IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 16 September 2023, accepted 29 September 2023, date of publication 4 October 2023,
date of current version 10 October 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3321710

RESEARCH ARTICLE

Prototype Development of an Automatic and Floating Structured Hydropower Plant

SAMANDAR KHAN AFRIDI[1], ABDUL SATTAR SAAND[1], ABDUL RAFAY KHATRI[2], MOHSIN ALI KOONDHAR[1], WONSUK KO[3], SISAM PARK[4], HYEONG-JIN CHOI[4], AND WAQAS AHMED[1]

[1]Department of Electrical Engineering, Quaid-e-Awam University of Engineering Science and Technology, Nawabshah 67480, Pakistan
[2]Department of Electronics Engineering, Quaid-e-Awam University of Engineering Science and Technology, Nawabshah 67480, Pakistan
[3]Department of Electrical Engineering, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia
[4]GS E&C Institute, GS E&C Corporation, Jongno, Seoul 03159, Republic of Korea

Corresponding author: Hyeong-Jin Choi (hjchoi@gsenc.com)

This work was supported by the Korea Agency for Infrastructure Technology Advancement, and funded by the Ministry of Land, Infrastructure and Transport under Grant RS-2019-KA153277.

ABSTRACT The prototype development of an automatic and floating structured hydropower plant constitutes a pioneering initiative aimed at addressing the critical issue of energy scarcity in remote areas. This research is centered on the creation of an innovative and sustainable energy solution that capitalizes on diverse water flow conditions. It involves design and construction of a floating hydropower plant that seamlessly integrates a Pico hydro turbine, generator, and control system. The IoT technology is incorporated to enable real-time monitoring and visualization of essential electrical parameters through mobile apps. In light of the escalating global demand for renewable energy solutions, this research holds immense significance. By extending access to electricity to off-grid communities, especially those residing in remote regions where conventional energy infrastructure is impractical, the proposed floating hydropower plant offers a reliable, eco-friendly power source. Its deployment in rivers and water bodies underscores its adaptability and potential to significantly alleviate energy deficits in underserved areas. As the world grapples with the pressing need for a transition toward sustainable energy sources, this project serves as a beacon of ingenuity and progress. By broadening the scope of the original research and exploring avenues for further enhancement, this endeavor underscores the commitment to a future where accessible, clean, and efficient power generation can transform the lives of communities plagued by energy scarcity. The outcomes and implications of this research endeavor not only contribute to the field of renewable energy but also provide a foundation for future innovations in sustainable power generation systems.

INDEX TERMS Floating hydropower plant, renewable energy, pico hydro turbine, automatic control system, IoT technology.

I. INTRODUCTION

In recent years, there has been growing interest in the concept of floating structure hydropower plants as an innovative and sustainable solution to overcome the limitations of traditional land-based installations [1]. Floating structure hydropower plants involve the installation of power generation facilities on floating platforms in water bodies such as lakes, reservoirs, rivers, or even offshore environments [2]. This approach offers several advantages, including increased flexibility in plant location, efficient utilization of underutilized water bodies, reduced environmental impact, and improved scalability. Hydropower is one of the oldest and most widely used forms of renewable energy. It has been used for thousands of years to power mills and other machinery, and in the 19th century, it became an important source of electricity for industrialized societies. The first hydropower plant was built in Northumberland, England in 1878 [3]. The plant used a water turbine to generate electricity, which was then used to power streetlights in the town of Cragside. Over the next few decades,

The associate editor coordinating the review of this manuscript and approving it for publication was Tariq Masood.

hydropower plants became increasingly common, especially in areas with abundant water resources [4]. In the early 20th century, hydropower technology continued to evolve. New types of turbines were developed that were more efficient and could generate more power. Dams were built to create large reservoirs of water, which could be used to generate electricity on demand. By the 1920s, hydropower was the primary source of electricity in many parts of the world [5].

In the decades that followed, hydropower continued to play an important role in the energy mix of many countries. However, there were also concerns about the environmental impact of large-scale hydropower projects. Dams can have significant ecological effects, including altering river flows and disrupting fish populations [6]. Despite these concerns, hydropower remains an important source of renewable energy today. It is used to generate electricity in countries all over the world, from the United States to China to Brazil. In recent years, there has been renewed interest in small-scale hydropower projects, which can be less damaging to the environment than large dams. The Prototype Development of an Automatic and Floating Structured HydroPower Plant aligns with key United Nations Sustainable Development Goals (SDGs). It addresses SDG 7 by providing affordable clean energy to remote areas through water currents, supporting SDG 9 by innovating with hydrokinetic turbines and IoT integration, contributing to SDG 11 by enhancing off-grid communities, advancing SDG 13 through reduced carbon emissions, and fostering partnerships for SDG 17, promoting collaboration among stakeholders for effective sustainable energy implementation [7].

Hydropower plants work by harnessing the energy of moving water to generate electricity. The most common type of hydropower plant is a dam, which creates a large reservoir of water that can be used to generate electricity on demand. When water flows through the dam, it turns a turbine, which in turn generates electricity. There are several different types of hydropower plants, each with its advantages and disadvantages. Run-of-river plants, for example, use the natural flow of a river to generate electricity, without the need for a dam [8]. This can be less damaging to the environment than large dams, but it can also be less reliable, as the amount of electricity generated depends on the amount of water flowing through the river. Another type of hydropower plant is a pumped-storage plant. These plants use excess electricity to pump water from a lower reservoir to a higher one.

This paper addresses key challenges in hydropower:

1. High costs hinder rural access. A cost-effective alternative is crucial [9].
2. Complex installation limits deployment. A floating structure aids flexibility [10].
3. Lack of monitoring and control hampers performance. IoT integration offers real-time oversight [11].
4. Current visualization methods are inadequate. A mobile app interface enhances transparency [12].

Addressing these problems will lead to the development of a low-cost, easy-to-install, and remotely monitored hydropower plant, providing a sustainable energy solution for remote and rural areas. The project's flexible and mobile nature makes it an ideal solution for powering communities that are off the grid or have limited access to electricity. The project can also provide a sustainable source of power for agriculture and irrigation systems, reducing the reliance on fossil fuels. The Prototype Development of an Automatic and Floating Structured Hydropower Plant is an innovative and sustainable solution to address energy scarcity in remote areas. The project's flexible and automatic nature makes it an ideal solution for generating power in various water flow conditions and supporting various applications. The integration of IoT technology allows for remote monitoring and control of the power generation system, making it a reliable and efficient source of power. The systematically navigates a comprehensive methodology encompassing the innovative design of a floating Pico-hydro turbine, intricate turbine wheel rotation calculations, seamless integration of an undershoot water wheel, and the strategic inclusion of a DC generator. The subsequent electronics circuit synergizes with IoT technology for enhanced efficiency. Results and analysis unveil the MATLAB/Simulink model simulation alongside prototype testing outcomes in a canal. This journey culminates in a conclusive reflection and prospects for future applications and development.

The existing body of literature extensively explores various dimensions of hydropower integration and related technologies. In [13] delve into the components and environmental aspects of conventional hydropower, emphasizing grid integration and pumped storage. In [14] focuses on design considerations for micro-hydroelectric power plants, employing MATLAB Simulink to determine parameters, with a sustainability and efficiency focus. In [15] study the efficiency of micro hydropower undershot turbines, highlighting blade tilt angles' impact on energy conversion. In () [16] present the modeling, simulation, and fabrication of an undershot floating waterwheel, demonstrating the effect of water flow velocity on power output. Integration of renewable, like micro hydropower, has been examined in [17], proposing hybrid PV systems and micro-hydropower systems for continuous power supply. In [18] model and simulate micro-hydropower plants, showcasing speed governing control system stability. Sharma and in [19] focus on run-off river plant modeling, comparing and analyzing hydraulic turbine and governor behavior using MATLAB/SIMULINK. Pico hydropower's potential in rural electrification is highlighted in [20], stressing its cost-effectiveness and suitability for remote areas. In [21] introduce a portable floating pico-hydro system, featuring a low-speed DC generator, controller, and DC-DC converter for power generation. In [22] design a prototype hydroelectric power station within floating cages, investigating wheel diameter and sensor systems' impact. In [23] optimizes gravity water wheel performance, evaluating undershot, breastshot, and overshot water wheels. In [24] models and simulates Shiroro Hydropower Plant's dynamics using MATLAB/Simulink. In [25] MATLAB/

SIMULINK-based simulation model explores hydropower plant dynamics. In [26] introduces a HYPER numerical simulation model for run-of-the-river hydropower plants. In [27] examines water wheels for rural electricity in Sri Lanka, optimizing blade configurations. In [28] low-head hydraulic turbine systems, align with renewable energy's changing landscape.

In [29] investigates micro-hydropower system management for rural electrification in Bhutan. In [30] explores wastewater discharge for electricity production using water turbine/electrical generator setups. Asynchronous vs. synchronous generators for small consumers are compared in [31]. Self propelled floating power plants (FPP) are discussed in [32]. Small-scale hydroelectric power plant evaluation and design intricacies are explored in [33]. In [34] assesses Nepal's hydropower potential and power supply planning. Innovative solutions for renewable energy generation are introduced by Gandhi et al. [2], Vermaak et al. [35], and Khan et al. [36]. Bryan Patrick Ho-Yan [37] designs a pico hydro turbine for rural electrification in Cameroon. In [38] reviews Ultra-Low Head hydropower's potential as an economical and environmentally friendly alternative to traditional methods.

In summarizing the insights from existing literature, several key drawbacks and potential solutions emerge. Traditional hydropower plants face challenges in grid integration and environmental impacts. While micro-hydroelectric power plants offer sustainable solutions, fluctuations in solar irradiance can affect hybrid PV systems' reliability. The importance of generator selection for small electric power consumers is stressed. The management of micro-hydropower systems for rural electrification requires load balancing and grid connectivity solutions. While wastewater discharge shows promise for electricity generation, the transition from large-scale hydropower to low-head systems presents design complexities. Despite the appeal of floating power generators, their real-world scalability and adaptability need evaluation. The research also highlights the significance of appropriate turbine design for rural electrification. The review emphasizes that Ultra-low-head hydropower can address environmental concerns, but installation sites and sustainable practices must be carefully considered. These insights underscore the need for innovative design approaches and comprehensive planning to maximize the benefits of hydropower while minimizing its drawbacks.

The novelty of the paper is as follows:

1. To develop a floating structure that is lightweight, modular, and easy to install and transport. The structure will be designed to withstand various environmental conditions, ensuring stability and durability while minimizing the need for extensive infrastructure.
2. To integrate IoT technology for remote monitoring and control of the hydropower plant. This will involve the implementation of sensors and communication systems to gather real-time data on performance parameters such as turbine speed, water flow, and power output. Remote monitoring and control will enable efficient operation and maintenance.
3. To develop a mobile app interface that enables visualization and tracking of the voltage, current, and power generated by the hydropower plant. The app will provide users with real-time data, allowing them to monitor the plant's performance, identify any issues, and make informed decisions regarding energy usage.

II. PROBLEM STATEMENT

The Prototype Development of an Automatic and Floating Structured Hydropower Plant aims to address several challenges and gaps in the field of renewable energy generation. The current problem revolves around the limited access to affordable and efficient hydropower solutions, especially in remote and rural areas. The existing hydropower plants are often expensive, complex to install, and lack advanced monitoring and control capabilities.

This research identifies the following key problems:

1. High cost and limited availability of hydropower solutions: Conventional hydropower plants are expensive to construct and maintain, making them inaccessible to remote and rural communities [39]. There is a need for a low-cost alternative that can provide affordable electricity generation.
2. Difficulty in installation and transportation: Existing hydropower plants require complex infrastructure and extensive construction, limiting their deployment in various locations [40]. There is a need for a floating structure that is easy to install and transport, enabling power generation in diverse water bodies.
3. Lack of remote monitoring and control: Traditional hydropower plants often lack advanced monitoring and control systems, making it challenging to monitor their performance and optimize power generation [41]. There is a need to integrate IoT technology for real-time monitoring and remote control of the plant, enabling efficient operation and maintenance.
4. Limited visualization of power generation parameters: Existing hydropower plants lack effective methods to visualize and track the voltage, current, and power generated [42]. There is a need to develop a mobile app interface that allows users to monitor and track the electrical parameters, promoting transparency and informed decision-making.
5. Evaluation of efficiency and cost-effectiveness: It is essential to evaluate the performance of the prototype in terms of its efficiency and cost-effectiveness compared to traditional hydropower plants [43]. This evaluation will help identify areas for improvement and ensure the viability of the developed solution.

Addressing these problems will lead to the development of a low-cost, easy-to-install, and remotely monitored hydropower plant, providing a sustainable energy solution for remote and rural areas.

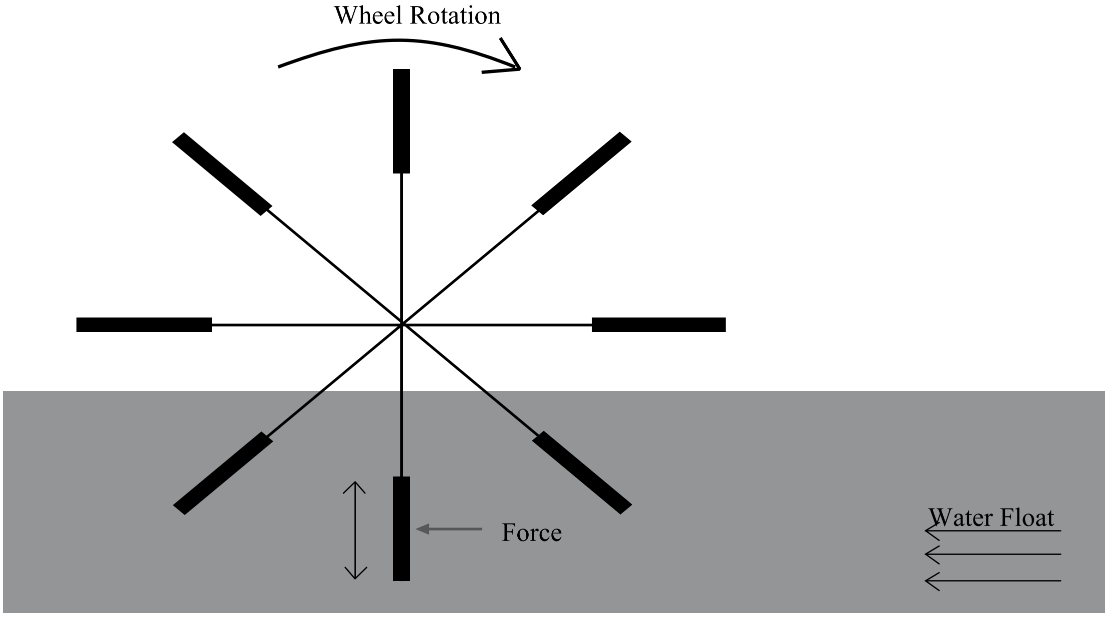

FIGURE 1. Side view of undershot waterwheel.

III. METHODOLOGY

A. FLOATING PICO-HYDRO TURBINE

The design of the floating structure is a critical aspect of the project. It focuses on developing a lightweight yet robust platform that can support the turbine, generator, and control system while floating on water. Material selection is critical to ensure corrosion resistance and durability, considering the aquatic environment and exposure to weather conditions.

Developing a hydroelectric power station integrated with floating cages involves various essential processes, including design and prototyping [44]. The hydroelectric power station system is meticulously designed to be seamlessly integrated into the floating cages, as illustrated in Figure 1. This design approach enables the hydroelectric power station to effectively harness the kinetic energy of the river's flow, converting it into clean and renewable electricity.

B. TURBINE WHEEL ROTATION CALCULATIONS

In the prototype hydropower plant, the gear system plays a crucial role in increasing the rotation speed of the generator to efficiently generate electricity. The gear setup consists of four gears: Turbine Gear, Gear1, Gear2, and Generator Gear.

The gear ratios can be represented as follows:

Turbine Gear : Gear1	Gear2 : Generator Gear
48 : 8	48 : 6
6 : 1	8 : 1

To calculate the Turbine Gear's rotation to Generator Gear's rotation, we can combine the gear ratios:

Turbine Gear : Generator Gear
$1 : (8 \times 6)$
$1 : 48$

Thus, for every single rotation of the Turbine Gear, the Generator Gear rotates 48 times. During the testing phase in the canal, the Turbine wheel was observed to rotate 15 times in one minute. Consequently, the Generator Gear will rotate $15 \times 48 = 720$ revolutions per minute as shown in Table 1.

TABLE 1. Different calculation of rotation of turbine water wheel.

Time	Turbine Wheel Rotation	Gear Box ---x48	Generator Rotation
If 2 sec	1 rotation	1x48=48	1440 rpm
Then 1 mint	30 rotation	30x48=1440	
If 3 sec	1 rotation	1x48=48	960 rpm
Then 1 mint	20 rotation	20x48=960	
If 4 sec	1 rotation	1x48=48	720 rpm
Then 1 mint	15 rotation	15x48=720	
If 5 sec	1 rotation	1x48=48	576 rpm
Then 1 mint	12 rotation	12x48=576	
If 6 sec	1 rotation	1x48=48	480 rpm
Then 1 mint	10 rotation	10x48=480	
If 7 sec	1 rotation	1x48=48	411 rpm
Then 1 mint	8.5 rotation	8.57x48=411	
If 8 sec	1 rotation	1x48=48	360 rpm
Then 1 mint	7.5 rotation	7.5x48=360	
If 9 sec	1 rotation	1x48=48	320 rpm
Then 1 mint	6.6 rotation	6.6x48=320	
If 10 sec	1 rotation	1x48=48	288 rpm
Then 1 mint	6 rotation	6x48=288	
If 11 sec	1 rotation	1x48=48	261 rpm
Then 1 mint	5.4 rotation	5.45x48=261	

This calculated data demonstrates the gear system's effectiveness in significantly increasing the generator's rotation speed, resulting in a higher rate of electricity generation.

C. UNDERSHOOT WATER WHEEL

The undershoot water wheel turbine is constructed with a Plastic plate featuring 12 closed blades. These blades are designed like a Pelton turbine, where the incoming water is directed to strike the turbine and subsequently gets trapped,

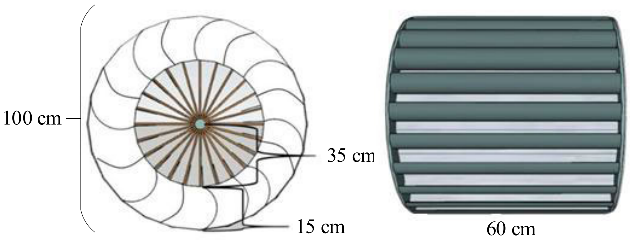

FIGURE 2. Water wheel design.

TABLE 2. Undershoot water wheel specification.

Specification	Unit
Material	Plastic
Number of blades	12 pcs
Wheel diameter	100 cm
Wheel width	60 cm
Height blade	15 cm
Rotation wheel at flow 4 m/s	15 rpm

TABLE 3. Specification of permanent magnet DC generator.

Specification	Unit
Length	14 cm
Diameter	9 cm
Type	Permanent Magnet
Nominal speed	600 rpm
Weight	2.2 kg
Voltage	DC 12 – 18 V
Current	4 A

imparting force to the turbine [45]. The Pelton turbine is characterized by its specially shaped buckets, which further enhance the efficiency of the turbine in capturing the water's kinetic energy as illustrated in Figure 2. Table 2 presents the specifications of the undershoot water wheel turbine, which is made of a plastic plate with 12 closed blades. The turbine's design, inspired by the Pelton turbine, allows efficient capture of kinetic energy from the flowing water.

D. DC GENERATOR

The DC generator with a permanent magnet is a crucial component of the hydroelectric power plant as it plays a vital role in converting the mechanical energy from the water wheel rotation into electrical power [46]. During the selection process, various parameters should be carefully considered, including the generator's nominal speed, power output, dimensions, and weight. These factors influence the overall performance and efficiency of the power generation system. Choosing an appropriate generator is essential to ensure optimal power conversion and reliable electricity generation from the kinetic energy harnessed by the water wheel. By evaluating and selecting the right DC generator, the hydropower plant can effectively and efficiently harness renewable energy from flowing water, contributing to a sustainable and eco-friendly power generation solution [40].

FIGURE 3. Permanent magnet DC generator.

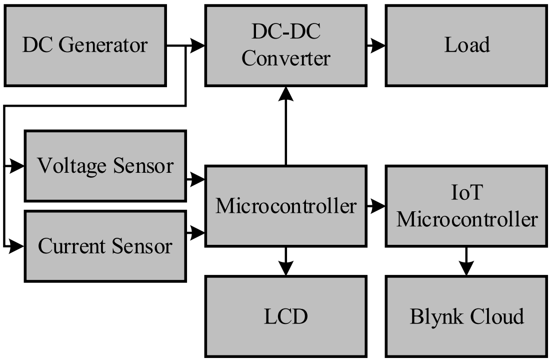

FIGURE 4. Block diagram.

Table 3 presents the specifications of the permanent magnet DC generator used in the hydroelectric power plant. The table includes details such as length, diameter, type, nominal speed, weight, voltage, and current, crucial for the generator's efficient functioning and integration into the system.

E. ELECTRONICS CIRCUIT

The electronic circuit of the hydroelectric power plant consists of several essential components, each playing a vital role in the efficient operation of the system. The main components include the electric power generator, DC-DC converters for voltage conversion, voltage and current sensors to monitor input and output parameters, microcontrollers for overall system control, an IoT microcontroller to transmit data to the internet cloud, an LCD, and the load. Figure 4 illustrates the block diagram of this electronic circuit [47], [48].

The DC-DC converters play a crucial role in converting the generated DC voltage to the desired voltage level suitable for various applications within the power plant. To ensure efficient performance and system safety, voltage and current sensors are incorporated to monitor the input and output parameters of the DC-DC converters continuously [49]. These sensors provide real-time feedback to the control system, allowing for accurate adjustments as needed. The microcontrollers act as the central control unit, overseeing and regulating the entire system's operation. They receive data from the sensors, process it, and make decisions to optimize power generation and system efficiency. The prototype's electronic circuit employs water turbine-generated power, amplified through a gearbox to drive a generator. A DC voltage regulator stabilizes fluctuating voltages, connecting to a load. Current and voltage sensors feed data to

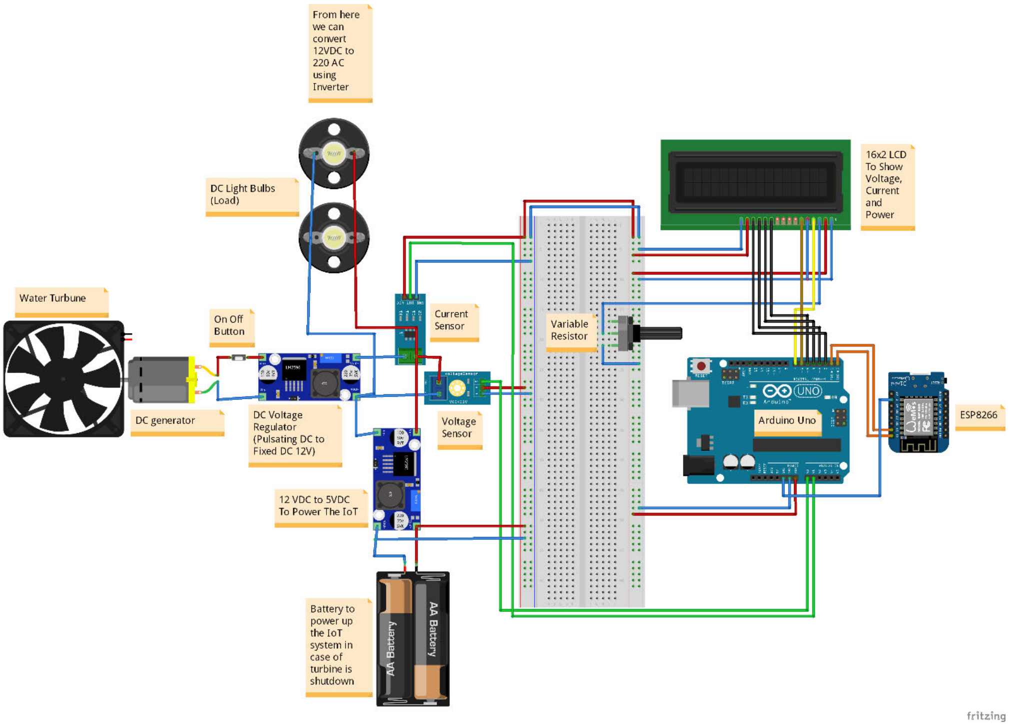

FIGURE 5. Complete electronic circuit.

an Arduino Uno microcontroller, displayed on an LCD. The ESP8266 microcontroller connects to Blynk Cloud via the internet, facilitating real-time data visualization and remote monitoring. This integrated circuit ensures stable electricity generation, enhanced by IoT connectivity for efficient and sustainable renewable energy harnessing from flowing water sources as shown in Figure 5.

F. INCORPORATION OF IOT TECHNOLOGY

The infusion of Internet of Things (IoT) technology into the project has revolutionized the Automatic and Floating Structured Hydropower Plant. Real-time data acquisition from sensors relayed to the Arduino Uno enables immediate insights into power output and system health. The integration of the ESP8266 (NodeMCU) microcontroller establishes seamless connectivity to the Blynk cloud platform shown in Figure 6, allowing remote monitoring and control. This IoT-driven approach enhances operational efficiency, data visualization, and sustainability, positioning the project as a pioneering solution in the realm of renewable energy.

The Blynk Cloud Platform lies at the core of the IoT integration, acting as a vital conduit connecting the hydro power plant's sensors and controllers to the user interface. It enables the real-time transmission of data from the plant's sensors, offering a secure and efficient data management solution. Figure 6 illustrates the platform's prowess in remote monitoring and control, empowering users with the ability to oversee the hydro power plant's status from virtually anywhere with internet access. This extends to monitoring key parameters like power output, voltage, and current, while also granting the flexibility to make remote adjustments or execute commands. The platform's user-friendly interface, thoughtfully depicted in Figure 6, provides an intuitive and visually engaging representation of critical data, ensuring that operators and maintenance personnel can readily interpret the plant's performance. This accessibility proves invaluable in the efficient operation and upkeep of the hydro power plant.

The mobile accessibility showcased in Figure 7 demonstrates a significant advantage of the Blynk Cloud Platform, as users can effortlessly tap into real-time data and exercise control over the hydro power plant via their smartphones or tablets. This functionality substantially enhances the system's flexibility, liberating users from the confines of a fixed location for monitoring and management. Impressively, the mobile view appears to be meticulously tailored for smaller screens, ensuring that users can navigate and engage with the platform seamlessly across a spectrum of mobile devices. This responsiveness is paramount for on-the-fly monitoring and swift decision-making. Moreover, this mobile interface grants users immediate insights into the hydro power plant's performance, allowing them to access vital information regarding power generation statistics, voltage and current readings, and other critical data without any delay. Such instantaneous access proves invaluable for efficient plant oversight and timely actions.

This IoT-driven approach enhances operational efficiency, data visualization, and sustainability, positioning the project as a pioneering solution in the realm of renewable energy.

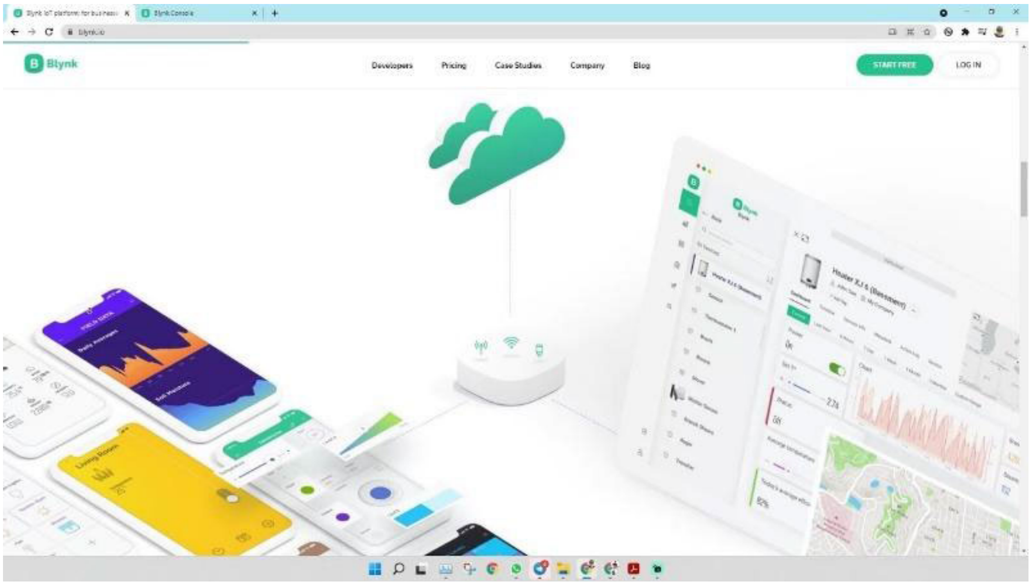

FIGURE 6. Showing blynk IoT cloud platform.

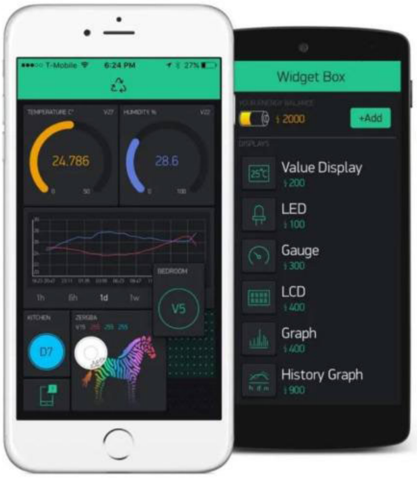

FIGURE 7. Showing blynk cloud mobile view.

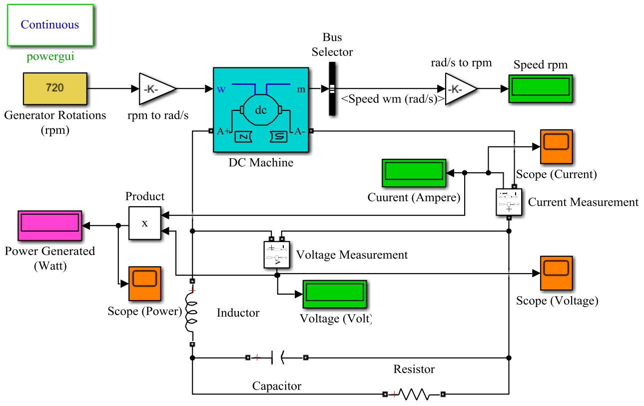

FIGURE 8. MATLAB/simulink model.

IV. RESULTS AND ANALYSIS

The presentation and analysis of results obtained from rigorous testing and validation, shed light on the prototype's performance and efficiency. A thorough comparison with existing systems or technologies accompanies the discussion, contributing to a comprehensive understanding of its implications and significance.

A. MATLAB/SIMULINK MODEL SIMULATION

The MATLAB/Simulink model simulates the prototype water turbine generator shown in Figure 8, where a PMDC machine is employed as the generator. The PMDC machine receives input in the form of speed from the prime mover. To convert the speed from RPM to rad/s, a constant block is connected through a gain block. This ensures that the PMDC machine receives speed in the appropriate units for generator operation.

The generator produces an output in the form of DC voltage and current, which is obtained from the positive and negative terminals. To measure the generated voltages and current, Voltmeter and Ammeter measuring instruments are used. To regulate the output of the generator, a combination of capacitor and inductor is connected. This is essential as the generator generates pulsating voltages, and the capacitor-inductor combination helps in stabilizing and maintaining a constant voltage. In the MATLAB/Simulink model, the output of the Voltmeter and Ammeter is multiplied using a product block to calculate the generated power. This enables us to visualize the power output of the water turbine generator.

The generated power is then displayed on the LCD screen, providing a clear and real-time representation of the power

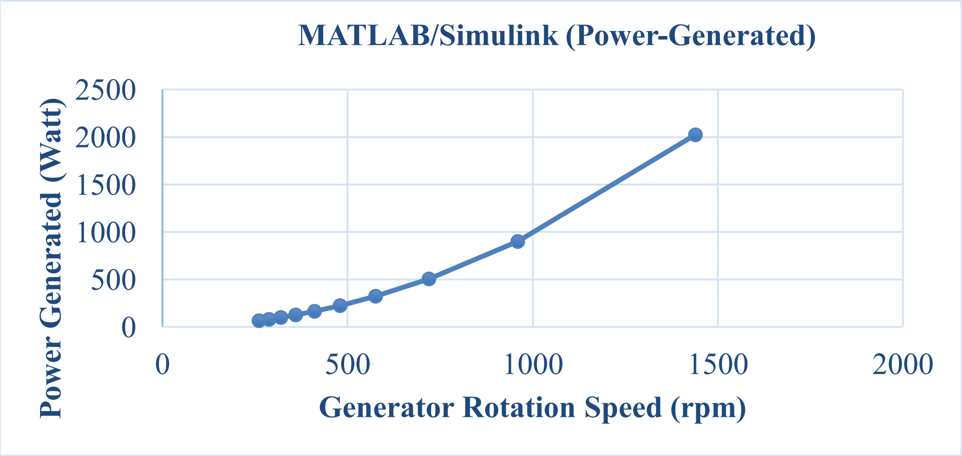

FIGURE 9. MATLAB/simulink (power-generated) curve.

TABLE 4. MATLAB/simulation power generated on different speeds.

Test Points	Time	Turbine Wheel Rotation	Generator Rotation	MATLAB/Simulink (Power-Generated)
1.	If 2 sec Then 1 mint	1 rotation 30 rotation	1440 rpm	2023 watt
2.	If 3 sec Then 1 mint	1 rotation 20 rotation	960 rpm	900 watt
3.	If 4 sec Then 1 mint	1 rotation 15 rotation	720 rpm	505.9 watt
4.	If 5 sec Then 1 mint	1 rotation 12 rotation	576 rpm	323.8 watt
5.	If 6 sec Then 1 mint	1 rotation 10 rotation	480 rpm	224.8 watt
6.	If 7 sec Then 1 mint	1 rotation 8.5 rotation	411 rpm	164.8 watt
7.	If 8 sec Then 1 mint	1 rotation 7.5 rotation	360 rpm	126.4 watt
8.	If 9 sec Then 1 mint	1 rotation 6.6 rotation	320 rpm	100 watt
9.	If 10 sec Then 1 mint	1 rotation 6 rotation	288 rpm	80 watt
10.	If 11 sec Then 1 mint	1 rotation 5.4 rotation	261 rpm	66.4 watt

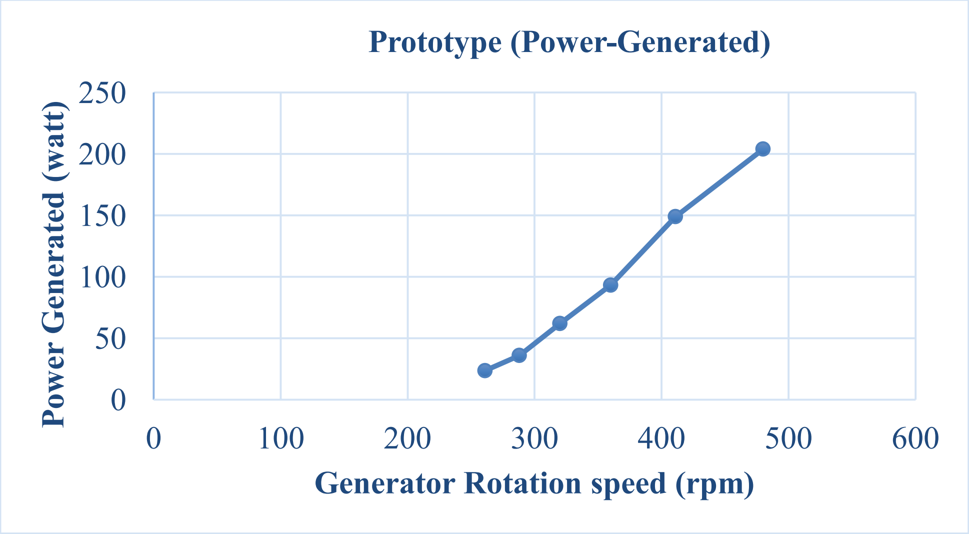

FIGURE 10. Prototype (power-generated) curve.

generated by the water turbine. This simulation allows for the evaluation of the system's performance and the efficiency of power generation under different operating conditions. By employing MATLAB/Simulink for the simulation, the


(a) (b)
(c) (d)

FIGURE 11. Snapshots of the developed prototype of an automatic and floating structured hydropower plant.

behavior of the prototype water turbine generator can be analyzed comprehensively. This model serves as a valuable tool for assessing the performance of the system, optimizing its design, and making informed decisions for its further development and implementation as shown in Figure 9.

Table 4 presents the results obtained from the simulation tests conducted using the MATLAB/Simulink model. These tests were performed to analyze the power generated by the water turbine generator at various speeds, showcasing its performance under different operating conditions.

B. THE RESULTS OBTAINED FROM TESTING OF PROTOTYPE IN THE CANAL

During the testing and validation of the prototype in the canal, it was observed that the performance of the floating structured hydropower plant was influenced by losses in the physical system. While the generated power closely aligned with the simulated results, some variations were noted due to losses in the system. These losses can be attributed to factors such as mechanical friction, electrical losses, and other inefficiencies. However, overall, the prototype demonstrated reliable and efficient power generation capabilities, despite minor deviations from the simulated performance.

During the testing phase, the prototype of the automatic and floating structured hydropower plant was subjected to six different generator rotation speeds, ranging from 480 rpm to 261 rpm. The corresponding power generated by the prototype at each speed was measured and recorded. The results indicated that the power generation was directly influenced by the rotation speed of the generator, with higher speeds resulting in higher power outputs. At 480 rpm, the prototype produced 204 watts of power, which gradually decreased as the generator rotation speed reduced. At 261 rpm, the prototype generated 23.6 watts of power. Table 5 illustrates

TABLE 5. Prototype power generated on different speeds.

Time	Turbine Wheel Rotation	Generator Rotation	Prototype (Power-Generated)
If 6 sec Then 1 mint	1 rotation 10 rotation	480 rpm	204 watt
If 7 sec Then 1 mint	1 rotation 8.5 rotation	411 rpm	149 watt
If 8 sec Then 1 mint	1 rotation 7.5 rotation	360 rpm	93.2 watt
If 9 sec Then 1 mint	1 rotation 6.6 rotation	320 rpm	62 watt
If 10 sec Then 1 mint	1 rotation 6 rotation	288 rpm	36 watt
If 11 sec Then 1 mint	1 rotation 5.4 rotation	261 rpm	23.6 watt

the prototype power generated at different speeds. Figure 10 shows the power generated under different rotational speeds and the graph line shows an exponential increase in the electrical power generated. These findings demonstrate the significant impact of generator rotation speed on power generation efficiency and help identify the optimal operating range for the prototype to achieve maximum power output.

The results obtained from the testing phase revealed the impressive power generation capabilities of the prototype. As the generator rotation speed increased, the power output exhibited a proportional rise, signifying the system's ability to effectively convert water's kinetic energy into electricity. The data revealed power generation values ranging from 23.6 watts at 261 rpm to 204 watts at 480 rpm. This direct correlation between generator speed and power output demonstrates the efficiency of the prototype.

In Figure 11, snapshots (a, b, c, d) colorfully capture the multifaceted prototype of the Automatic and Floating Structured Hydropower Plant. These images show the prototype from diverse angles, presenting its innovative design and real-world testing scenario within a canal environment.

V. CONCLUSION

The Prototype Development of an Automatic and Floating Structured Hydro Power Plant signifies a remarkable achievement in the realm of sustainable energy solutions. Through innovative design and the integration of IoT technology, the project has effectively demonstrated the potential of a versatile and efficient floating hydro power plant, producing a noteworthy 204 watts of power at 480 rpm. These findings underscore the prototype's enhanced efficiency, scalability, and adaptability, positioning it as a transformative solution for remote and off-grid power generation. This contribution to renewable energy practices not only empowers underserved communities but also showcases significant technological advancements. Consequently, this endeavor propels us closer to realizing a greener and more accessible energy future. The portable nature of the floating pico-hydro system further reinforces its efficiency and cost-effectiveness, as it requires no permanent civil works installation, is user-friendly, and has minimal ecological impact, making it a promising and sustainable energy solution.

VI. APPLICATIONS AND FUTURE WORK

The Prototype Development of an Automatic and Floating Structured Hydropower Plant exhibits versatile applications and beckons future endeavors. This innovation holds the potential to illuminate remote communities and power agricultural irrigation systems, mitigating energy scarcity. Furthermore, its scalability and adaptability position it as a key player in disaster relief efforts. Future work should delve into real-world implementation, optimizing turbine designs, exploring hybrid renewable energy systems, and conducting comprehensive environmental impact assessments. This holistic approach will not only refine the prototype's performance but also shape the blueprint for a sustainable and energy-abundant future.

AUTHOR CONTRIBUTIONS

Samandar Khan Afridi, Abdul Sattar Saand, Abdul Rafay Khatri, and Mohsin Ali Koondhar: conceptualization, formal analysis, investigation, methodology, and visualization; Samandar Khan Afridi, Abdul Sattar Saand, Abdul Rafay Khatri, Mohsin Ali Koondhar, Waqas Ahmed, and Wonsuk Ko: writing, review, and editing; Samandar Khan Afridi, Abdul Sattar Saand, Mohsin Ali Koondhar, Sisam Park, Hyeong-Jin Choi, and Waqas Ahmed: methodology and resources; Abdul Sattar Saand, Abdul Rafay Khatri, Mohsin Ali Koondhar, and Wonsuk Ko: formal analysis, resources, and software; Hyeong-Jin Choi: funding acquisition.

CONFLICTS OF INTEREST

The authors declare no competing interests.

REFERENCES

[1] M. A. R. Miah, S. R. Rahman, and R. Kabir, "Techno-economic analysis of floating solar PV integrating with hydropower plant in Bangladesh," in *Proc. IEEE Green Technol. Conf. (GreenTech)*, Apr. 2021, pp. 30–36.

[2] J. Gandhi, H. Jha, S. Jha, and D. Patel, "Renewable energy based floating power generator (rivers and canals)," *Int. J. Eng. Res. Appl.*, vol. 6, pp. 49–52, Jan. 2016.

[3] I. D. Jones, "Assessment and design of small-scale hydro-electric power plants," Ph.D. thesis, Univ. Salford, Salford, U.K., 1988.

[4] K. Kaygusuz, "Hydropower and the world's energy future," *Energy Sources*, vol. 26, no. 3, pp. 215–224, Feb. 2004.

[5] S. Bilgen, K. Kaygusuz, and A. Sari, "Renewable energy for a clean and sustainable future," *Energy Sour.*, vol. 26, no. 12, pp. 1119–1129, Oct. 2004.

[6] A. Kuriqi, A. N. Pinheiro, A. Sordo-Ward, M. D. Bejarano, and L. Garrote, "Ecological impacts of run-of-river hydropower plants—Current status and future prospects on the brink of energy transition," *Renew. Sustain. Energy Rev.*, vol. 142, May 2021, Art. no. 110833.

[7] R. Lal et al., "Soils and sustainable development goals of the United Nations: An international union of soil sciences perspective," *Geoderma Regional*, vol. 25, Jun. 2021, Art. no. e00398.

[8] A. Raheem, S. A. Abbasi, A. Memon, S. R. Samo, Y. H. Taufiq-Yap, M. K. Danquah, and R. Harun, "Renewable energy deployment to combat energy crisis in Pakistan," *Energy, Sustainability Soc.*, vol. 6, no. 1, pp. 1–13, Dec. 2016.

[9] J. Yaron, M. P. Benjamin, and G. L. Piprek, *Rural Finance: Issues, Design, and Best Practices*, vol. 14. Washington, DC, USA: World Bank, 1997.

[10] J. Bere, C. Jones, S. Jones, and M. Munday, "Energy and development in the periphery: A regional perspective on small hydropower projects," *Environ. Planning C, Politics Space*, vol. 35, no. 2, pp. 355–375, Mar. 2017.
[11] A. Kumar, Z.-G. Yu, J. J. Klemeš, and A. Bokhari, "A state-of-the-art review of greenhouse gas emissions from Indian hydropower reservoirs," *J. Cleaner Prod.*, vol. 320, Oct. 2021, Art. no. 128806.
[12] T. V. Kumar, "E-democracy for smart cities: Conclusion and path ahead," in *E-Democracy for Smart Cities*. Singapore: Springer, 2017, pp. 523–551.
[13] P. Kumar, S. Singh, V. Kumar, and V. K. Ahuja, "Hydropower plant," *Appl. Sci. Eng. J. Adv. Res.*, vol. 2, no. 3, pp. 10–13, May 2023.
[14] B. A. Nasir, "Design considerations of micro-hydro-electric power plant," *Energy Proc.*, vol. 50, pp. 19–29, Jan. 2014.
[15] E. Y. Setyawan, S. Djiwo, S. Saputro, R. A. M. Napitupulu, P. Siagian, J. Panjaitan, and R. Litiloly, "Investigation on the micro hydropower undershot type floating blade tilt angle for low-flow hydropower," *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 1007, no. 1, Dec. 2020, Art. no. 012183.
[16] F. U. Khan, A. Ahmed, U. K. Jadoon, and F. Haider, "Modeling, simulation and fabrication of an undershot floating waterwheel," *J. Eng. Appl. Sci.*, vol. 34, no. 2, pp. 55–69, 2017.
[17] M. Melamu, E. Orumwense, and K. M. Abo-Al-Ez, "Simulation of a hybrid PV system and micro-hydropower using MATLAB/Simulink," in *Proc. AIUE 18th Ind. Commercial Use Energy Conf.*, 2020, pp. 1–6.
[18] A. A. Usman and R. A. Abdulkadir, "Modelling and simulation of micro hydropower plant using MATLAB Simulink," *Int. J. Adv. Technol. Eng. Sci.*, vol. 3, pp. 260–272, Jan. 2015.
[19] H. Sharma and J. Singh, "A ideal approach of designing run off river plant," in *Proc. Int. Conf. Advancements Eng. Technol.* Sangrur, Punjab: B.G.I.E.T, 2019.
[20] D. S. Dave, A. A. Parmar, A. P. Shah, and N. M. Vyas, "Pico hydropower generation: Renewable energy technology for rural electrification," *Int. J. Adv. Sci. Eng., Sci. Manag.*, pp. 1–10, 2014.
[21] D. Dewatama, M. Fauziah, H. Safitri, and S. Adhisuwignjo, "Design and implementation: Portable floating pico-hydro," *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 732, no. 1, 2020, Art. no. 012049.
[22] Z. Fakhrudin, D. Irawan, Z. Irfan, and N. Islami, "A comprehensive prototype design of hydroelectric power station for floating-cages energy resources," *J. Phys., Conf. Ser.*, vol. 1655, no. 1, Oct. 2020, Art. no. 012066.
[23] E. Quaranta, "Investigation and optimization of the performance of gravity water wheels," Ph.D. thesis, Doktorska dizertacija, Doktorski studij Inženjerstvo Zaštite okoliša, Politecnico di Torino, Turin, Italy, 2017.
[24] S. Gbadamosi and O. A. Ojo, "Dynamic modeling and simulation of Shiroro hydropower plant in Nigeria using MATLAB/Simulink," *Int. J. Sci. Eng. Res.*, vol. 6, pp. 1–8, Jan. 2015.
[25] M. Sattouf, "Simulation model of hydropower plant using MATLAB/Simulink," *Int. J. Eng. Res. Appl.*, vol. 4, pp. 295–301, May 2014.
[26] V. Yildiz, "Numerical simulation model of run of river hydropower plants: Concepts, numerical modeling, Turbine system and selection, and design optimization," Ph.D. thesis, Univ. California, Irvine, CA, USA, 2015.
[27] T. P. Kumara, "Analysis of floating type water wheel for pico hydro systems in Sri Lanka," M.S. thesis, 2014.
[28] J. Chen, "Design-develop-test a low head hydraulic turbine using new theory for the standard modular hydropower technology," Ph.D. thesis, Michigan State Univ., East Lansing, MI, USA, 2020.
[29] K. Dorji, "The sustainable management of micro hydropower systems for rural electrification: The case of Bhutan," M.S. thesis, 2007.
[30] R. A. Saenz, "Micro hydroelectric power generation," M.S. thesis, 2012.
[31] A. Zhamalovich, Z. Alaibek, and D. Obozov, "Selection of generator for the micro hydropower plant," *Amer.-Eurasian J. Sci. Res.*, vol. 8, pp. 104–108, Feb. 2013.
[32] F. Acuner and Ş. Helvacioğlu, "Self propelled floating power plants," *GİDB Dergi*, vol. 12, pp. 53–57, Jan. 2017.
[33] I. D. Jones, "Assessment and design of small scale hydroelectric power plants," Ph.D. thesis, Univ. Salford, Salford, U.K., 1988.
[34] I. Bajracharya, "Assessment of run-of-river hydropower potential and power supply planning in Nepal using hydro resources," M.S. thesis, 2015.
[35] H. J. Vermaak, K. Kusakana, and S. P. Koko, "Status of micro-hydrokinetic river technology in rural applications: A review of literature," *Renew. Sustain. Energy Rev.*, vol. 29, pp. 625–633, Jan. 2014.
[36] M. J. Khan, G. Bhuyan, M. T. Iqbal, and J. E. Quaicoe, "Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review," *Appl. Energy*, vol. 86, no. 10, pp. 1823–1835, Oct. 2009.
[37] B. Ho-Yan, "Design of a low head pico hydro turbine for rural electrification in Cameroon," Univ. Guelph, Guelph, ON, Canada, 2012.
[38] F. Ali, C. Srisuwan, K. Techato, and A. Bennui, "Assessment of small hydropower in Songkhla Lake basin, Thailand using GIS-MCDM," *Sustain. Water Resour. Manage.*, vol. 9, no. 1, p. 25, Feb. 2023.
[39] K. Kaygusuz, "Energy services and energy poverty for sustainable rural development," *Renew. Sustain. Energy Rev.*, vol. 15, no. 2, pp. 936–947, Feb. 2011.
[40] A. Rahman, O. Farrok, and M. M. Haque, "Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic," *Renew. Sustain. Energy Rev.*, vol. 161, Jun. 2022, Art. no. 112279.
[41] T. W. Karani, "Improved operations and reliability by upgrading Olkaria I control system and installing remote monitoring and control system for Olkaria I and II geothermal power plants in Kenya," M.S. thesis, Geothermal Training in Iceland, 2008.
[42] Z. Jia, B. Wang, S. Song, and Y. Fan, "Blue energy: Current technologies for sustainable power generation from water salinity gradient," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 91–100, Mar. 2014.
[43] G. Miller, D. Corren, P. Armstrong, and J. Franceschi, "A study of an axial-flow turbine for kinetic hydro power generation," *Energy*, vol. 12, no. 2, pp. 155–162, Feb. 1987.
[44] S. Xu, S. Wang, and C. G. Soares, "Review of mooring design for floating wave energy converters," *Renew. Sustain. Energy Rev.*, vol. 111, pp. 595–621, Sep. 2019.
[45] E. Alexander, J. Kingston, P. P. Da Silva, C. Inductivo, R. de Janeiro, and B. L. Lartey, "Resource assessment," in *Training in Alternative Energy Technologies Program*. Gainesville, FL, USA: Univ. of Florida.
[46] O. Farrok, K. Ahmed, A. D. Tahlil, M. M. Farah, M. R. Kiran, and M. R. Islam, "Electrical power generation from the oceanic wave for sustainable advancement in renewable energy technologies," *Sustainability*, vol. 12, no. 6, p. 2178, Mar. 2020.
[47] T. Paterova, M. Prauzek, J. Konecny, S. Ozana, P. Zmij, M. Stankus, D. Weise, and A. Pierer, "Environment-monitoring IoT devices powered by a TEG which converts thermal flux between air and near-surface soil into electrical energy," *Sensors*, vol. 21, no. 23, p. 8098, Dec. 2021.
[48] S. Y. Prasad, B. B. Chhetri, B. Adhikary, and D. Bista, "Microcontroller based intelligent DC/DC converter to track maximum power point for solar photovoltaic module," in *Proc. IEEE Conf. Innov. Technol. Efficient Reliable Electr. Supply*, Sep. 2010, pp. 94–101.
[49] G. K. Kumar and D. Elangovan, "Review on fault-diagnosis and fault-tolerance for DC–DC converters," *IET Power Electron.*, vol. 13, no. 1, pp. 1–13, Jan. 2020.

SAMANDAR KHAN AFRIDI was born in Nawabshah, Sindh, Pakistan, in 2002. He received the B.E. degree in electrical engineering from Quaid-e-Awam University, Nawabshah, and the Diploma degree in the IoT from the National Vocational and Technical Training Commission (NAVTTC), Karachi. He is a highly motivated and dedicated electrical engineer with a strong passion for innovation and emerging technologies. He has gained valuable practical experience through various internships, including with Habib Sugar Mills Ltd., and the 132kV Society Grid Station, Nawabshah. His commitment to pushing the boundaries of electrical engineering is evident in his final year research project, where he developed an innovative automatic and floating structured hydropower plant, utilizing advanced automation and IoT technology for sustainable power generation. He has a strong social and technical skills. He actively contributes to the field through his YouTube channel, where he shares informative videos on electrical engineering projects, the IoT, and programming. With his dedication to continuous learning and his desire to make a meaningful impact in industry, he is a valuable asset to any research team.

ABDUL SATTAR SAAND received the B.E. degree (Hons.) in electrical engineering from the Quaid-e-Awam University of Engineering, Sciences and Technology (QUEST), Nawabshah, Sindh, Pakistan, in 1999, the M.E. degree in communication systems and networks from the Mehran University of Engineering and Technology, Jamshoro (MUET), Sindh, in 2005, and the Ph.D. degree in electrical and electronic engineering from Universiti Teknologi PETRONAS (UTP), Perak, Malaysia, in January 2016. He started his carrier as a Lecturer with the NED University of Engineering and Technology Karachi, Sindh, from March 2000 to June 2001. He worked for more than eight years as a Senior Engineer Telecom (IP and multimedia broadband) with Pakistan Telecommunication Company Ltd., from June 2001 to July 2009. In July 2009, he joined QUEST Nawabshah, as an Assistant Professor, where he is currently a Professor and the HoD of Department. He is a conveyor and a member of various statutory and non-statutory bodies of the university. He has more than 20 years of professional and academic experience with national and international level. He is the author of a book chapter entitled *Beamforming for Relay Assisted MIMO* (IGI Global, USA, 2017). His research interests are MIMO technology, relay assisted MIMO technology, massive MIMO, massive MIMO underwater communications, maritime wireless broadband networks, using evaporation duct channel characteristics and MIMO OFDM based systems, and non-linear signal processing for MIMO networks. He was with various organizations at technical managerial level and is well trained nationally and internationally. He received many professional and academic awards.

ABDUL RAFAY KHATRI received the B.E. and P.G.D. degrees from MUET, the M.Sc. degree from Bremen, Germany, and the Ph.D. degree from the University of Kassel, Germany. He is an Associate Professor with the Department of Electronic Engineering, QUEST, Nawabshah, Pakistan. He has extensive experience in academia and research. He was an Assistant Professor and a Lecturer with QUEST; and a Research Assistant and a Ph.D. Researcher with the University of Kassel, Germany. He has taught various courses related to microprocessors, microcontrollers, automation, robotics, FPGA-based system design, control systems, digital electronics, microprocessor interfacing techniques, and digital signal processing. He has published several papers in renowned conferences and journals, showcasing his contributions to the field. His research interests include fault injection, testing, verification, dependability analysis of FPGA-based system design and applications, and the Internet of Things applications and development. His current research focuses on the Internet of Things and system development, particularly in the context of FPGA-based system design. He is a member of the Pakistan Engineering Council.

MOHSIN ALI KOONDHAR was born in Nawabshah, Sindh, Pakistan, in 1985. He received the B.E. and M.E. degrees from the Electrical Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology, in 2007 and 2016, respectively. He is currently a Lecturer with the Quaid-e-Awam University of Engineering, Science, and Technology. His research interests include the control of dc and ac machines, renewable energy, and programmable logic controllers. He has served as a Reviewer for *IET Generation, Transmission and Distribution IIUM Engineering Journal*, Malaysia.

WONSUK KO received the B.S. and M.S. degrees from Kyungwon University, Seongnam, South Korea, in 1996 and 1998, respectively, and the Ph.D. degree in electrical engineering from the University of Central Florida, Orlando, FL, USA, in 2007. He was a Researcher with the Gachon Energy Research Institute, Gachon University, South Korea, where he was also an Instructor with the Department of Electrical Engineering. He is currently an Associate Professor with the Department of Electrical Engineering, King Saud University, Riyadh, Saudi Arabia. His research interests include energy management, demand response, renewable energy, and smart grids.

SISAM PARK received the B.S., M.S., and Ph.D. degrees in civil engineering from Hongik University, Seoul, South Korea, in 1998, 2000, and 2004, respectively. Currently, he is a Principal Research Engineer with GS Engineering and Construction Corporation. His research interests include smart city, renewable energy, and energy management systems.

HYEONG-JIN CHOI received the B.S., M.S., and Ph.D. degrees in electrical engineering from Kwangwoon University. Since 2010, he has been a Researcher Engineer with the GS Engineering and Construction Institute, GS Engineering and Construction Corporation. His research interests include renewable energy conversion, energy storage systems, renewable energy, and switching converters.

WAQAS AHMED was born in Nawabshah, Sindh, Pakistan, in 2001. He received the B.E. degree in electrical engineering from Quaid-e-Awam University, Nawabshah. He is a highly motivated and dedicated electrical engineer with a strong passion for innovation and emerging technologies. His research interests are power systems, power electronics, and MATLAB programming.

• • •