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Development of Prototype Micro Hydropower System with Internet of Things (IoT) Feature

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Abstract: This project involved designing, creating, and testing a prototype micro hydropower system that incorporates Internet of Things (IoT) features, aiming to provide efficient energy generation and management. Recognizing an urgent need for reliable, energy-efficient and easily maintained micro hydropower solutions, this project sought to produce a system capable of yielding a maximum output capacity of 300W, ideal for powering remote communities, households, and small enterprises. The methodology included selecting suitable hardware and software components and integrating IoT technology for remote, real-time monitoring and control of the system. Rigorous testing was performed to verify the system's performance. The completed project resulted in a micro hydropower system demonstrating the expected maximum output capacity and effective compatibility with IoT for remote access, a clear indication of the potential of advanced technology in renewable energy. This project's success marks a significant step towards a future powered by sustainable and renewable energy alternatives, particularly demonstrating the potential of micro hydropower systems in off-grid locations. Furthermore, this project serves as an impetus for more research and implementation in renewable energy technologies, reinforcing the viability and impact of such systems in transforming energy generation and consumption.

Keywords: Micro Hydropower System, Internet of Things (IoT)

1. Introduction

This paper highlights the development of a prototype micro hydropower system integrated with IoT features. In rural areas without access to electricity, there is often a water source available, such as a waterfall or river [1]. However, extending the electrical grid to these areas can be expensive and environmentally challenging, often involving the construction of transmission lines and deforestation. To overcome these issues, the project suggests installing a renewable, off-grid power system that harnesses the available water source [2].

Micro hydro power systems offer a promising solution by generating electricity from a consistent flow of water without the need for large transmission infrastructure. Unlike solar power, which can be

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affected by seasonal variations, micro hydropower systems can provide more reliable and continuous electricity generation [3]. By converting potential energy into kinetic energy through a mechanical turbine, these systems drive a generator to produce electricity. The amount of electricity generated is directly proportional to the water flow rate [3]. Integrating IoT technology into micro hydropower systems provides several advantages. It enables real-time monitoring and control of the system, allowing for efficient management and optimization of power generation. IoT features can include remote monitoring of output and water flow, enabling proactive maintenance and promptly addressing operational issues [4]. Additionally, IoT integration contributes to environmental sustainability as micro hydropower systems produce fewer greenhouse gas emissions than conventional energy production methods [4].

The problem statement addresses critical issues that justify the project. Firstly, micro hydropower systems offer sustainability as a clean renewable energy source that produces no greenhouse gas emissions [4]. Secondly, they provide reliability by consistently generating electricity even when weather conditions are not ideal for other renewable energy sources such as solar or wind [3]. Thirdly, micro hydropower systems offer cost-effectiveness, with lower operating costs than other energy sources in the long run [3]. Fourthly, they provide a sense of independence by allowing households and communities to generate their electricity, reducing reliance on the grid [5]. Finally, micro hydropower systems can be versatile, meeting a range of power needs from single homes to small villages [2]. Project’s objective focus on the design, development, and validation of a prototype micro hydropower system with IoT features. These objectives include the creation of a working prototype with a maximum output capacity of 300W, the incorporation of IoT technology for real-time monitoring and control, and the validation of the system's effectiveness and performance.

The scope of the study encompasses multiple aspects, including the development of the micro hydropower prototype capable of generating at least 300W of power. Component electronics like the Arduino microcontroller and sensors will be developed from scratch. Implementing IoT capabilities will enable remote monitoring and control of the micro hydropower system through a web-based interface. Performance validation will ensure the proper functioning of the prototype and compliance with specified requirements. The design and development process of the prototype will be thoroughly documented, including any encountered challenges and the corresponding solutions. The ultimate measure of success for this project is developing a functional prototype micro hydropower system with IoT capabilities that meets all specified requirements.

2. Literature Review

Micro hydropower systems are an innovative and sustainable solution that harnesses the natural flow of water to generate electricity. These small-scale renewable energy systems, with a capacity of less than 100kW, offer numerous advantages in terms of environmental friendliness and energy production [6]. By utilizing the potential energy of flowing water, micro hydropower systems provide a clean and non-polluting source of electricity, without contributing to greenhouse gas emissions or other harmful environmental impacts [6]. One of the key aspects in evaluating the effectiveness of micro hydropower systems is their ability to convert the mechanical energy of water into electrical power. This conversion process is crucial in determining the overall efficiency and viability of these systems [7]. By calculating the output power from electrical power conversion, engineers and designers can assess the system's performance and ensure optimal energy generation.

Hydropower, including micro hydropower, holds significant promise as an alternative to traditional energy sources. It offers a range of benefits that contribute to a more sustainable and greener energy landscape. One of the major advantages of hydropower is its ability to significantly reduce the consumption of fossil fuels, such as oil and coal, which results in a substantial decrease in greenhouse gas emissions [8]. The reliance on hydropower can help combat climate change and mitigate the environmental impacts associated with traditional energy generation. Furthermore, hydropower is widely recognized as a clean and safe source of energy, making it a favorable choice in comparison to other forms of renewable energy [9]. Unlike fossil fuel-based power plants, hydropower systems do not produce air pollution or contribute to the release of harmful pollutants. Additionally, hydropower plants have long lifespans and require minimal maintenance, making them a reliable and sustainable energy option [9].

When considering the construction of micro hydropower systems in remote areas, several factors must be taken into account to ensure their sustainability. These factors include technical, economic, social, cultural, institutional, and environmental considerations [11]. From a technical perspective, proper design and operation are critical to achieving optimal performance and reliability. Additionally, environmental concerns, such as water outflow, natural disaster resilience, and land use conversion, should be carefully assessed and addressed to minimize any potential negative impacts on the surrounding ecosystem [11]. A fundamental component of micro hydropower systems is the Pelton turbine, which is widely used in these systems due to its effectiveness in converting water power into rotational force. The Pelton turbine is specifically designed to handle high-head applications, where there is a significant difference in water level, and low flow rates [12]. Its design consists of a runner, typically made of metal, with a series of cups or buckets attached. When a high-velocity water jet is directed at the turbine through a nozzle, the water strikes the cups or buckets, causing the runner to rotate. This rotational motion is then used to drive a generator and produce electricity [12].

The superiority of the Pelton turbine lies in its efficiency compared to previous impulse turbine designs. Before the invention of the Pelton turbine, other designs were not as effective, as they allowed water to leave the turbines at high speeds, carrying away a significant amount of energy. The Pelton turbine system overcomes this limitation by utilizing a water jet velocity that is twice the velocity of the buckets, maximizing power and efficiency [14]. Choosing the appropriate turbine is crucial for optimizing the overall efficiency of micro hydropower systems [15]. The Pelton turbine, with its ability to convert kinetic energy into mechanical energy, provides an efficient and reliable solution for micro hydropower applications. The turbine operates based on the principle of impulse forces, where energy flow is fully converted into kinetic energy before reaching the runner. The variation in flow velocity enables the transmission of impulse forces, ensuring an effective conversion of water power into rotational force [15].

The integration of IoT technology in micro hydropower systems offers advanced monitoring and control capabilities. Traditionally, remote monitoring and control of substation equipment required manual intervention or costly Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) systems. However, with the implementation of IoT technology, a smart monitoring and control system can be achieved, enabling remote access and improved efficiency in managing substation equipment. IoT involves connecting physical objects, such as sensors and actuators, to gather and exchange data, facilitating real-time monitoring and control. In the context of micro hydropower systems, IoT enables the use of microcontrollers like Arduino to collect and transmit data through the internet and cellular networks. This connectivity empowers users to remotely monitor the system, view real-time data, and take necessary actions as required. Furthermore, IoT technology offers a range of features designed to enhance life quality and safety, including image visualization, data analytics, and predictive maintenance.

Recent advancements in AI, machine learning, and IoT have transformed environmental monitoring into a smart environment monitoring (SEM) system, incorporating IoT, Wireless Sensor Networks (WSN), and sensors for precise monitoring and control of environmental parameters. Integrating IoT into micro hydropower systems offers benefits such as improved energy efficiency, reduced environmental impact, and better monitoring and control of hydropower dams for safety and reliability. IoT systems with wireless sensors provide accurate data on voltage, flow rate, current, and power generated, enabling real-time monitoring, remote interaction, and proactive response to emergencies. This ensures the smooth operation and protection of micro hydropower systems.

3. Methodology

The micro hydropower project comprises four phases. The first phase involves conducting research and literature review to understand the current state of micro hydropower systems and IoT technology integration. In the second phase, a working prototype of a 300W micro hydropower generator is designed and developed by selecting suitable hardware components and developing the generator circuit. The turbine part is obtained from the renewable energy laboratory. The third phase focuses on designing and developing an IoT mechanism and mobile apps for control and monitoring. This includes creating control algorithms and implementing them through programming. The final phase encompasses integrating the IoT devices with the micro hydropower system to enable real-time monitoring and control. Testing and validation are performed to ensure the system's output capacity, efficiency, stability, and control functions are optimized. Figure 1 shows the whole project workflow.

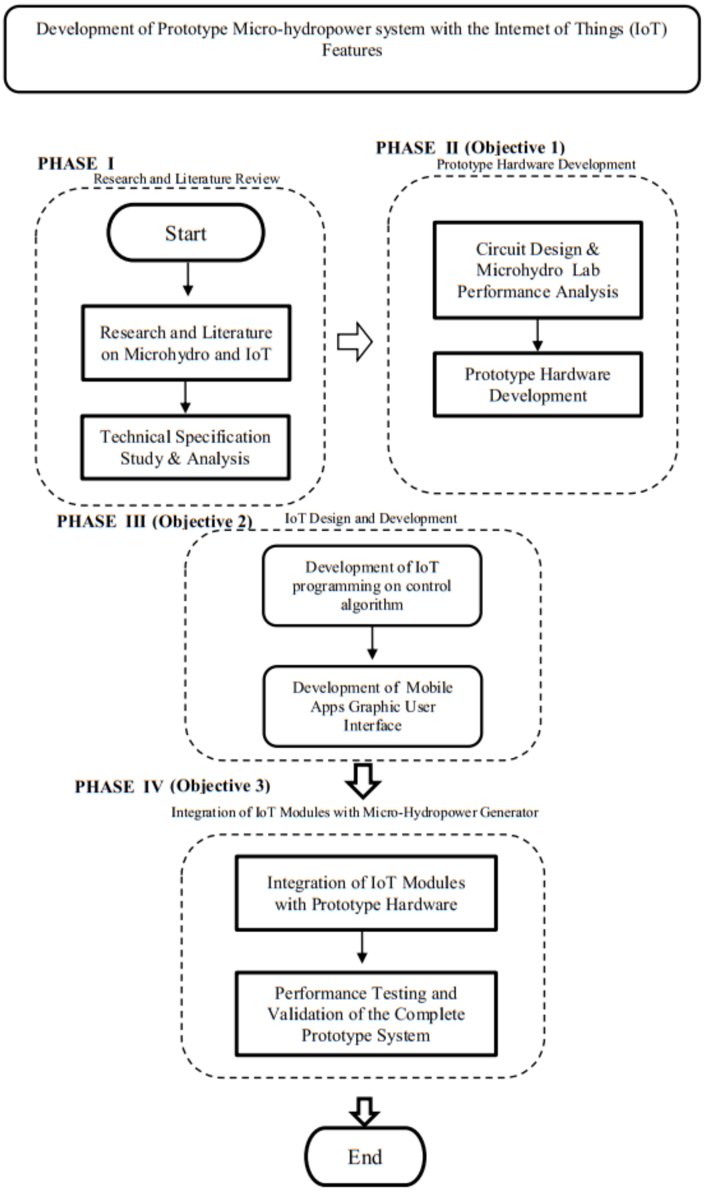


Figure 1: Project Workflow

The system's operational principle starts with water flowing through a Pelton turbine, which rotates and generates electricity. The turbine produces an AC voltage ranging from 100-220V AC, depending on the water flow rate. To ensure stable power output, an AC to DC converter is used to convert the turbine's AC voltage into a stable 24V DC output. Since the load operates on AC power, a 2000W inverter is employed to convert the 24V DC back to a stable 220V AC output suitable for powering the load. The output from the inverter is connected to a distribution box (DB) that contains various components such as circuit breakers to ensure safety and effective distribution of the AC power to connected devices. In terms of structural design, the hydro turbine is mounted on a sturdy metal stand for stability. A PVC pipe is strategically placed as the water outlet to minimize disruptions and ensure controlled water flow. A dedicated pipe holder facilitates the water inlet at the turbine, ensuring a consistent and uninterrupted water supply. Other components such as the voltmeter, converter, charge controller, inverter, distribution box (DB), and load are securely fastened onto a wooden board to minimize movement or damage during operation. . Figure 2 illustrates diagram of the project structural.

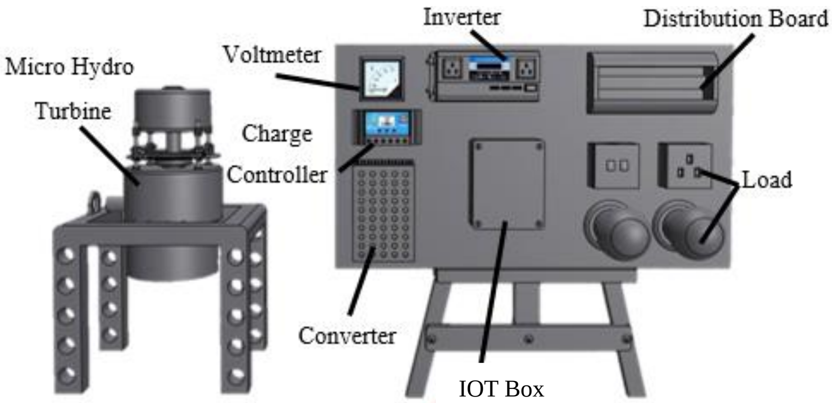


Figure 2: Structural Design of The Prototype

The hardware development involves designing and building the system, including the turbine, generator, inverter, and control and monitoring equipment. The selected hardware components are chosen based on their trade-off analysis and justification. For the microcontroller unit, the ESP32 is selected over the ESP8266 due to its robust features and capabilities, despite higher power consumption. The HOT Pelton turbine is selected for its compact design and technical specifications suitable for standalone micro hydropower systems. The AC to DC 24V power supply and the 24V DC to 220V AC inverter are chosen based on their voltage, power capacity, and application suitability. The monitoring system consists of an ESP32 module, AC voltage and current sensors, resistors, capacitors, and a load. Sensor data is collected and transmitted to a smartphone app called Blynk via the microcontroller. Blynk allows real-time access to data, enabling remote monitoring and control of the micro hydropower system. The system's behavior is defined by a software algorithm developed on the Blynk platform. Blynk provides a user-friendly interface with widgets to display sensor data and control the system. It shows voltage, current, and water flow rate data from the sensors.

4. Results and Discussion

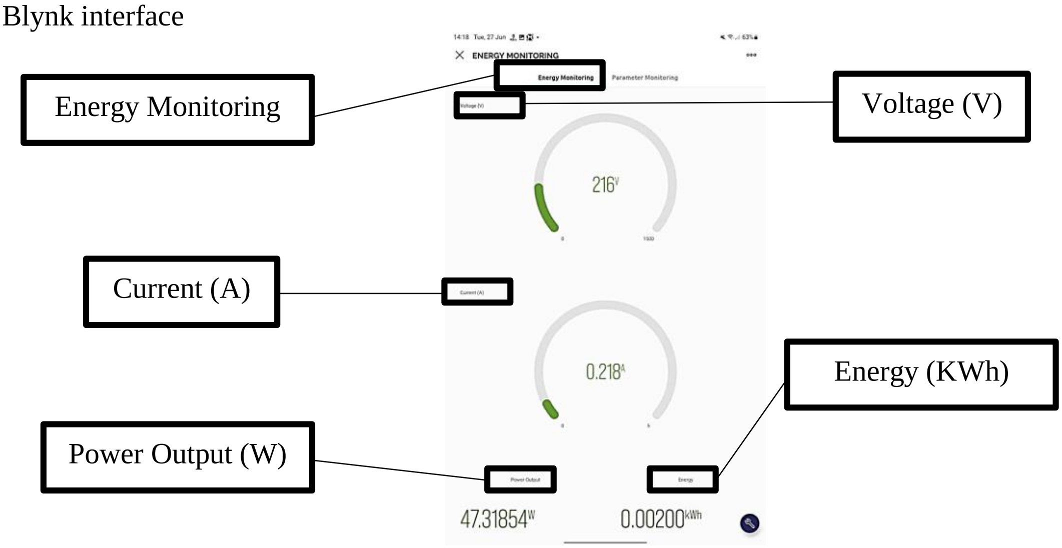
This section presents the results and discussions from implementing and testing the IoT-enabled Micro Hydropower System. It covers the hardware setup, including the turbine and ESP32, and the connection to the Blynk application on a smartphone. This section provides an analysis of collected data, calibration processes, and their implications for system performance. By examining the results, it aims to offer valuable insights and facilitate discussions on the system's effectiveness and potential improvements.

4.1 The integration data of IoT and Micro Hydropower System

The Blynk interface, operating on a client-server architecture, follows a defined algorithm for seamless communication and interaction between the user's device and the Blynk server. This algorithm includes essential steps that ensure the interface's functionality and effectiveness. Communication is established by connecting the micro hydropower system to the Blynk server using the Blynk library functions. Through this secure connection, real-time data exchange and remote monitoring and control capabilities are enabled. User interaction takes place through the Blynk app interface, allowing users to engage with widgets associated with current, voltage, and water flow rate. The app provides real-time updates and feedback from the micro hydropower system, enabling informed decision-making. The Blynk server acts as an intermediary for cloud interaction, ensuring reliable and private data transmission between the hardware and the app. The integration of IoT and micro hydropower systems has revolutionized energy generation, emphasizing the importance of data integration for monitoring and optimizing performance. To achieve this, the Blynk platform is utilized, along with three types of sensors: current transformer, voltage sensor, and water flow sensor. A comprehensive data collection process is established during testing, as presented in Table 1.

Table 1: Data Collection for Integration of IoT and Micro Hydropower System

Turbine Output	Voltage (V)	175 V AC
	Current (A)	0.221 A
Voltage after DB (V)		220 V AC
Water Flow Rate (L/min)		25L/min
Blynk interface		



The integration of IoT into the micro hydropower system demonstrated good performance, as evident from the closely matched data recorded in the Blynk application compared to the measurements obtained using a multimeter. This indicates the effectiveness of the system in accurately capturing and transmitting data.

4.2 Discussion and Data Collection for Micro Hydropower System

During the testing and development phase of the prototype, Tables 2 and 3 were utilized to collect various data aimed at optimizing the system's performance. Specifically, the data confirmed that the turbine output was in AC form. Following the successful connection of the turbine output to a rectifier, which converted 220V AC to 12V DC, further testing was conducted to evaluate the prototype's ability to generate stable 220V AC power. This involved incorporating an inverter into the system to convert the 12V DC output back to AC power. The testing process rigorously examined the inverter's performance and efficiency, ensuring its capability to deliver a reliable and consistent 220V AC output. Table 4 presents the data collected during the voltage conversion process using the rectifier and a 12V DC 350W inverter.

Table 2: Recorded testing data without pump

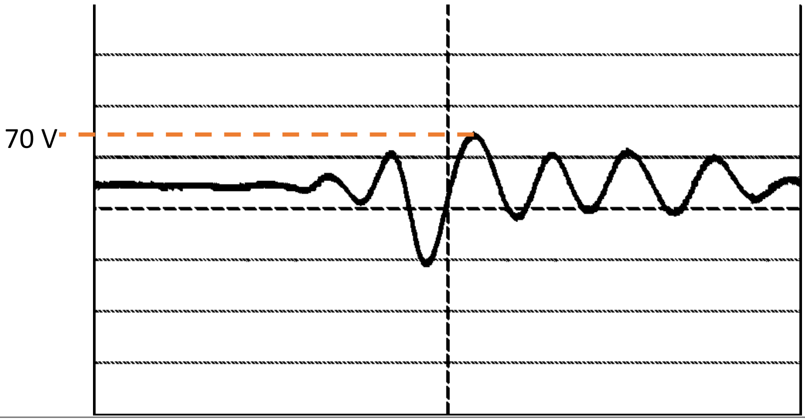
Connection	Direct to turbine output
Turbine Output Waveform	
Flow Rate (L/min)	10 L/min
Voltage (V)	70 V AC
Current (A)	0.087 A

Table 3: Recorded testing data with pump

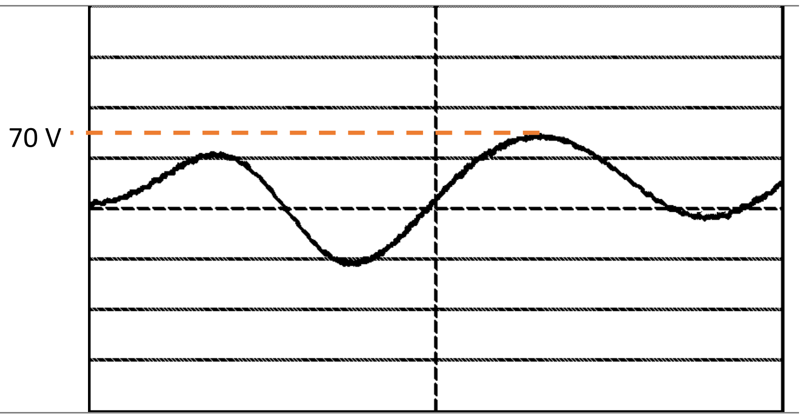
Connection	Direct to turbine output
Turbine Output Waveform	
Flow Rate	30 L/min
Voltage (V)	210 V AC
Current (A)	0.261 A

Table 4: Recorded testing data using rectifier and Inverter

		Rectifier	Inverter	Inverter Condition
Voltage (V)	Input	190 V ac	12.5 V dc	
	Output	12.5 V dc	223 V ac	OK
Voltage (A)	Input	371 V ac	25.6 V dc	
	Output	25.5 V dc	-	X

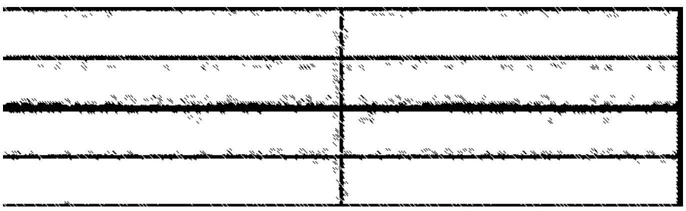
During testing, it was discovered that excessive water pressure caused an unexpected increase in voltage output from the turbine. This led to the rectifier receiving a voltage beyond its capacity, resulting in ineffective voltage regulation and an overvoltage condition at the inverter's input. The excessive voltage caused internal components to overheat and led to the inverter burning out. To prevent future incidents, alternative approaches were evaluated, including using an Automatic Voltage Regulator (AVR) or a higher specification inverter capable of handling 24V input. AC to DC converter was also considered for producing stable 24V DC. Recorded data in Table 5 and Table 6 show testing results with the higher specification inverter and the output waveform of the converter and inverter, respectively. Additionally, Table 7 presents recorded testing data using the AVR.

Table 5: Recorded testing data using converter and inverter.

		Converter AC – DC (100-240Vac) – (24Vdc)	Inverter DC – AC (12-24Vdc) – (220Vac)
Voltage (V)	Input	157V AC	24.1V AC
	Output	24.1V DC	220V AC
Current (A)	Input	0.2A	0.17A
	Output	0.17A	0.13A
Flow rate		25L/min	25L/min

Table 6: Output waveform of Converter and Inverter

Converter



Inverter

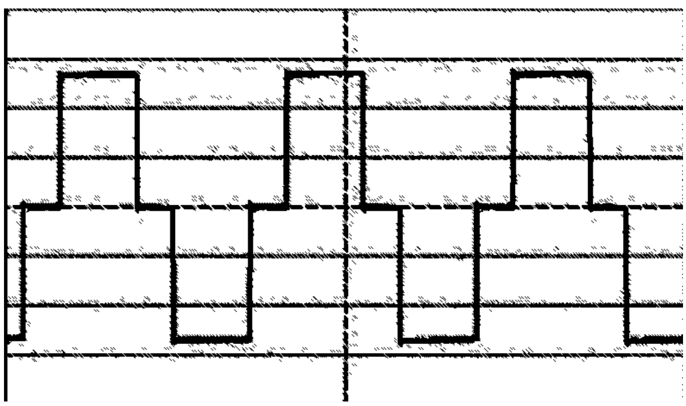
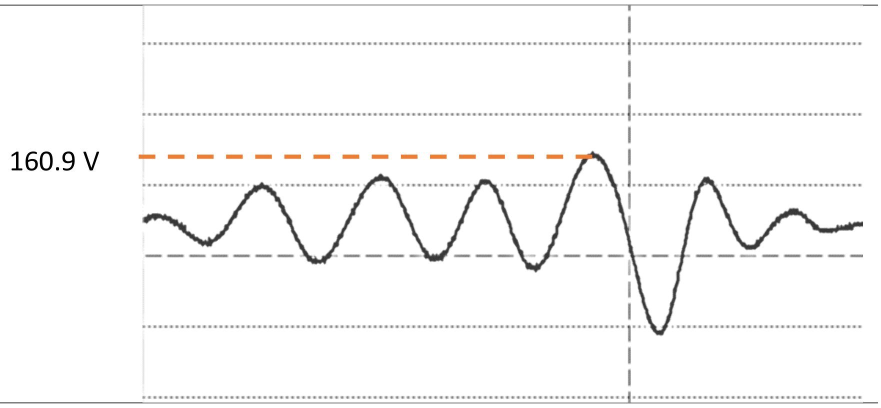


Table 7: Recorded testing data using AVR

Connection	**Direct to turbine output**
Output Waveform	

	
Flow Rate	23 L/min
Voltage (V)	160.9V AC
Current (A)	0.200 A

Based on the comprehensive evaluation and analysis of the collected data, it is recommended to utilize an inverter in conjunction with a converter for voltage regulation. The higher specification inverter proved its capability to handle a 24V input and effectively regulate voltage, providing a stable power supply to the connected system. By integrating an AC to DC converter, the system can produce a stable 24V DC output, further enhancing the stability and reliability of the power supply. The decision to opt for the inverter and converter solution was primarily driven by the unsuitability of the AVR, given the water flow rate limitations. The inability of the AVR to operate within the required voltage range raised concerns about its reliability and ability to consistently provide power to the system.

4.3 Complete Prototype Setup

The incorporation of IoT features into a micro hydropower system, offers numerous advantages for rural communities. One significant benefit is the enhanced efficiency and monitoring of energy generation processes, particularly in remote areas with limited access to conventional power grids. By integrating IoT technology into the hydropower system, it becomes possible to remotely supervise and control its operation. This capability is especially valuable in rural regions where physical access to the hydropower installation is challenging. Through IoT-enabled remote monitoring, real-time adjustments can be made to optimize energy production based on factors such as water flow rates, weather conditions, and energy demand. This results in more efficient energy generation, ensuring a stable and reliable power supply for the local community.

Furthermore, the utilization of IoT features allows for the gathering and analysis of data pertaining to the system's performance and energy output. This data can provide valuable insights into the efficiency and effectiveness of the hydropower system, enabling operators to identify opportunities for optimization and fine-tuning. By leveraging this data, rural communities can make informed decisions regarding energy usage, implement energy conservation measures, and potentially reduce operational expenses. Moreover, the remote monitoring capabilities offered by IoT technology facilitate early detection of any anomalies or issues within the system. This proactive approach to maintenance and troubleshooting helps prevent major disruptions and costly repairs. By promptly identifying and addressing potential problems, rural communities can ensure the continuous and reliable operation of their micro hydropower systems, thereby enhancing energy availability and minimizing downtime. Figure 3 shows the complete prototype setup with IoT feature.

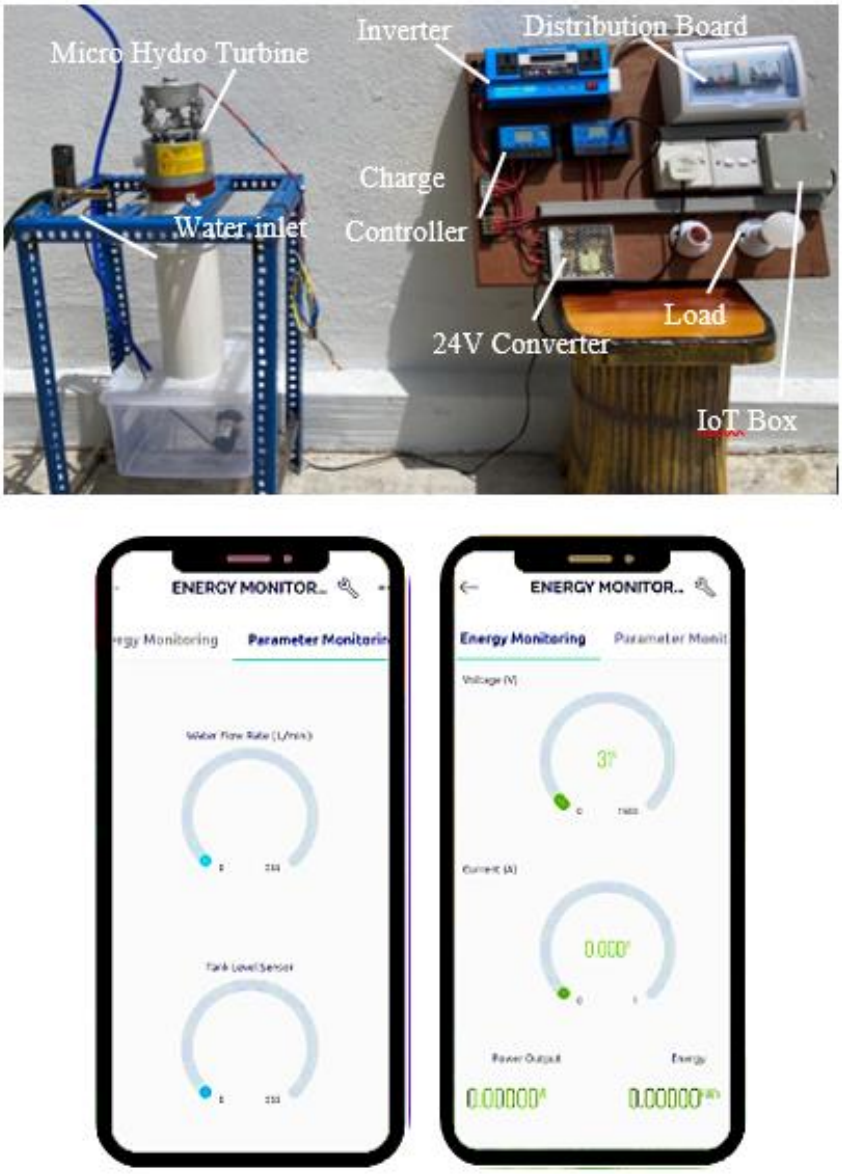


Figure 3: Complete Prototype Setup with IoT Feature

5. Conclusion

The objective of this project is to develop a prototype micro hydropower generator integrated with IoT capabilities, aiming to harness the energy of falling water for sustainable electricity generation on a small scale. The system incorporates an efficient HOT Pelton turbine that meets the required specifications and an inverter for converting the generated direct current into alternating current. Additionally, the system incorporates a smart monitoring system consisting of an Arduino microcontroller, a Wi-Fi module, sensors, and a smartphone application to enable remote monitoring and control.

In the initial phase of the project, careful selection and optimization of hardware and software components are undertaken to ensure optimal system performance and power output. The prototype micro hydropower generator with IoT features holds great potential for providing affordable, efficient, and sustainable electricity in remote or off-grid areas. Overall, this solution offers a promising approach to small-scale power generation that can be implemented in various settings, including residential, commercial, and remote locations where electricity availability is limited.

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