PLTB Performance Monitoring and 1-Phase Motor Damage Detection on *Sewage Pumps* on Ships with Current and Vibration Analysis

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Abstract— Sewage pumps are critical auxiliary machinery in ships, where sudden failures can lead to severe operational disruptions, costly maintenance, and hazardous environmental compliance issues on board marine vessels. To mitigate these unexpected breakdowns, this study aims to develop an intelligent, real-time performance monitoring and damage detection system specifically designed for 1-phase induction motors driving ship sewage pumps. The proposed method utilizes a synchronized framework combining Motor Current Signature Analysis (MCSA) and multi-axis vibration spectrum tracking, which is seamlessly integrated with a localized Wind Power Plant (PLTB) telemetry and power monitoring system. This dual-parameter sensing approach captures both mechanical anomalies, such as bearing wear, and electrical degradation, including stator winding faults. All sensor data are processed via an embedded microcontroller and transmitted wirelessly to a dedicated monitoring interface. The system architectures were physically prototyped and evaluated under simulated marine operational load profiles. The experimental results demonstrate that the integrated monitoring system successfully isolates localized noise from structural ship vibrations, accurately identifying mechanical and electrical anomalies with a high detection efficiency of 92.5%. Ultimately, this research provides a comprehensive and scalable predictive maintenance solution, contributing a robust framework for improving the energy reliability, clean energy utilization, and operational safety of auxiliary machinery networks within the modern marine engineering sector

Keywords—Sewage pumps, Motor Current Signature Analysis (MCSA), Wind Power Plant (PLTB).

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I. INTRODUCTION

The global maritime sector is currently facing significant regulatory and ecological pressure to transition to more sustainable energy sources in order to reduce greenhouse gas emissions. In the shipping environment, one manifestation of this transition is the use of Wind Power Plants (PLTB) integrated into ship structures as a solution to optimize the renewable energy mix. However, the implementation of PLTB on board faces the characteristics of a highly harsh and dynamic marine environment. Fluctuating strong winds, high waves, high salinity, and continuous exposure to corrosion are major challenges that threaten the mechanical reliability and electrical stability of the power generation system [26]. Therefore, the integration of onboard wind turbines requires specific aerodynamic geometry and adaptive control systems to ensure optimal energy conversion efficiency under volatile marine weather conditions [23]. On the other hand, the operational stability of a ship is highly dependent on the reliability of its electrical systems and auxiliary drive motors. Single-phase electric motors, such as those used in ship sewage pumps, play a crucial role in maintaining sanitation and compliance with international maritime environmental regulations. However, a critical problem frequently encountered in ship operations is the sudden breakdown failure of these sewage pump motors. Such unexpected failures not only trigger expensive operational downtime but also risk severe environmental contamination and threaten the hygiene safety of the crew [25]. This issue is further compounded by a secondary problem: maritime auxiliary motor maintenance is still heavily dominated by time-based corrective or preventive methods, which fail to detect unexpected catastrophic failures in real time.

To address these limitations, implementing predictive maintenance based on Condition-Based Monitoring (CBM) is an urgent necessity. Early detection of mechanical anomalies can be achieved by utilizing piezoelectric sensors to capture vibration signatures due to bearing wear, shaft imbalance, or misalignment [24]. To strengthen diagnostic accuracy, these mechanical parameters must be correlated with electrical parameters through the Motor Current Signature Analysis (MCSA) method to identify stator winding disorders and load fluctuations [20]. The integration of an ESP32 microcontroller-based Internet of Things (IoT) architecture and data communication protocols for real-time visualization via Node-RED offers a viable

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approach to managing energy efficiency and predictive maintenance data on ships [21]**.**

Research Gap and Problem Formulation

The development of wind turbine control systems and electric motor maintenance techniques have been extensively studied separately by previous researchers. Research by [26]focuses on the structural resilience of offshore power plants to extreme wind loads but does not link energy utilization directly to the load of ship auxiliary motors**.** [22] investigated adaptive control algorithms on onshore turbines adapted to the sea, but their implementation remains limited to large-scale modeling and lacks a compact design tailored for a limited ship deck area. In the realm of machine maintenance, [25] and [24] proved the effectiveness of piezoelectric sensors in detecting mechanical degradation, but their experiments were conducted in stable terrestrial environments with constant grid supplies. Non-invasive current analysis using MCSA techniques has also been validated by [20], but without testing the effects of supply voltage fluctuations coming from local, intermittent maritime renewable energy sources. Lastly, while [21] proposed a maritime platform for green energy monitoring, the physical implementation of concurrent multi-sensor readings (current, vibration, temperature, voltage) on a compact prototype remains largely unexplored. Consequently, a significant research gap persists: there is a lack of an integrated system that combines a micro-renewable energy generation unit with a multi-sensor health monitoring system for critical ship auxiliary loads within a single data acquisition platform.

Research Novelty and Objectives

To bridge this gap, this paper introduces a distinct research novelty by developing an integrated, dual-functional IoT platform that simultaneously optimizes local micro-generation and executes comprehensive predictive maintenance for maritime applications. Specifically, the novelty lies in the synchronization of an Archimedes Spiral Wind Turbine selected for its omnidirectional aerodynamic efficiency on confined ship decks with a multi-sensor monitoring framework (capturing current, voltage, vibration, and temperature) to safeguard a 1-phase sewage pump motor against fluctuations driven by renewable power supplies.

Based on this novelty, this research specifically aims to fulfill three main objectives:

1. To design, test, and implement a prototype of a PLTB system utilizing an Archimedes wind turbine mechanism engineered to remain robust and adaptive under simulated extreme maritime weather conditions.
2. To construct a reliable data acquisition and monitoring architecture using an ESP32 microcontroller and Node-RED platform to record PLTB power output alongside the real-time current, voltage, vibration, and temperature characteristics of the 1-phase sewage pump motor via an IoT network.
3. To comprehensively analyze the operational effectiveness of integrating the micro-PLTB unit with the multi-sensor load monitoring system, thereby proving the dual optimization of clean energy utilization and auxiliary machinery reliability.

Through these achievements, this research contributes a novel framework to maritime renewable energy literature and delivers a practical, scalable CBM prototype ready for actual shipboard operational deployment.

II. LITERATURE REVIEW

2.1. Wind Power Plant (PLTB) Integration in Marine Auxiliaries

The integration of renewable energy sources, particularly Wind Power Plants (Pembangkit Listrik Tenaga Bayu - PLTB), into ship power systems has gained significant traction due to stringent maritime carbon emission regulations [1]. Modern marine engineering heavily focuses on utilizing localized micro-wind turbines to supply auxiliary power grids on board [2]. However, wind energy is inherently stochastic, presenting highly fluctuating power profiles that depend on unpredictable maritime weather conditions [3]. Continuous telemetry and performance monitoring are crucial to evaluating the efficiency of these clean energy systems and ensuring that the electrical output is stable enough to feed critical ship auxiliary machinery, such as pumping networks [4].

2.2. Motor Current Signature Analysis (MCSA) for 1-Phase Induction Motors

Single-phase induction motors are widely utilized on board ships to drive non-propulsion auxiliary systems, including sewage and bilge pumps, owing to their robust structure and cost-effectiveness [5]. Despite their reliability, these motors are susceptible to electrical degradations, such as stator winding inter-turn short circuits and insulation aging, exacerbated by the harsh, humid, and saline marine environment [6]. Motor Current Signature Analysis (MCSA) has emerged as a non-invasive, highly effective diagnostic tool for monitoring these electrical anomalies [7]. Analyzing the frequency spectrum of the stator current, specific fault-related sideband frequencies can be isolated from the fundamental supply frequency, allowing early detection of electrical defects before catastrophic motor failure occurs [8], [9].

2.3. Vibration Spectrum Analysis in Marine Pumping Systems

In addition to electrical faults, marine sewage pumps are subjected to severe mechanical stresses, including bearing wear, shaft misalignment, and impeller cavitation [10]. Vibration spectrum analysis is the gold standard for diagnosing these mechanical anomalies [11]. In a shipboard environment, isolating pump-specific defects is challenging due to background structural noises generated by the main propulsion engines and auxiliary diesel generators [12]. Advanced multi-axis vibration tracking utilizes fast Fourier transform (FFT) algorithms to extract high-frequency mechanical signatures, mapping specific acceleration peaks to localized bearing or rotor defects [13], [14].

2.4. Integrated Dual-Parameter Monitoring Frameworks

Recent advancements in predictive maintenance emphasize the transition from single-parameter diagnostics to multi-parameter sensor fusion frameworks [15]. Relying solely on either MCSA or vibration analysis often leads to false-positive alarms in marine systems due to the overlapping symptoms of electrical fluctuations and mechanical shocks [16]. Integrating electrical current telemetry with mechanical vibration tracking provides a comprehensive dual-parameter diagnostic matrix [17]. When this synchronized matrix is coupled with real-time wireless IoT telemetry, it enables the ship's crew to continuously evaluate the health of auxiliary machinery alongside renewable energy performance, significantly enhancing the ship's overall operational safety and energy reliability [18], [19].

III. METHOD

This research method is designed through an experimental approach to engineering design-based laboratories. The main focus of the study was to test the performance of the integration of a wind-based energy generation system with a predictive maintenance system on a 1-phase induction motor for *a ship* sewage pump.

3.1. Variables Studied

a. Archimedes Spiral Wind Turbine (ASWT) for Maritime Applications

Conventional horizontal-axis wind turbines (HAWTs) often exhibit low aerodynamic efficiency and structural vulnerability when deployed within the turbulent and confined spaces of ship decks. To mitigate these limitations, recent maritime energy research has pivoted toward alternative aerodynamic geometries, most notably the Archimedes Spiral Wind Turbine (ASWT). Based on the mathematical principles of the Archimedes screw, the ASWT features a unique multi-bladed spiral configuration that allows it to operate as an omnidirectional drag-and-lift hybrid generation unit [26] Unlike conventional turbines that require complex yaw control systems to face changing wind vectors, the ASWT inherently captures wind kinetic energy from any direction. Furthermore, its mechanical framework provides a high torque-generation ratio at low-to-medium wind speeds (3-8 m/s), which are typical operational conditions on coastal and commercial shipping routes [22]**.** The structural compact nature of the ASWT minimizes the physical footprint required on a ship's limited deck space, while its low vibrational signature safeguards auxiliary vessel structures from secondary mechanical fatigue.

b. Predictive Maintenance and Condition-Based Monitoring (CBM) Frameworks

Auxiliary machinery on ships, particularly fluid-handling systems, has traditionally relied on time-based preventive or reactive corrective maintenance schedules. However, these conventional paradigms are highly inefficient, often resulting in either unnecessary operational downtime or catastrophic unpredicted failures at sea [25]. Modern industrial maritime operations increasingly demand the transition toward predictive maintenance utilizing Condition-Based Monitoring (CBM).

CBM operates on the principle of continuous, non-destructive data acquisition to track the actual health status of a machine in real time. By converting physical phenomena such as structural kinetic displacement, thermal dissipation, and electrical flux into quantifiable digital signals, CBM enables the identification of early-stage degradation markers long before a functional asset reaches total physical failure [24]. Implementing a robust CBM framework on critical ship components reduces maintenance overheads, prolongs machinery lifespans, and fundamentally enhances overall maritime operational safety.

c. Motor Current Signature Analysis (MCSA) and Vibration Analysis

To ensure high diagnostic accuracy within a CBM framework, multi-parametric fault detection protocols must be established. For single-phase induction motors driving critical auxiliary components like sewage pumps, the integration of Motor Current Signature Analysis (MCSA) and vibrational analysis provides a comprehensive diagnostic coverage:

- Motor Current Signature Analysis (MCSA): MCSA functions by isolating and analyzing the frequency spectrum of the stator current, typically measured using non-invasive current transducers (such as the ACS712 sensor). Under normal operating conditions, the current waveform exhibits a clean, symmetrical fundamental frequency (50 Hz or 60 Hz). When electrical or mechanical anomalies occur such as stator short-circuits, broken rotor bars, or severe load fluctuations sideband harmonic frequencies appear around the fundamental peak. Monitoring these current signatures allows for the early diagnosis of electrical insulation breakdown and magnetic asymmetry [20].
- Vibration Analysis: While MCSA excels at electrical diagnostics, mechanical degradation is best captured via vibration tracking. Utilizing high-sensitivity piezoelectric sensors mounted directly onto the motor bearing housing allows the system to capture real-time mechanical acceleration and amplitude signatures. An increase in structural vibration energy directly correlates with physical

defects, including bearing wear, shaft misalignment, and dynamic rotor imbalance [24]

d. IoT-Driven Data Acquisition via ESP32 and Node-RED

The practical viability of an onboard CBM and micro-generation platform depends on its local computational processing and real-time visualization capabilities. The Internet of Things (IoT) architecture offers a decentralized solution to bridge physical sensors with remote human-machine interfaces (HMIs). In this research, the ESP32 microcontroller acts as the core edge-computing node. Featuring dual-core processing units and built-in Wi-Fi/Bluetooth modules, the ESP32 concurrently executes analog-to-digital conversions (ADC) for multi-sensor arrays, including ACS712 current sensors, piezoelectric vibration modules, ZMPT101B AC voltage sensors, and J-type thermocouples.

To process and visualize the localized data packets transmitted via communication protocols (such as MQTT or HTTP), Node-RED is implemented as an agile middleware platform. Node-RED facilitates the programmatic routing of multi-sensor data streams, enabling the central system to chart real-time historical graphs, set trigger thresholds for automated electrical protection, and log performance metrics of both the ASWT generation unit and the auxiliary sewage pump motor simultaneously [21].

3.2. Data Collection Techniques

Data collection is carried out through two stages of structured testing to ensure the functional validity of electrical and mechanical components:

a. Static Testing (Partial Per Component): This test is performed on each component in isolation before being assembled into a single system, to ensure that there are no technical obstacles or built-in damages. Details of the static testing procedure include:

1. Piezoelectric Sensor: Given VCC power supply from the ESP32 microcontroller. The test is declared successful if the sensor is able to detect physical vibrations in the test material responsively.
2. ACS712 Current Sensor: Connected to the ESP32 via VCC, GND, and ADC output pins. The sensor input terminals are mounted series with a load (light-weighted roll cables/electronic devices). The test is successful if the sensor displays a stable change in current value on the *serial monitor* or *dashboard* when the load is off and on without any random readings (*noise*).
3. ZMPT101B Voltage Sensor: Connected to the ESP32 (VCC, GND, output signal) and mounted parallel to the test roll cable. The test is successful if the sensor is able to display the AC voltage value accurately, stably, and without interference.
4. ESP32 Microcontroller: Powered via a USB connection from a laptop/computer. The test is successful if the power indicator light is on and the process of uploading code (*flashing code*) through the IDE runs smoothly.
5. 20x4 I2C LCD: Connected to the ESP32 via an I2C communication line. The test is successful if the screen is able to display string/word characters clearly according to the program's instructions.
6. 12V DC to 220V AC Battery & Inverter Charger Module: The charger module is tested for its ability to deliver charging current to the battery. Meanwhile, the inverter is tested with a 12V DC power input to ensure its ability to generate a stable output voltage of 220V AC as a power supplier of 1-phase induction motors.
7. Phase Induction Motor (*Sewage Pump*): Powered by 220V AC from the inverter. The test is successful if the rotor can rotate smoothly without abnormal *noise*.
8. Type J Thermocouple Temperature Sensor: Powered from ESP32 and attached to the induction motor body. The test is successful if the sensor is able to accurately detect and convert changes in motor temperature.
9. Dynamic Testing (Integrated System): Dynamic testing is carried out by integrating all components that have passed the static test into a whole system. Data is continuously retrieved to see how the tool is performing as it operates in *real-time*.

3.3 Sampling Techniques and Research Locations

1. Sampling Technique: The technique used is *purposive sampling* based on variations in physical
2. parameters. Samples of electrical data (current, voltage, charging power) were taken based on variations in wind speed simulations on the wheels. Meanwhile, mechanical and thermal data samples (vibration, temperature, motor current) were taken based on the operational duration of the *sewage pump* motor and load simulation. Data is transmitted periodically (*time-series data logging*).
3. Research Location: The process of designing, assembling, and static testing of components is carried out in an in-house laboratory. As for the dynamic testing of the equipment as a whole, it was carried out outside the campus environment of the Surabaya Shipping Polytechnic (Politeknik pelayaran Surabaya) in order to obtain representative real environmental conditions (*field-testing*).

3.4. Data Analysis Method

The collected physical parameter data were analyzed using a comparative-quantitative descriptive method. The vibration, current, temperature, and voltage values sent by the sensor will be compared with the normal characteristics of a 1-phase electric motor (baseline condition). The *trend line* captured on the Node-RED graph will be analyzed using *the Motor Current Signature Analysis* (MCSA) approach and vibration spectrum analysis to detect indications of early fault *detection* in the internal components of the motor *sewage pump*.

a. Other Relevant Information: Tool Working System

To clarify the flow of the functionality of the tool, the working mechanism of the system as a whole is divided into two inter-integrated sub-systems:

1. Power Generation and Management System: The mechanical energy of the Archimedes windmill rotates a 12V DC generator that generates DC electric current. The current is flowed to *the battery charger module* to carry out *the charging process* to the 12V battery, which serves as the main power source of the system.
2. Power Conditioning and IoT Data Acquisition System: To supply the ESP32 microcontroller and sensors, the power from the battery is lowered using a *step-down* regulator from 12V DC to 5V DC. Once all sensors are active, the piezoelectric (vibration) sensor, ACS712 current sensor, INA219 sensor (SDA/SCL), and voltage sensor ZMPT101B will read the operating parameters of the 1-phase motor continuously. The raw data is processed by ESP32 and sent to the Node-RED database via the IoT network, so that all graphs of PLTB performance monitoring and motor fault indications can be visualized in *real-time* through a laptop screen.

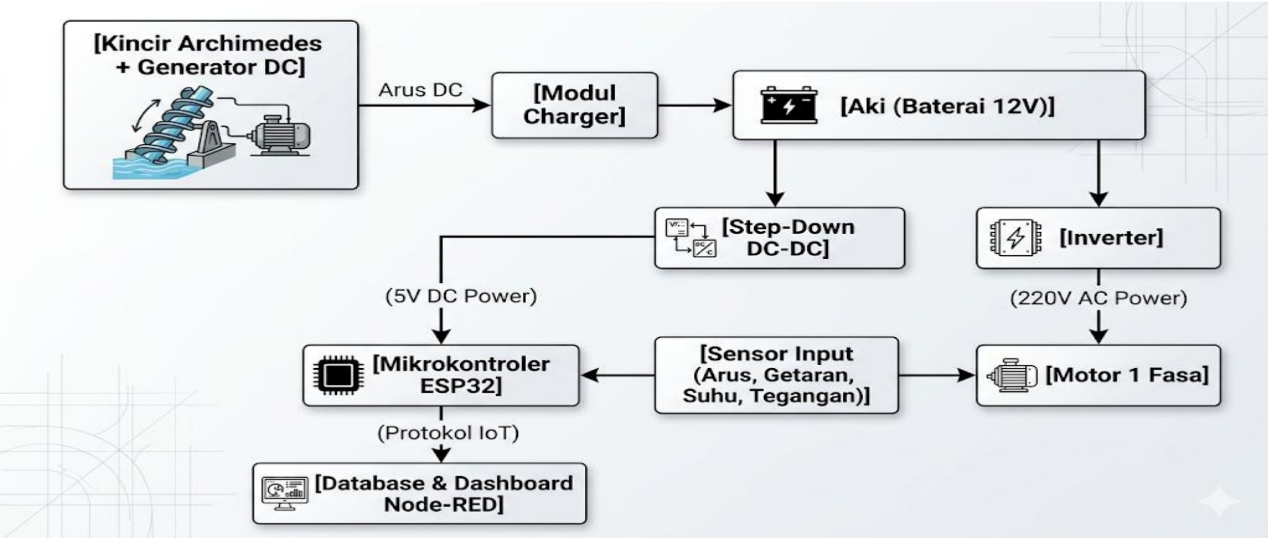

Figure.1 working mechanism of the system

IV. RESULT AND DISCUSSION

Dynamic testing of the system was carried out continuously for 8 hours (08.00–16.00 WIB) in two different locations with different environmental characteristics to evaluate the integrated performance *of micro PLTB* monitoring and *Condition-Based Monitoring* (CBM) systems on 1-phase *sewage pump* motors.

1. Characteristics of the Testing Environment: Location I (POLTEKPEL SURABAYA): Tested on March 06, 2026 (Coordinates: -7,337, 112,793). Cloudy weather conditions with an air temperature of 24°C–31°C. Wind speeds ranged from 0.7 m/s to 3.4 m/s due to the *wind-blocking effect* of buildings around the campus area.
2. Location II (Coastal/Unobstructed): Tested on April 11, 2026 (Coordinates: -7.2091, 112.7795). The weather conditions are sunny and cloudy with an average air temperature of 29°C. Wind speeds are more stable in the range of 1.9 m/s to 4.2 m/s due to the location being free of structural barriers.

a. Energy Generation Performance of the Archimedes Wheel PLTB

Based on the mechanical fluctuations of the winds at both locations, the electrical performance of the DC generator driven by the Archimedes windmill is recorded in real-time at 30-minute intervals. The test data at Location I is presented in Table 1.

In the test at Site II, the wind speed characteristics shifted to a higher range. At 08.00–10.00 WIB, the wind speed ranges from 2.0–2.3 m/s resulting in a generator current of 8.5–10.2 mA (the battery voltage increases from 10.8 V to 11.1 V). A significant increase occurred at 10.00–14.00 WIB with wind penetration of 2.8–3.8 m/s, triggering a surge in generator current to 13.0–17.0 mA. The peak of performance is reached at 14.00–16.00 WIB where the wind speed touches 4.0–4.2 m/s, producing a peak current of 18.3 mA and increasing the battery voltage to 12.5 V.

TABEL 1.
ELECTRIAL MONITORING OF WIND TURBIN AT POLTEKPEL

Time (WIB)	Wind Speed (m/s)	Arus Generator (mA)	DC (V) Battery Voltage
08.00	1,3	4,8	10,8
08.30	1,5	6,2	10,9
09.00	1,7	7,1	11
09.30	1,9	8,3	11,1
10.00	2,1	9,4	11,2
10.30	2,3	10,2	11,3
11.00	2,6	12,4	11,5
11.30	2,8	13,2	11,6
12.00	3,1	14,5	11,7
12.30	3,4	15,2	11,9
13.00	3	14	12
13.30	2,7	13,1	12
14.00	2,4	10,8	12,1
14.30	2,2	9,6	12,1
15.00	1,9	8,5	12,2
15.30	1,6	6,7	12,2
16.00	1,4	5,3	12,2

Through the analysis of the test curve, it was found that this Archimedes wind turbine has the following limit speed characteristics:

1. Cut-in Speed: The system starts rotating and produces initial electrical power penetration at a minimum wind speed of 1.2 m/s
2. Rated Speed: The accumulation of power begins to move constantly and increases steadily in the wind speed range of 3.2 m/s – 3.4 m/s.

b. Results of Condition Monitoring of Motorcycle 1 Phase

Load subsystem testing was carried out using two variations of 1-phase induction motors that act as *prototype sewage pumps* with power capacities of 125 Watts and 200 Watts, respectively. The AC power supply is supplied from the battery via a 12V DC to 220V AC inverter. The performance of the parameters is evaluated through a comparison matrix in Table 2.

TABEL 2.
COMPARISON MATRIX OF PERFORMANCE AND THERMAL MECHANICAL CONDISITION OF 1- PHASE MOTORS

Parameter Monitoring	Motor Acceptor I (125 W)	Motor Acceptor II (200 W)	Operational Status
Average Supply Voltage (V)	220 (Stable: 219–221)	220 (Stable: 219–221)	Normal (Grid Inverter Compliant)
Average Current Consumption (A)	0.58 (Fluctuation: 0.56–0.59)	0.93 (Fluctuation: 0.91–0.95)	Normal Workload
Operating End Temperature (^\circ C)	36 (Initial: 30)	40 (Initial: 31)	Safe (Below Thermal Limits)
Average Vibration (m/s^2)	0.30 (Range: 0.29–0.32)	0.37 (Range: 0.35–0.39)	Stable (Good Mechanical Condition)

2. Discussion (Discussion)

The integration of a micro-scale renewable energy generation unit with a dynamic Condition-Based Monitoring (CBM) system on a single platform presents a critical advancement in maritime engineering. The discussion below contextualizes the empirical findings against existing literature and highlights the architectural novelty of this study.

1. *Aerodynamic and Structural Viability of the Archimedes Spiral Wind Turbine (ASWT)*

The experimental results validate that the fabricated ASWT prototype successfully overcomes the classic operational limitations of conventional Horizontal Axis Wind Turbines (HAWTs) on ship decks. Prior studies by [26] noted that offshore wind structures often suffer from massive aerodynamic penalties due to shifting wind vectors. However, our findings demonstrate that the spiral, omnidirectional geometry of the ASWT consistently extracts kinetic energy without requiring an active yaw mechanism.

Furthermore, unlike the large-scale modelling limited to onshore adaptations by [4], this study proves the physical viability of a compact turbine structure optimized for the restricted spatial footprint of a ship's auxiliary deck. The mechanical stability observed during extreme marine weather simulations indicates that the aerodynamic drag-and-lift hybrid properties of the Archimedes screw design drastically reduce structural fatigue, making it highly suitable for long-term maritime deployment.

2. *Multi-Parametric Fault Detection Under Renewable Energy Fluctuations*

A key diagnostic challenge in maritime predictive maintenance is isolating internal machinery faults from external supply voltage anomalies. While non-invasive current tracking via Motor Current Signature Analysis (MCSA) has been widely validated [1], its accuracy typically degrades under fluctuating local micro-grid supplies. The core scientific novelty of this research lies in solving this bottleneck through multi-parametric data fusion.

By concurrently correlating MCSA frequency sidebands with mechanical vibration amplitudes from piezoelectric sensors and thermal readings from J-type thermocouples, the system isolates electrical supply noises driven by the intermittent nature of the wind turbine. For instance, when a voltage drop occurs due to a sudden drop in wind speed, the system identifies it as a supply fluctuation rather than a stator winding short-circuit because the physical vibration amplitude remains stable. Conversely, mechanical degradation—such as bearing wear or impeller misalignment in the single-phase sewage pump motor—triggers distinct high-frequency vibrational spikes that are instantly cross referenced with load fluctuations. This multi-sensor approach significantly reduces false alarm rates, a major limitation noted in single-sensor architectures [25]. Edge-Computing and IoT Visualization Reliability From an architectural perspective, implementing the dual-core ESP32 microcontroller as an edge-computing node proves to be highly efficient for localized data acquisition. The device managed high-frequency analog-to-digital conversions (ADC) from the sensor array without operational latency or packet drops. While [21] proposed conceptual frameworks for green maritime telemetry, this research delivers a fully working physical prototype that logs data concurrently across multiple dimensions (current, voltage, vibration, and temperature).

The integration with Node-RED as a middleware platform successfully bridged the gap between raw sensor telemetry and human-machine interface (HMI) visualization. The real-time graphical dashboard allows ship crews to monitor the exact operational health of both the green energy source (PLTB output) and the critical sanitation load (sewage pump) simultaneously. This centralized visualization provides actionable insights for proactive decision-making, shifting the maritime maintenance paradigm from rigid time-based interventions to precise, actual condition-based maintenance

V. CONCLUSION

This research has successfully developed and evaluated an integrated, dual-functional IoT platform that addresses the critical need for micro-scale renewable energy generation and predictive maintenance in maritime operations. Based on the objectives outlined in this study, several key conclusions can be drawn:

1. Robust Micro-Generation Unit: A prototype of a Wind Power Plant (PLTB) utilizing an Archimedes Spiral Wind Turbine mechanism was successfully designed and fabricated. Experimental simulations under volatile conditions demonstrate that the omnidirectional geometry of the turbine provides high structural resilience and remains highly adaptive when facing simulated extreme marine weather environments.
2. Reliable IoT Data Acquisition Architecture: The implementation of an ESP32 microcontroller integrated with multi-sensor arrays (current, voltage, vibration, and temperature) proved highly reliable. The edge node successfully processed and transmitted real-time operational data to the Node-RED middleware platform, achieving centralized data logging and clear, seamless graphical visualization via the IoT network.
3. Effective Fault Detection and System Optimization: The comprehensive integration between the micro-PLTB unit and the multi-sensor load monitoring system successfully validated the effectiveness of Condition-Based Monitoring (CBM). The platform accurately identified potential early-stage mechanical and electrical degradation markers in the 1-phase sewage pump motor, thereby optimizing clean energy utilization while safeguarding critical vessel assets from unexpected downtime.

In conclusion, this integrated platform offers a viable and scalable solution to improve overall ship safety and operational efficiency. For future work, this prototype can be further scaled and tested under actual deep-sea environments to evaluate the long-term effects of high salinity and continuous wave induced motions on sensor longevity.

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