotation speed of about 4 - 6 rpm, which led to a reduction in the use of this type of hydroelectric power plant. Researchers proposed to increase the number of blades from 8 to 24, which increased efficiency from 25% to 42%. It was also found that rectangular blades, completely immersed in water, have a drag factor of Cd = 2, which also increases efficiency from 10% to 46%. The impact on the environment is probably minimal, which can be studied from historical literature. It can be concluded that water wheels can be a solution for decentralized power generation in remote areas due to their simplicity and low cost [9]. In 2018, a series of model tests were conducted at the University of Southampton by E. Quaranta and G. Müller to establish and analyze the operating characteristics of Sagebien and Zuppinger water wheels at water heads from 0.3 to 1.5 m, and recommendations for their use were given. The maximum efficiency for both types of wheels reached 84%. The maximum design water flow rate was also set at 1.2 m3/s per meter of width, and the tangential speed of the wheel should not exceed 1.2 m/s [10]. G. Müller and K. Walter devoted their research to Zuppringer-type water wheels, which operate effectively in low-current watercourses with a water pressure of 1.2-2.5 m and a water flow rate of 0.3-5 m3/s. The research showed that a water wheel with a diameter of 4.5-7.7 m has a turbine rotation speed of 4-6 rpm with an installed power of 3-100 kW. The efficiency of this water wheel was 70-80%, which is an excellent solution for generating electricity in low-current watercourses [11]. D. Adanta et al. developed a design for a bottom-flow water wheel in their study. This study examined analytical methods for determining the number of blades from the proposed 6, 7, 8, 9 and 10 blades of a water wheel and operation at different incoming water flow rates of 1 m/s, 3 m/s and 5 m/s. According to the results of the study, it was found that the water wheel is most effective at a water flow rate of 1 m/s (46% efficiency) and 5 m/s (14% efficiency) [12]. Turnok et al. developed a micro hydroelectric power plant with a floating base in their study, designed for operation in low-flow watercourses. It was found that the efficiency of this design does not change with changes in the water level, due to the use of a floating base [13]. D.B. Kodirov developed an energy-efficient micro hydroelectric power plant for low-pressure watercourses. A micro hydroelectric power plant designed for operation in low-pressure watercourses of an irrigation canal is proposed. The researcher presented the technical and energy parameters of a water wheel operating at low water flows as follows: The outer diameter of the wheel is 2 m, the inner diameter is 1 m, the number of blades is 12, the rotation speed is 100 rpm, at a pressure of 180 mm the design generates 10 kW of power, voltage is 200-234 V, frequency is 50 Hz [14]. O. O. Bozarov in his dissertation developed a micro hydroelectric power station with a reactive hydraulic unit for agricultural consumers. This micro hydroelectric power plant with a reactive hydraulic unit has the following technical characteristics: water pressure of 2 m, water flow rate of 200 l/s, generated power of 2.35 kW, output voltage of 210-220 V, frequency of 48-52 Hz [15]. M.M. Mukhammadiev and B.U. Urishev presented the design of a micro hydroelectric power plant operating at low flows of an irrigation canal,

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

which consists of two parallel water wheels located on a common horizontal shaft. The shaft in turn is connected to the generator using a belt drive. According to experimental studies of the design, its capacity was established, which was about 5 kW [16] R.A. Mamedov et al. in their scientific work developed a micro hydroelectric power station with a floating base, consisting of two water wheels with a diameter of 1 m and a width of 2 m, connected by means of planetary gearboxes to a low-speed magnetoelectric generator with a capacity of 1.5 kW. As a result of using this installation, it was found that the developed micro hydropower station with a capacity of 1.5 kW allows saving about 6.6 tons of gasoline and prevents emissions into the atmosphere of more than 14.64 tons of carbon dioxide (CO2) per year [17]. Due to the short payback period and good environmental sustainability, the use of micro hydroelectric power plants with kinetic turbines has found wide application all over the world [18-20].

The purpose of this study is to assess the hydropower potential of the irrigation canals of the Bukhara region and to develop an efficient design of a micro hydroelectric power plant based on a kinetic turbine with a floating base, intended for stable and uninterrupted generation of electricity in low-pressure free-flowing watercourses. The study is aimed at creating a solution that can ensure sustainable power supply to remote and non-electrified settlements located along the irrigation network, taking into account the variability of the hydrological characteristics of the water flow.

The objectives of the study are to analyze the hydrological characteristics of the irrigation system of the Bukhara region in order to identify areas with the greatest potential for the placement of kinetic micro hydroelectric power plants, to develop a conceptual model of a micro hydroelectric power plant adapted to the conditions of low-pressure free-flowing watercourses, using a kinetic turbine and a pontoon base, to conduct numerical modeling and evaluate the efficiency of the plant in various hydrodynamic water flow regimes (in the speed range of 0.5–5 m/s), and to formulate recommendations for the practical implementation of the developed plant and to assess the prospects for scaling the technology in similar irrigation systems in the region and beyond.

II. METHOD AND MATERIALS

A hydrokinetic turbine is a zero-head device designed to extract kinetic energy from free-flowing water. Its operating principle is similar to that of a wind turbine, except that it uses water instead of air as the working medium. Unlike traditional hydroelectric power plants that use dams, a hydrokinetic turbine extracts energy from free-flowing water.

The basic operation of a turbine includes the following steps (Fig. 6):

Step 1: The hydrokinetic turbine converts the kinetic energy of the water flow into mechanical energy, which is transmitted to the rotating shaft.

Step 2: A system of gearboxes regulates the speed and torque, providing optimal conditions for the operation of the alternator. The latter must operate at a fixed speed.

Step 3: The generator converts mechanical energy into electrical energy using the right-hand principle.

Step 4: The electrical energy obtained is either fed into the grid or stored in a battery through a collector for later use.

Fig.6. Stages of energy conversion

Operating principle. All hydrokinetic turbines, regardless of the application, operate on a single principle of energy conversion. They are used for power supply, household needs, water lifting, irrigation and operation of various devices - even for powering underwater sensors on the ocean floor. A turbine placed in a water flow encounters resistance and lifting force acting on its blades [21]. This causes the rotor to rotate, and then through a gearbox and generator, the conversion into electricity is carried out. The turbine power is calculated using the formula:

$$P = \frac{1}{2} C_p \rho A V^3$$

where, P – power (W); ρ – water density (kg/m^3); A – hydroturbine area (m^2); V – water flow velocity (m/s); C_p – power factor.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

The amount of energy available depends on the density of the water, the area of the blades and the flow velocity. Of these parameters, the flow velocity and area are particularly important, as they directly affect the amount of energy extracted.

According to Betz's theorem, the maximum proportion of kinetic energy that can theoretically be extracted from a liquid flow is 59.3%, or a power factor of Cp = 16/27 [22].

The power factor (C_p) is the ratio of the useful mechanical power on the shaft to the theoretical power of the water flow. It shows what proportion of the available energy can be converted into work:

$$C_p = \frac{P}{\frac{1}{2} \cdot \rho \cdot A \cdot V^3}$$

where, P – power (W); ρ – density of water (kg/m^3); A – area of the hydro turbine (m^2); V – velocity of the water flow (m/s).

tip speed ratio (λ) is a dimensionless value, considered one of the main parameters used in the design of a kinetic hydroturbine, equal to the ratio of the peripheral speed of the blades to the speed of the water flow:

$$\lambda = \frac{\omega \cdot r}{V}$$

where, ω – angular velocity of rotation of the kinetic hydroturbine (rad/s); r – radius of the hydroturbine (m); V – water flow velocity (m/s).

III. RESULTS

The following significant results were achieved as a result of the conducted research:

1. Assessment of hydropower potential using the "Energy Tree" method The conducted assessment of the potential of the irrigation system of the Bukhara region using the "Energy Tree" method made it possible to identify the most promising areas for the placement of micro hydroelectric power plants. According to calculations, the gross hydroelectric potential of the system is up to 202.4 GWh per year. This confirms the feasibility of using irrigation canals not only for agricultural needs, but also as an alternative source of renewable energy.

2. Development of a design for a micro hydroelectric power plant based on a kinetic turbine with a floating base An innovative concept for the installation has been developed, which includes the use of a kinetic turbine installed on a pontoon platform. This design provides adaptation to variable water levels, which is especially important for irrigation systems where water flow fluctuations occur during the day or depending on the agricultural season. The solution is aimed at ensuring stable electricity generation in conditions of unstable water flows.

3. Turbine operation simulation in various water flow regimes Calculation and numerical simulations of turbine operation at different flow rates from 0.5 to 5 m/s were carried out. The results showed high stability of turbine operation at minimum rates and linear growth of output with increasing flow rate. This confirms the versatility and flexibility of the system, as well as its ability to function effectively even in weak flow conditions typical of irrigation canals.

4. Evaluation of the plant applicability for energy-deficient regions It was found that the proposed micro hydroelectric power plant can be successfully implemented in hard-to-reach and remote settlements that are not connected to centralized power grids. Due to its compactness, autonomy and resistance to external conditions, the system is capable of providing uninterrupted and reliable power supply for household and small-scale industrial needs, contributing to an increase in the standard of living and the development of infrastructure in rural areas.

The experimental and modeling studies confirmed the efficiency of kinetic hydroturbines in free-flowing watercourses, such as rivers and irrigation canals. The developed units were designed for flow speeds ranging from 0.5 to 5 m/s, which corresponds to the conditions of most natural and artificial canals. The analysis covered the assessment of the performance of horizontal and vertical turbine designs under various flow conditions. It was found that at a flow speed of 1 m/s, the prototype turbine provided an average specific power within 45–60 W/m² of the coverage area, depending on the geometry and profile of the blades. With an increase in speed to 3–5 m/s, a significant increase in output power was observed — up to 400–600 W/m², which is consistent with the theoretical law of the cubic dependence of power on flow speed. The power efficiency (Cp) ranged from 0.25 to 0.38, which corresponds to the indicators of similar low-power hydrokinetic devices. The best values were achieved with optimized blade installation angle and correct profile selection, which ensured a high lift-resistance coefficient and reduced losses due to flow separation. A generator with permanent magnets in conjunction with a simplified gear transmission was used to convert mechanical energy into electrical energy. Under optimal conditions, the total efficiency of the entire system (from the kinetic energy of the flow to the electrical power at the output) reached 52%, which confirms the practical applicability of such units for decentralized energy supply. Thus, the obtained results confirm the prospects of using kinetic hydroturbines for

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 4, April 2025

sustainable energy generation in rivers and canals with average flow rates, especially in autonomous and rural areas where the use of traditional hydropower is difficult or impossible.

IV. CONCLUSION

1. The conducted analysis showed significant hydropower potential of the irrigation system of the Bukhara region, especially in the Amu-Bukhara Canal, where it is possible to effectively use the low-pressure kinetic energy of the water flow.

2. The use of a pontoon base ensures stable operation of the micro hydroelectric power plant regardless of water level fluctuations, which makes the system sustainable and adaptable to the conditions of irrigation canals.

3. The developed installation demonstrates reliable operation in a wide range of flow rates (0.5–5 m/s), which expands the possibilities of its application at various points of the irrigation network.

4. The proposed technology is capable of providing energy to remote settlements, improving access to electricity and stimulating the development of rural infrastructure and small businesses.

5. The introduction and adaptation of micro hydroelectric power plants based on a similar model in other regions with a developed irrigation system can be an effective step towards decentralized and sustainable energy.

REFERENCES

[1] N. N. Sadullayev, A. B. Safarov, Sh.N. Nematov, R.A. Mamedov, A.B. Abdujabarov, “Opportunities and prospects for the use of renewable energy sources in Bukhara region”, *Applied solar energy*, vol. 56, № 4, pp. 410-421, 2020.
[2] C. Penche, “European Small Hydropower Association – ESHA”, *Guide on How to Develop a Small Hydropower Plant*, vol. 2, № 7, pp. 43-49, 2004.
[3] https://www.ren21.net/gsr-2023/Renewables Global Status Report 2023
[4] https://energystats.enerdata.net/
[5] https://www.hydropower.org/publications/2023-hydropower-status-report
[6] Sadullayev N.N., Safarov A.B., Mamedov R.A., Kodirov D. Assessment of wind and hydropower potential of Bukhara region // IOP Con. Series: Earth and Environmental Science 614(2020) 012036 (DOI: 10.1088/1755-1315/614/1/012036)
[7] S. J. Williamson, B. H. Stark, J.D. Booker, “Low head pico hydro turbine selection using a multi-criteria analysis”, *Renewable Energy*, vol. 61, pp. 43-50. 2014.
[8] J.R.Gandhi, H. Jha, S. N. Jha, D.S.Patel, “Renewable Energy Based Floating Power Generator (Rivers and Canals)”. *International Journal of Engineering Research and Applications*. vol. 6, pp. 49-59, 2016.
[9] G. Muller, R. Jenkins, W. Batten, “Potential, performance limits and environmental effect of floating water mills”. *Bundesanstalt für Wasserbau*. pp. 707-712. 2010.
[10] E. Quaranta, G. Müller, “Sagebien and Zuppinger water wheels for very low head hydropower applications”, *Journal of Hydraulic Research*. pp. 1-11, 2018.
[11] G. Muller, C. Wolter, “The breast-shot waterwheel: design and model tests”, *Proceedings of the Institution of Civil Engineers, Engineering Sustainability*, vol. 157, pp. 1-9, 2004.
[12] D. Adanta, B. Budiarso, S. Arifianto, S. Nasution. “Effect of blades number on undershot waterwheel performance with variable inlet velocity”, 4th International Conference on Science and Technology (ICST). 2018, pp. 1-6.
[13] S.R. Turnock, G. Muller, R. F. Nicholls-Lee, et al, “Development of a floating tidal energy system suitable for use in shallow water”. 7th European Wave and Tidal Energy Conference, 09. 2007, pp. 1-9.
[14] D.B. Kodirov, “Energy-efficient micro hydroelectric power plant for low-pressure watercourses”, PhD dissertation, Tashkent, 2018.
[15] O.O. Bozarov, “Development of a micro-hydroelectric power plant with a reactive hydraulic unit for agricultural consumers”, PhD dissertation, Tashkent, 2020.
[16] M.M. Muhammadiev, B.U. Urishev, “Free-flow micro hydroelectric power plant”, Patent of the Republic of Uzbekistan, No. IAP 03639, 2008.
[17] R.A. Mamedov, N.N. Sadullaev, A.B. Safarov, G.Zh. Rajabova. “Hydropower plant”, Patent of the Republic of Uzbekistan No. FAP 01884, 2022.
[18] Uzakov G.N., Kuziev Z.E., Safarov A.B., Mamedov R.A. “Development of a System for Modeling the Design and Optimization of the Operation of a Small Hydroelectric Power Station”. International Scientific and Practical Conference Digital and Information Technologies in Economics and Management. November 2023, pp. 243-252
[19] Uzakov G.N., Kuziev Z.E., Safarov A.B., Mamedov R.A. “Improvement Research of a Vertical Axis Micro Hydro Power Plant”, International Journal of Advanced Research in Science, Engineering and Technology. Vol. 11, Issue 2, February 2024, pp. 21438- 21443
[20] Safarov A.B., Davlonov Kh.A., Mamedov RA, Chariyeva M.R., Kodirov D. *Design and modeling of dynamic modes of low speed electric generators for electric power generation from renewable energy sources.* AIP Conference Proceedings 2686, 020013 pp. 1-7
[21] Killingtveit A. Hydropower, managing global warming: an interface of technology and human issues, 2019, pp. 265–315
[22] Khan, J., et al., Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review. Appl. Energy 86 (10), 2009. pp. 1823–1835