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Design and Development of a Marine Current Power Plant Using a Horizontal Axis Turbine of The Naca S814 Propeller

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Abstract. *The increasing demand for electrical energy and the limited availability of fossil fuels have driven the development of renewable energy sources, including marine current energy, which remains underutilized in coastal and remote maritime regions. This study presents the design and realization of a small-scale marine current power generation prototype using a horizontal axis propeller turbine with a NACA S814 blade profile and analyzes the effect of turbine rotational speed on electrical power output. The system converts marine current kinetic energy into mechanical energy through turbine rotation and subsequently into DC electrical energy using a generator, which is stabilized by a Buck–Boost Converter and Maximum Power Point Tracking (MPPT) for charging a 12 VDC battery. Real-time monitoring of electrical and mechanical parameters is implemented using an Internet of Things (IoT)–based system comprising an ESP32 microcontroller, a PZEM-017 sensor, and an RPM sensor. Experimental results demonstrate a positive correlation between water flow rate, turbine rotational speed, and generator output voltage. The system begins operating at a minimum flow rate of 35.2 L/s at 56 RPM, producing 0.2 V, while optimal performance is achieved at 45.3 L/s and 516 RPM, generating up to 13.3 V. These results indicate that the proposed prototype is a viable alternative renewable energy source for marine applications.*

Keywords: *12V DC Battery; DC Generator; Horizontal Axis Turbine; Marine Renewable Energy; Ocean Current Energy.*

1. INTRODUCTION

The Electricity constitutes a fundamental necessity for human activity; however, current energy consumption remains heavily focused on fossil fuels such as oil, natural gas, and coal (Adiputra, 2023). This unsustainable dependence has precipitated severe environmental consequences, including global warming, air and water pollution, and the degradation of natural habitats (Mesriana, 2024). Furthermore, the continuous exploitation of finite fossil fuel reserves has led to escalating costs and supply scarcity, creating significant uncertainty regarding the future security of global energy supplies (Dwisari et al., 2023). Consequently, there is an urgent imperative to innovate and transition toward renewable energy alternatives to mitigate reliance on fossil sources.

Various renewable energy sources are currently being explored to address these challenges, including solar, biomass, wind, hydroelectric, geothermal, and wave energy (Fitriani et al., 2024). For instance, recent innovations in the maritime sector have demonstrated the viability of green vessel concepts by integrating solar panels to provide sustainable onboard energy solutions (Atmadja et al., 2025). Among these options, marine current energy represents a highly optimal yet underutilized resource. In the Indonesian context specifically, marine current energy is recognized as a key sector within the new renewable energy framework (Al

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Hakim, 2020). Diversifying into this sector allows for a reduced dependency on traditional energy sources while leveraging the country's archipelagic geography.

Marine current energy offers distinct advantages over other renewable sources. It possesses substantial kinetic energy and demonstrates greater consistency compared to intermittent sources such as wind or solar power. Therefore, ocean currents are identified as a feasible and significant resource for the advancement of renewable energy infrastructures (Alamsah et al., 2025). This predictability makes marine currents a promising candidate for baseload power generation, which is critical for grid stability.

Previous studies substantiate the technical viability of this technology. For instance, current speeds in areas like Awerange Bay have been recorded at 0.25–0.36 m/s, suggesting suitability for tidal energy extraction using marine current turbines (Husain & Widianingrum, 2020). The application of turbines for mechanical energy conversion is further supported by research on the design and performance testing of NACA S814 propeller-type turbines intended for salt pond pumps (Agit Prakoso et al., 2022). These studies confirm that the NACA S814 profile is effective for hydrokinetic applications, though its specific application for electricity generation requires further exploration.

Despite this promise, the technological implementation of marine current energy remains suboptimal. Indonesia possesses a significant potential capacity of 17.9 GW—equivalent to approximately 53.3% of the Java-Bali grid capacity—yet actual utilization remains minimal (Riansyah, 2021). This substantial disparity between high potential and low realization indicates a lack of effective conversion systems ready for widespread deployment.

Based on this background, this study focuses on the design and construction of a marine current power generation system utilizing a horizontal axis propeller-type turbine with a NACA S814 blade profile. The study aims to design and develop a power generation system capable of converting the kinetic energy of marine currents into electrical energy, as well as to analyze the effect of turbine rotational speed on the electrical power output. Through the development of a functional prototype and performance analysis of the system, this study is expected to provide technical data on the relationship between turbine rotational speed and electrical power output, thereby serving as a basis for bridging the gap between Indonesia’s marine current energy potential and its practical utilization.

2. LITERATURE REVIEW

Marine Current Energy

Marine current energy is recognized as a vital component of Indonesia's new renewable energy sector (Al Hakim, 2020). Given the nation's vast maritime territory, which spans nearly 8 million km², there is an increasing focus on inventorying non- biological resources, with marine current potential identified as a key asset (Khair et al., 2021). This energy source

possesses immense capacity, particularly in geographic features such as straits and estuaries where currents are strong. Furthermore, marine currents are highly attractive for power generation development due to their inherent stability and predictable characteristics (Nurman et al., 2024). Theoretically, the extraction of kinetic energy from marine currents operates on principles similar to those utilized in wind power generation, allowing for analogous technological applications in the underwater environment (Alamsah et al., 2025).

Marine Current Power Plants

Marine current power plants are technological systems designed to utilize ocean currents as a primary energy source, employing a multi-stage process to convert this energy into electricity (Riansyah et al., 2022). The fundamental operational principle developed for this technology involves the conversion of the kinetic energy inherent in the seawater mass into electrical power (Prayoga & Permatasari, 2019). Specifically, the hydrodynamic force of the current drives a turbine, creating mechanical rotation that subsequently activates a generator to produce the required electric current and voltage (Makkulau et al., 2023).

In terms of mechanical design, the turbines employed in these systems are broadly categorized into two primary configurations: horizontal axis turbines and vertical axis turbines (Harrison et al., 2025.

Horizontal Axis Turbine of The NACA S814 Propeller Type

The NACA S814 propeller turbine is characterized by its operational versatility, designed to function effectively under low-head conditions while accommodating high water volumes, yet it retains the capacity to operate efficiently even during low-capacity periods (Susanto, 2025). Structurally, this propeller type typically features a configuration of three to six blades, bearing a morphological resemblance to aircraft propellers. This robust design allows the propeller to be utilized across a diverse range of water flow regimes.

Empirical application of this technology has been documented in recent studies. Research conducted by Agit Prakoso et al. (2022) utilized the NACA S814 propeller turbine within a marine current power plant system as the primary medium for hydrokinetic energy conversion. The results of this study were highly favorable, demonstrating that the NACA S814 profile possesses satisfactory capabilities for effectively converting the kinetic energy of marine currents into usable power.

ESP32 Microcontroler

The ESP32 serves as a versatile microcontroller designed to regulate a wide array of modules, sensors, and supporting hardware components such as relays (Bayu et al., 2021). A distinguishing technical feature of the ESP32 architecture is its integration of dual-mode Wi-Fi (Wireless Fidelity) and Bluetooth connectivity within a single board configuration, allowing for robust communication capabilities (Noerifanza, 2022).

A primary advantage of the ESP32 lies in these inherent wireless capabilities, which significantly streamline the development of Internet of Things (IoT) systems requiring wireless network infrastructure (Natasya & Santoso, 2023). This observation aligns with the assessment of Kusumo and Ardiansyah (2024), who state that the principal benefit of the ESP32 is its integration of Wi-Fi and Bluetooth modules, a feature that greatly facilitates the construction of wirelessly connected IoT architectures.

Monitoring and Control (IoT)

The modernization of power plants involves the integration of the Internet of Things (IoT) for real-time monitoring. The ESP32 microcontroller serves as the core of this system, offering built-in Wi-Fi and Bluetooth capabilities. It processes data from sensors and transmits it to a cloud server or mobile application.

PZEM-017 Sensor: This is a dedicated DC communication module used to measure voltage, current, power, and energy consumption. It communicates via the RS485 interface, known for its robustness against electrical noise, making it ideal for generator environments. Its high precision allows for accurate monitoring of the system's electrical yield.

Hall Effect Sensor: To monitor the turbine's performance, a Hall Effect sensor is employed to measure rotational speed (RPM). It detects the passage of magnetic poles attached to the rotor shaft, generating a pulse train that the ESP32 converts into an RPM reading. This data is critical for correlating physical flow conditions with electrical output.

Previous Studies

Evans et al. (2023) conducted sea trials on a small-scale tidal turbine and emphasized the importance of reliable test equipment to validate numerical models, demonstrating that small-scale testing is an effective and cost-effective initial step towards full-scale implementation. Husain and Widianingrum (2020) also examined the potential of ocean current energy in Awerange Bay and validated that the local current characteristics are adequate for electricity generation. In line with this research, Agit Prakoso et al. (2022) focused their study on the geometric specifications of hydro turbines, including blade length, angle, and cross-sectional area, to maximize ocean energy conversion.

3. RESEARCH METHODOLOGY

Research Design

This study utilizes a Research and Development (R&D) methodology. As defined by Sugiyono (2018), R&D is a research method used to produce a certain product and test the effectiveness of that product. The research proceeds through a structured lifecycle: identification of potential and problems, data collection, product design, design validation, prototype fabrication, performance testing, and analysis. The ultimate goal is to produce a validated prototype of an ocean current power plant that solves the specific problem of harnessing low-velocity currents efficiently.

System Architecture

The system is conceptualized as a linear energy conversion chain. The Input is the kinetic energy of the water flow. The Process involves the turbine (NACA S814) converting kinetic energy to mechanical rotation, which drives the DC Generator via a shaft. The electrical output is then processed by a Buck-Boost Converter to stabilize the voltage. An ESP32 microcontroller, interfaced with PZEM-017 and Hall Effect sensors, acts as the control and monitoring unit. The Output is the regulated electrical energy stored in a 12V DC Battery and the data stream displayed on a user interface.

Block Diagram Analysis

Figure 1 illustrates the system's block diagram. The process initiates with the rotation of the NACA S814 propeller-type water turbine, which is directly influenced by the velocity of the ocean current. This mechanical rotation is transmitted to the DC generator via a shaft coupling. The DC generator converts this mechanical energy into electrical energy based on the principle of electromotive force (EMF). However, due to variable turbine speeds, the generator's output is unstable. Consequently, a Buck-Boost Converter is employed to stabilize this output. Finally, the regulated power is stored in an accumulator (battery) to supply electrical loads, ranging from small-scale lighting to motor operation.

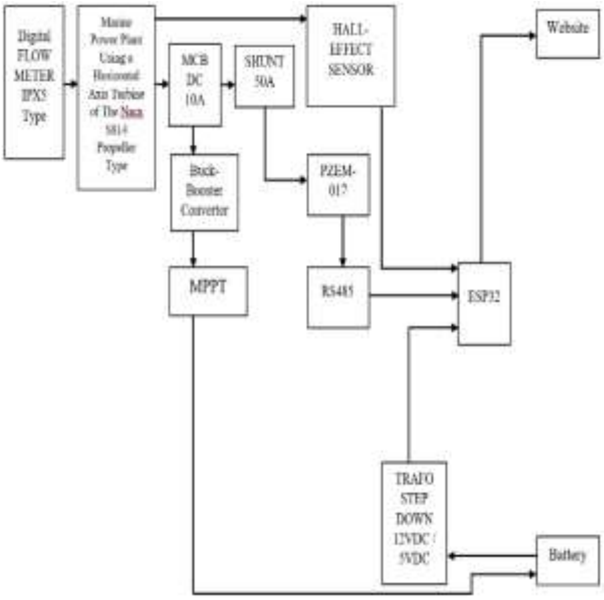

Figure 1. Block Diaram.

Operational Logic (Flow Chart)

Figure 2 depicts the operational flowchart of the prototype, focusing on the battery charging process. The electrical output from the generator is monitored by a PZEM-017 sensor, which reads voltage and current data processed by the ESP32 microcontroller. A specific set point is established (≤ 10V, 3A). If the sensor readings meet or exceed this set point, the system signals the relay to engage, allowing power to flow. Conversely, if the output falls below the threshold, the relay prevents power transmission, ensuring the battery is not subjected to insufficient charging conditions. Ultimately, the regulated power is directed towards battery storage.

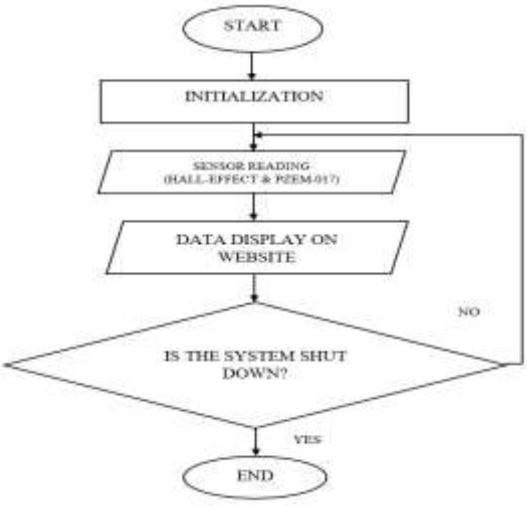

Figure 2. Operational Logic (Flow Chart).

Prototype Design and Fabrication

Turbine Design

Figure 3 (a) and (b) present the side and front views of the prototype design. The NACA S814 propeller turbine serves as the primary mechanical component, converting the kinetic energy of the current into mechanical energy to drive the DC generator's rotor shaft. The design specifications include a testing tank measuring 200 cm (length) x 50 cm (width) x 50 cm (height), resulting in a volume of 500,000 cm³. This volume is calculated to maximize the system's operational capability. As depicted in the design, the power generation unit is positioned centrally within the tank. This placement is strategic, intended to capture the maximum kinetic energy, as the current velocity is assessed to be strongest in the center of the testing channel.

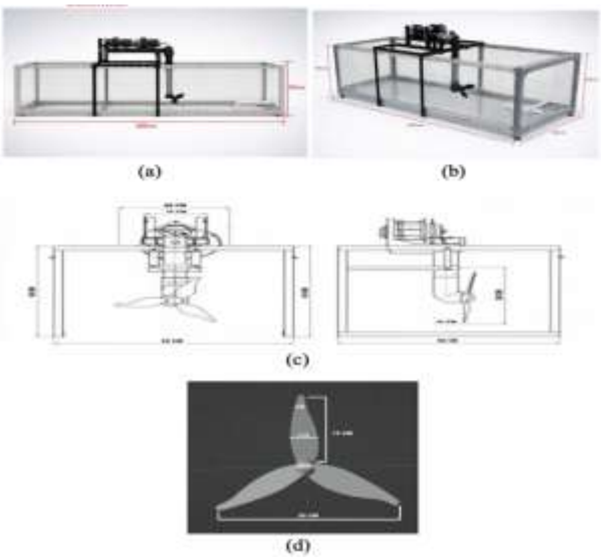

Figure 3. Turbine Designe.

Test Rig Setup:

The testing environment is a customized water channel measuring 200 cm in length, 50 cm in width, and 50 cm in height, creating a volume of 500,000 cm³. A water pump is used to circulate water and create a controllable current. The turbine is positioned in the center of the channel to maximize flow interception and avoid boundary layer effects from the tank walls. A digital flow meter is installed to measure the water discharge rate (L/s) accurately, serving as the primary independent variable in the experiments.

Wiring and Electronics:

The electrical system follows a defined wiring diagram. The generator output feeds into the Buck-Boost converter. The output of the converter passes through a shunt resistor associated with the PZEM-017 sensor before reaching the MPPT and battery. The ESP32 is powered by a separate step-down converter connected to the battery, ensuring the monitoring system remains active even when the turbine is not generating power. A relay module is included to manage load switching based on voltage setpoints to protect the battery and system components from deep discharge or overvoltage.

Testing Procedure

The testing plan is divided into two distinct phases to ensure component reliability before full system integration:

Dynamic Testing:

This phase tests the integrated system in the water channel under simulated operating conditions.

a. Minimum Testing (Cut-in Speed): Identifying the minimum flow rate required to overcome the static friction (stiction) of the generator and bearings to start the turbine rotation.
b. Maximum Testing: Increasing flow rate to determine the maximum power output and identify the structural or electrical limits of the turbine system.
c. Range Testing: Operating the system across the effective working range to plot the performance curves (Flow vs. RPM vs. Voltage).

Duration: Each test run lasts for 30 minutes, with data logged every 3 minutes to ensure thermal stability and data consistency.

4. RESULTS AND DISCUSSION

Dynamic Testing Results

Dynamic testing evaluated the system's performance under actual water flow conditions. The results are categorized into minimum, maximum, and operational range performance.

4.1.1 Minimum Performance (Cut-in Speed)

The system was tested by gradually increasing the water discharge rate from 20.4 L/s.

a. Observation: Below 35.0 L/s, the turbine remained stationary. This indicates that the hydrodynamic torque generated by the NACA S814 blades was insufficient to overcome the cogging torque of the generator and the friction of the bearings.
b. Cut-in Point: At a discharge rate of 35.2 L/s, the turbine began to rotate, achieving 56 RPM and generating 0.2 V. This establishes the system's cut-in threshold. While 0.2V is insufficient for charging, it marks the transition from static to dynamic operation.

Table 1. Minimum Testing Data.

No	Water Debit (L/s)	RPM	Voltage (V)	Time (Min)
1	20.4	0	0	3
2	23.5	0	0	6
3	27.1	0	0	9
4	30.7	0	0	12
5	31.2	0	0	15
6	33.1	0	0	18
7	33.8	0	0	21
8	34.5	0	0	24
9	35.0	0	0	27
10	35.2	56	0.2	30

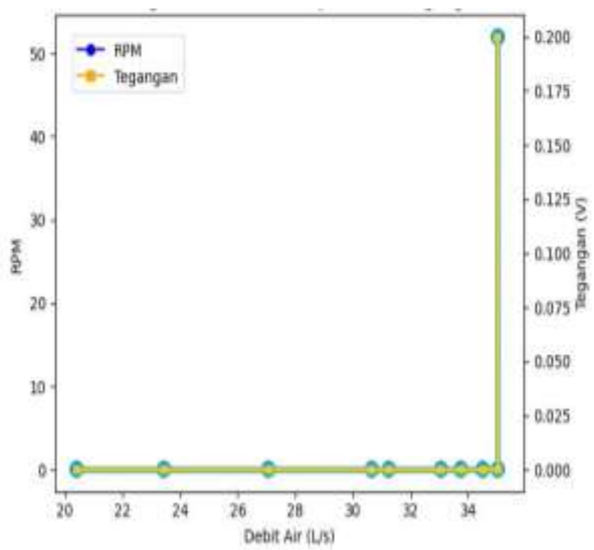

Figure 4. Minimum Test Graph.

Maximum Performance

The flow rate was increased to test the upper limits of the prototype.

a. Observation: Performance increased linearly with flow. At 40.0 L/s, the turbine reached 372 RPM (7.9 V).

b. Peak Performance: The system operated optimally at 45.3 L/s, achieving 516 RPM and generating 13.3 V. This voltage is ideal for charging a 12V lead-acid battery.

c. System Failure: At the highest tested flow settings, the turbine speed reached 554 RPM (14.2 V). At this point, the data reading for debit became unstable, and the text notes that the system experienced a structural failure where the turbine surface broke. This indicates the mechanical limit of the printed NACA S814 prototype had been reached.

Table 2. Maximum Testing Data.

No	Water Debit (L/s)	RPM	Voltage (V)	Time (Min)
1	40.0	372	7.9	3
2	40.7	379	8.6	6
3	41.0	387	9.3	9
4	41.4	394	9.0	12
5	42.1	400	9.4	15
6	42.8	419	11.0	18
7	43.1	470	11.3	21
8	44.7	506	12.8	24
9	45.3	516	13.3	27
10	-	554	14.2	30

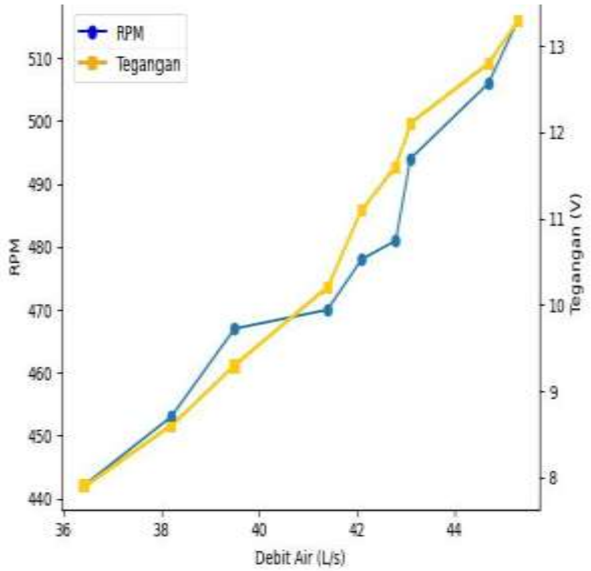

Figure 5. Maximum Test Graph.

Operational Range Analysis

The operational range represents the stable working conditions between cut-in and maximum/failure speeds.

Table 4. Operational Range Testing Data.

No	Water Debit (L/s)	RPM	Voltage (V)	Time (Min)
1	35.2	56	0.2	3
2	37.1	115	3.4	6
3	38.9	255	5.6	9
4	39.0	317	7.1	12
5	41.6	398	9.4	15
6	42.7	419	11.0	18
7	43.4	475	11.3	21
8	44.2	496	12.0	24
9	44.9	506	12.8	27
10	45.3	516	13.3	30

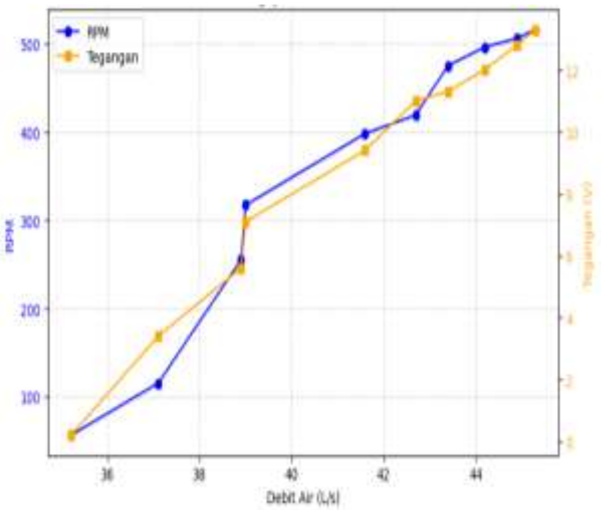

Figure 6. Working Range Test Graph.

Discussion

The results confirm the fundamental physics of hydrokinetic energy conversion as described by Equation 2.1; power output increases significantly with fluid velocity (represented here by discharge rate). The linear correlation between flow rate, RPM, and voltage confirms the stability of the HAT design within its operating envelope.

Hydrodynamic Performance: The NACA S814 profile demonstrated effective lift generation at low speeds, allowing the turbine to self-start at 35.2 L/s. This aligns with findings by Susanto (2025) and Agit Prakoso (2022), who advocated for this profile in low-head or low-velocity applications. However, the mechanical failure at 554 RPM suggests that while the *aerodynamic* design is sound, the *material selection* or *structural infill* (likely 3D printed plastic for the prototype) requires reinforcement to withstand the high torque and drag forces of water, which is far denser than air. The structural failure serves as a crucial data point for future material selection, pointing towards the need for composites like carbon fiber or reinforced nylon.

Electrical System Integration: The integration of the Buck-Boost converter proved critical. As shown in the data, the generator produces effective charging voltages (>12V) only above ~500 RPM. However, the converter's ability to step up lower voltages (e.g., boosting 7.9V at 372 RPM) potentially expands the usable energy harvesting window, although the current would be proportionally lower. The IoT system provided reliable real-time data, enabling the precise identification of the cut-in and failure points, which is a significant advantage over traditional analog logging methods. The voltage readings from the ESP32 system matched the manual measurements, proving the viability of this low-cost monitoring solution for remote marine applications.

5. CONCLUSION AND RECOMENDATIONS

Conclusion

Based This research successfully designed, developed, and characterized a small-scale ocean current power plant prototype utilizing a Horizontal Axis Turbine with a NACA S814 profile. The study yields the following conclusions: (1) Feasibility: The prototype successfully converts low-velocity water flow into electrical energy. The integration of the turbine with a DC generator and Buck-Boost converter creates a viable energy harvesting system for maritime environments. (2) Performance Characteristics: Cut-in Threshold: The system requires a minimum water discharge of 35.2 L/s to overcome mechanical inertia, resulting in 56 RPM and 0.2 V output. Optimal Operation: The system achieves peak stability and charging capability at 45.3 L/s, producing 13.3 V at 516 RPM. This confirms that the energy extraction scales effectively with current velocity. Correlation: There is a verified direct positive correlation between water discharge, turbine RPM, and output voltage. (3) Monitoring: The ESP32-based IoT monitoring system, coupled with the PZEM-017 sensor, demonstrated high accuracy (~99%) and reliability in tracking system performance parameters in real-time, providing essential data for performance analysis and remote management.

Recommendations

To enhance the performance and durability of future iterations of this technology, the following recommendations are proposed:

Material Optimization: Transition from standard prototyping materials to high-strength composites such as carbon fiber or reinforced fiberglass for the turbine blades. This will reduce inertia for easier starting and prevent structural failure at high rotational speeds

Field Testing: Move beyond the controlled water channel to field tests in actual maritime environments using floating platforms. This will expose the system to real-world variables such as turbulence, salinity, and biofouling, providing data on long-term durability.

Advanced Control: Implement active pitch control for the turbine blades to mechanically regulate speed during high-flow events, thereby protecting the generator and structure without relying solely on electrical braking or structural failure.

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