International Journal of Marine Engineering Innovation and Research, Vol. 11(2), Jun. 2026. 457-466
(pISSN: 2541-5972, eISSN: 2548-1479)

Design and Initial Performance Characterization of DC Electric Motor as a Propulsion System for Small-Scale Fishing Vessels

Rahmat Rabbani[1], Fis Purwangka[2*], Budhi Hascaryo Iskandar[3], Dwi Putra Yuwandana[4]

(Received: 30 March 2026 / Revised: 6 April 2026 / Accepted: 21 April 2026 / Available Online: 3 June 2026)

Abstract**—** This study examines the need for sustainable propulsion systems in Indonesia's small-scale fisheries, where about 95.6% of fishermen rely on small vessels powered by fossil-fuel outboard engines that contribute to air and noise pollution. The transition to cleaner propulsion technologies is therefore necessary. This research aims to design and conduct an initial evaluation of an electric propulsion system for small fishing vessels by adapting an electric scooter motor. A design-based experimental method was applied by integrating key components, including an electric motor, battery, controller, shaft, and propeller, into a functional system. Performance testing was conducted to assess operational feasibility, estimate energy consumption, and determine suitable battery capacity. The results show that the system is functionally operable at Technology Readiness Level 2, indicating early-stage development. However, performance remains suboptimal due to inefficiencies in component integration. The estimated energy requirement is 282.24 Wh, and a 24 V 12 Ah battery is recommended for further testing and system improvement.

*Keywords***—** DC electric motor, electric propulsion system, fossil fuel, small-scale fisheries.

**Corresponding Author: fis@apps.ipb.ac.id*

I. INTRODUCTION

Based on statistical data from the Ministry of Marine Affairs and Fisheries, the number of fishers in the capture fisheries sub-sector reached 2,773,538 individuals in 2023, of which approximately 95.6% are classified as small-scale or traditional fishers operating mainly in coastal waters [1]. According to Law No. 7/2016 on the Protection and Empowerment of Fishers, Fish Farmers, and Salt Farmers, small-scale fishers are defined as individuals who conduct fishing activities to fulfill daily livelihood needs, either without vessels or using vessels with a maximum capacity of 10 gross tonnage (GT). Another definition proposed is that small-scale fishers operate vessels under 5 GT and use simple fishing gear [2]. Their fishing activities are predominantly characterized as one-day fishing operations, requiring daily preparation of operational necessities, including food provisions and fuel. This operational pattern highlights the vulnerability of small-scale fisheries to fluctuations in input availability, particularly energy sources.

Fuel oil remains a critical determinant of fishing operation success, as it serves as the primary energy source for vessel propulsion. For small-scale fishers, fuel expenditure can account for approximately 50% to 70% of total operational costs, making it the largest cost component in fishing activities [3]. This high dependence on fossil fuel introduces significant economic risks, especially under conditions of fuel price volatility and limited access to subsidized fuel. Such constraints disproportionately affect small-scale fishers with limited financial capacity, leading to operational uncertainty and reduced fishing frequency [4]. This condition represents a fundamental problem in the sustainability of small-scale fisheries, where economic resilience is strongly tied to energy accessibility.

Fishing operations in small-scale fisheries are generally conducted using vessels equipped with fuel-powered outboard engines. While these engines provide practical mobility, their use results in both economic and environmental challenges. Combustion of fossil fuels contributes to greenhouse gas emissions and air pollution [5], while engine noise generates acoustic disturbances that may negatively affect both human health and marine ecosystems [6]. Despite these concerns, research on alternative propulsion systems specifically tailored for small-scale fishing vessels remains limited. This gap indicates the need for technological innovation that is not only energy-efficient but also environmentally sustainable. One promising alternative is the application of electric propulsion systems, which offer advantages in terms of reduced emissions, lower noise levels, and improved energy efficiency [7]. However, the adaptation of such systems to small-scale fisheries requires further investigation, particularly in terms of technical feasibility and operational suitability.

An electric motor is a device that converts electrical energy into mechanical energy in the form of rotational motion [8]. Its operation is based on electromagnetic principles, where an electric current passing through a conductor generates a magnetic field that induces rotational movement in the rotor [9]. Electric motors are

Rahmat Rabbani is with Department of Fisheries Resources Utilization, IPB University, Bogor, 16680, Indonesia. E-mail: rabbani25rahmat@apps.ipb.ac.id
Fis Purwangka is with Department of Fisheries Resources Utilization, IPB University, Bogor, 16680, Indonesia. E-mail: fis@apps.ipb.ac.id
Budhi Hascaryo Iskandar is with Department of Fisheries Resources Utilization, IPB University, Bogor, 16680, Indonesia. E-mail: budhihascaryo@apps.ipb.ac.id
Dwi Putra Yuwandana is with Department of Fisheries Resources Utilization, IPB University, Bogor, 16680, Indonesia. E-mail: dwiputra@apps.ipb.ac.id

generally classified based on the type of current used, namely alternating current (AC) and direct current (DC) motors [10]. AC motors operate using alternating current, which periodically reverses direction to generate a rotating magnetic field, whereas DC motors operate using a unidirectional current [11]. Understanding these fundamental characteristics is essential for selecting appropriate propulsion technology for small-scale marine applications.

DC electric motors have been widely implemented in various low-power applications, including electric fans, lawn equipment, and electric bicycles. Their operation relies on a commutator and brushes to maintain continuous rotation by reversing current direction within the rotor [9]. Compared to AC motors, DC motors offer a simpler construction, easier control, and lower initial investment cost, making them suitable for small-scale and cost-sensitive applications. In addition, DC motors exhibit relatively high efficiency and produce minimal direct emissions during operation [12]. These characteristics suggest their potential suitability for small-scale fishing vessels, particularly in contexts where affordability and operational simplicity are key considerations.

Previous studies have demonstrated the potential advantages of DC-based propulsion systems in marine applications. A comparative analysis showed that DC motors are approximately 31-41% lighter than AC motors, which is beneficial for small vessels with limited load capacity [13]. Furthermore, simulation studies on hybrid propulsion systems incorporating DC motors indicated a potential reduction in fuel consumption of 20-25% over one year of operation. Despite these promising findings, most existing studies remain at the simulation or conceptual level and have not sufficiently explored practical implementation using readily available and low-cost components. In particular, the utilization of electric scooter motors as propulsion units for fishing vessels has not been extensively investigated. This limitation highlights a research gap related to the practical adaptation, performance characterization, and energy requirement estimation of such systems under real operating conditions.

Based on the identified problems and research gaps, this study aims to design and develop a DC electric propulsion system for small-scale fishing vessels by adapting commercially available electric scooter motors. In addition, this study seeks to evaluate system performance and estimate energy consumption patterns, power requirements, and appropriate battery capacity. The novelty of this research lies in the practical integration of low-cost, widely available components into a functional propulsion system and the provision of empirical performance data at an early development stage. The expected contribution of this study includes improving operational efficiency, reducing dependence on fossil fuels, and supporting environmentally sustainable fishing practices. Furthermore, the results are anticipated to provide a technical reference for the future development and implementation of electric propulsion systems in small-scale fisheries.

II. METHOD

The research was conducted from December 2024 to April 2025 and consisted of two stages: assembly and testing. The assembly was carried out at the Secretariat of the Boat Modeling Club (BMC). Equipment testing was conducted at the Fish Behavior Laboratory, Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Science, IPB University. The tools and materials used in this research included a wattmeter, tachometer, stopwatch, multimeter, controller, throttle handgrip, power lock, dimmer, 24V dynamo, two 12V 5Ah lead-acid batteries, propeller shaft, propeller, cables, a water-filled tank, stationery, and notebooks. The software used consisted of Microsoft Excel and 3D design software.

A. *Research Procedures*

This study employed an experimental approach combined with a literature review. The data consisted of both primary and secondary sources. Primary data were obtained directly through a series of designed experiments, which included the fabrication process, power requirements during operation, and the average power demand. Meanwhile, secondary data encompassed supporting information related to engine specifications, engine capacity, and the electrical system design utilized.

a. Electric Propulsion System Design Procedure

The design process of the electric propulsion system was carried out in several stages, beginning with the development of the system design and concept, followed by the preparation of components, tools, and materials required. The electrical system was then assembled by connecting several components, including the battery, dimmer, wattmeter, controller, power lock, throttle handgrip, and dynamo. Subsequently, the construction of the shaft, propeller, and engine mount was assembled. The propeller shaft, equipped with bearings, was connected to the dynamo using a universal joint, enabling the dynamo to drive the propeller. A locking mechanism was also added at the end of the shaft to reduce rotational vibration. Once the electrical system was fully connected and the propeller operated properly, the electric propulsion system was ready for performance testing.

b. Performance Measurement Procedure

The motor performance measurement procedure involved the use of a wattmeter to record power (watt), voltage (volt), current (ampere), and accumulated energy (watt-hour), as well as a tachometer to measure propeller rotational speed (revolutions per minute). Measurements were conducted under three speed conditions: high, medium, and low. The dimmer was set to 100% for high speed, 75% for medium speed, and 50% for low speed. Each test was conducted for 15 minutes, with data recorded at one-minute intervals. According to the guidelines of the performance test, a 15-minute test duration is sufficient for the motor to reach stable conditions [14]. The collected data were then processed using Microsoft Excel.

B. Data Analysis

The data analyzed in this study were primary data obtained through direct measurement. The performance data of the electric motor were collected across several parameters, including voltage, current, power (watt), energy consumption (watt-hour), and rotational speed (revolutions per minute).

The analytical methods applied to achieve the research objectives consisted of descriptive analysis, simple linear regression analysis, and energy requirement analysis. Descriptive analysis was employed to provide a detailed description of the design stages, specifications, and overall system design of the electric motor. Furthermore, a technology readiness level (TRL) assessment was conducted to evaluate the readiness level of the proposed electric propulsion system design.

III. Results and Discussion

A. Conceptual Design of an Electric Propulsion System

The electric propulsion system developed in this study is based on the fundamental principle of converting electrical energy into mechanical motion through rotational torque generated by an electric motor. When an electric current flows through a conductor within a magnetic field, an electromagnetic force is produced, resulting in rotational motion of the rotor. To achieve stable and continuous rotation, the motor is designed with multiple coils and field interactions that ensure consistent torque generation [9]. This principle forms the basis for adapting electric motor technology into a propulsion system for small-scale vessels.

Electric motors have been extensively applied in industrial and domestic sectors, particularly DC motors, which are widely used in transportation devices and household equipment such as fans, blenders, and mixers due to their simple configuration and controllability [8]. Despite their widespread use, the application of DC motors in small-scale fisheries remains limited. This study addresses this gap by proposing a practical adaptation of an electric motor, specifically one derived from electric scooter technology, into a propulsion system for fishing vessels. The conceptual design emphasizes the use of low-cost, commercially available components to ensure accessibility and applicability for small-scale fishers, representing a key practical contribution of this research.

From an engineering perspective, the propulsion system is designed as an integrated energy conversion chain, where electrical energy stored in the battery is regulated by the controller, converted into rotational motion by the motor, and transmitted through the shaft to drive the propeller. This energy flow configuration is critical, as inefficiencies may arise at each stage, particularly in electrical control, mechanical coupling, and hydrodynamic interaction at the propeller. Therefore, the conceptual design not only focuses on functionality but also considers potential sources of energy loss that may affect overall system performance.

a. Development Stages of an Electric Propulsion System

The development process began with the creation of a three-dimensional (3D) design that included top and side views, along with detailed dimensions of the main components, such as the dynamo, battery, controller, dimmer, throttle handle, shaft, and propeller. The design was developed based on relevant technical references and adjusted to approximate the physical characteristics of conventional outboard engines used by small-scale fishers. This approach was intended to enhance practical compatibility and facilitate future implementation. The central electrical enclosure was designed with dimensions of 20 × 20 × 18 cm. A box-shaped configuration was selected to optimize internal component arrangement, improve spatial efficiency, and allow flexible installation and handling during operation.

The electrical enclosure was connected to a 150 cm shaft and a 50 cm throttle handle. The shaft was modified from a standard factory-produced shaft, typically ranging from 200 to 250 cm in length and commonly used in diesel engine systems. The reduction in shaft length was based on mechanical considerations, as excessive shaft length can increase rotational resistance, structural load, and energy loss during power transmission. By shortening the shaft, the design aims to improve mechanical efficiency and reduce unnecessary load on the motor, although this modification may also influence torque distribution and propulsion characteristics. A complete visualization of the prototype design is presented in Figure 1.

The subsequent stage involved the development of the electrical system layout, which defines the configuration and interconnection of all components. This layout plays a critical role in ensuring system reliability, as it enables clear identification of current pathways and simplifies troubleshooting during operation. The circuit was arranged based on functional requirements, where the battery serves as the primary energy source, the controller regulates power delivery, and the motor converts electrical input into mechanical output. Particular attention was given to wiring organization, component placement, and electrical safety to minimize resistance losses and potential system failure.

Following the completion of the layout, all components were assembled and interconnected according to their respective functions, forming a fully integrated propulsion system. This stage represents the transition from conceptual design to initial prototype implementation, enabling subsequent performance testing. At this stage, the system demonstrates early functional integration, which is essential for validating the feasibility of adapting low-cost electric motor technology as a propulsion alternative for small-scale fishing vessels. However, due to the preliminary nature of the design, further refinement is required to improve system efficiency, structural robustness, and operational reliability.

b. Component Specifications and Functional Description of the Electric Propulsion System

Each component in the electric propulsion system performs a specific and interdependent function within the overall energy conversion chain, transforming electrical energy into mechanical thrust. Rather than operating as isolated units, these components form an integrated system in which performance is influenced by the compatibility and interaction between electrical, mechanical, and control subsystems. Therefore, the design not only considers individual component specifications but also emphasizes system-level efficiency and operational stability.

The dynamo functions as the primary energy conversion unit, transforming electrical energy into kinetic energy in the form of rotational motion [8]. DC motors are generally classified into brushed and brushless (BLDC) types. Brushed DC motors rely on mechanical commutation using brushes and a commutator, whereas BLDC motors employ electronic commutation, resulting in higher efficiency and longer service life [15]. Although BLDC motors offer superior performance, this study deliberately adopts a brushed DC motor due to its lower cost, simpler control requirements, and high starting torque, which are critical for small-scale and low-speed marine propulsion applications [16]. This selection reflects a practical trade-off between performance and accessibility. The motor operates based on electromagnetic interaction between the current-carrying coil and the magnetic field, producing rotational motion at the shaft [17]. The selected motor has specifications of 24 V, 250 W, 2750 rpm, and 14 A nominal current, which are typical for electric scooters and bicycles, making it a cost-effective and readily available solution [19]. From a system perspective, the use of such a motor represents a key novelty of this study, as it demonstrates the feasibility of repurposing non-marine components for marine propulsion.

The motor is mechanically connected to the shaft through a universal joint, which functions as a flexible coupling element. Compared to rigid couplings, the universal joint accommodates minor misalignment between the motor axis and the shaft, reducing vibration and mechanical stress during operation. This is particularly important at the prototype stage, where perfect alignment is difficult to achieve. However, the use of a universal joint may introduce minor transmission losses due to angular deviation, which should be considered in performance evaluation. Despite this limitation, the joint significantly improves system reliability and reduces the risk of mechanical failure, thereby supporting stable operation during testing.

The battery serves as the primary energy storage unit, converting chemical energy into electrical energy through electrochemical reactions [20]. Among available battery technologies, lead-acid (VRLA) and lithium-ion are the most commonly used [21]. This study employs a 12 V 5 Ah VRLA battery connected in series to produce a 24 V supply, matching the motor requirements. The selection of VRLA batteries is based on their low cost, high current capability, and operational safety, particularly in laboratory conditions where robustness and ease of handling are prioritized [22]. While lithium-ion batteries offer higher energy density, their higher cost and more complex management systems limit their applicability in early-stage prototype development [23]. Thus, the choice of VRLA reflects a deliberate design decision prioritizing affordability and availability over energy density [24]. However, this choice also implies limitations in endurance and weight efficiency, which should be addressed in future system optimization [25].

The controller plays a central role in regulating electrical input to the motor by controlling voltage and current through Pulse Width Modulation (PWM) [26]. PWM technology enables efficient speed control by adjusting the duty cycle of the voltage signal supplied to the motor, thereby minimizing energy losses compared to linear control methods [27]. The use of a PWM-based DC controller in this system ensures stable motor operation under varying load conditions while maintaining relatively high efficiency. Compared to controllers used in AC or BLDC systems, DC controllers offer simpler circuitry and lower implementation cost [28]. The controller used in this study operates at 24 V, compatible with the battery configuration, and utilizes a switching frequency in the kilohertz range to ensure smooth motor response without significant oscillation [29]. Nevertheless, switching losses and heat generation remain potential sources of inefficiency, particularly under high load conditions.

The throttle handgrip acts as the primary user interface, controlling motor speed by transmitting variable voltage signals to the controller [30]. It operates using internal sensors such as Hall sensors or potentiometers, converting mechanical rotation into electrical signals that regulate motor output [31]. The twist-grip model used in this study provides ergonomic advantages, allowing smooth and gradual speed control while minimizing operator fatigue. Its compatibility with common electric vehicle systems enhances its practicality. However, manual control may introduce variability in experimental conditions, which is why additional control elements, such as the dimmer, are incorporated for more consistent testing.

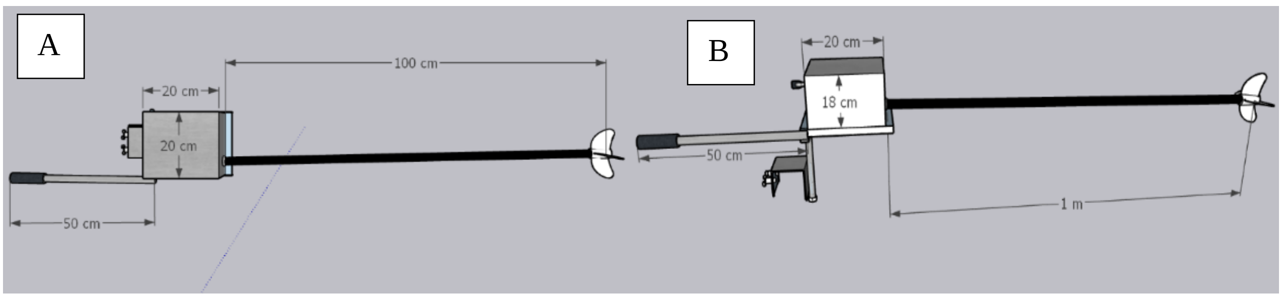

Figure 1. Final 3D Design (a. top view, b. side view)

The power lock serves as a critical safety component by controlling the main electrical connection between the battery and the system. It ensures that the propulsion system is only activated through deliberate user action, thereby preventing accidental motor operation. The use of a key-type power lock enhances user familiarity and operational safety, particularly in environments where manual supervision is required [32]. Its mechanical simplicity contributes to system reliability, although it does not provide advanced protection features such as overcurrent or thermal shutdown, which could be considered in future designs.

The dimmer is utilized as an auxiliary control device to regulate motor input voltage using PWM techniques, allowing more stable and repeatable speed control during testing [29]. Unlike the throttle, which depends on user input, the dimmer enables controlled experimental conditions by maintaining constant voltage levels. This is particularly important for performance characterization, where consistency is required to obtain reliable data [33]. The selected 12–24 V dimmer is simple, widely available, and compatible with battery-based systems, making it suitable for laboratory-scale experimentation [34]. However, the addition of multiple control elements may introduce redundancy and minor efficiency losses due to additional electronic components.

The wattmeter functions as a measurement instrument for monitoring voltage, current, and power consumption in real time [35]. Its use enables accurate assessment of electrical input parameters, which are essential for evaluating system performance and estimating energy requirements. Unlike AC systems, DC power measurement does not require power factor correction, allowing direct calculation of power consumption. The digital wattmeter also records cumulative energy usage, providing a reliable basis for analyzing system efficiency. This measurement capability is critical for validating the feasibility of the propulsion system and forms the basis for energy demand estimation discussed in subsequent sections.

The shaft serves as the primary mechanical transmission element, transferring rotational energy from the motor to the propeller. Constructed from stainless steel with a length of 150 cm, the shaft offers high strength, corrosion resistance, and durability under rotational loads. Bearings are incorporated to reduce friction and vibration, while a locking mechanism maintains alignment during operation. The selected shaft length reflects a compromise between structural stability and transmission efficiency, as longer shafts may increase torsional vibration and energy loss [36]. The inclusion of a stabilizing fin further enhances hydrodynamic performance by improving water flow around the propeller. Despite these design considerations, mechanical losses due to friction and misalignment remain potential factors affecting overall efficiency.

The propeller is the final component in the energy conversion chain, responsible for generating thrust by converting rotational motion into hydrodynamic force [37]. Its operation is governed by Newton’s third law, where backward water displacement produces forward thrust [38]. The use of a fixed-pitch, two-blade aluminium propeller with a 15 cm diameter and 15° pitch angle reflects a design choice aimed at reducing drag and achieving higher rotational speed efficiency [39]. This configuration is suitable for low- to medium-speed operation, consistent with the characteristics of DC motors. Aluminium material provides a balance between weight and corrosion resistance, making it suitable for marine environments [40]. However, fixed-pitch designs may limit performance adaptability under varying load conditions, indicating a potential area for future improvement.

Overall, the integration of these components demonstrates that a functional electric propulsion system can be constructed using readily available and low-cost technologies. The novelty of this system lies in the practical adaptation of non-marine DC motor components into a cohesive propulsion unit, supported by a simplified control architecture. While the system achieves initial functionality, the analysis also indicates that inefficiencies may arise from electrical control, mechanical transmission, and hydrodynamic interaction. These findings provide a foundation for further optimization and highlight critical areas for improving system performance in subsequent development stages.

Figure 2. Final Prototype and Electrical Wiring Diagram

B. Technology Readiness Level of the Electric Propulsion System

The Technology Readiness Level (TRL) is a systematic approach used to evaluate the readiness of a technology based on its functional capabilities. This assessment is crucial to ensure that technological development progresses beyond theoretical concepts and achieves practical applicability. Each stage of technical development must be methodologically reviewed to ensure that innovation outcomes have measurable application value.

According to the Regulation of the Minister of Research, Technology, and Higher Education of the Republic of Indonesia No. 42 of 2016, TRL serves as a framework for measuring the progression of a technology from the early research phase to commercialization. This evaluation is applied across various contexts, including research and development projects, industrial implementation, and academic research within universities and research institutions.

TRL is a quantitative indicator that reflects the level of technological maturity on a scale of 1 to 9, where TRL 1 represents the identification of basic principles, and TRL 9 indicates that the technology has been successfully demonstrated under actual operational conditions [41]. The application of TRL assessment in this study aims to objectively evaluate the readiness level of the electric propulsion system and to identify the necessary validation stages before large-scale implementation.

The design and development of an electric motor system for ship propulsion has reached Technology Readiness Level (TRL) 2, where the fundamental electrical principles have been successfully applied [42]. However, further studies are required on supporting aspects such as vessel stability, ergonomic design, and other technical factors to ensure the system's optimal applicability. At this stage, the theoretical and empirical design concepts have been identified, and the characteristics of the technological components to be developed are well understood.

Moreover, at TRL 2, the experimental procedures have been defined using valid and reliable equipment to ensure data accuracy. This TRL assessment serves as a foundation for subsequent development phases, particularly the proof-of-concept stage, which validates the supporting studies conducted to advance the electric propulsion system toward higher levels of readiness and practical implementation.

C. Initial Performance Characterization of the Electric Propulsion System

The electric motor testing was conducted periodically at one-minute intervals under three different variable conditions for a total duration of 15 minutes. These conditions included variations in rotational speed categorized as high, medium, and low. The experiment produced average, maximum, and minimum values for several measured parameters, including voltage (V), current (A), power (W), accumulated power (Wh), and rotational speed (RPM). The testing was performed under a no-load condition, with the propeller detached, to determine the initial performance characteristics of the electric motor before water-based trials. The motor's performance characteristics are presented in Table 1.

TABLE 1
PERFORMANCE CHARACTERISTICS OF THE ELECTRIC PROPULSION SYSTEM

Parameter	High Speed	Medium Speed	Low Speed
Average Voltage (V)	20.64	20.77	20.45
Average Current (A)	1.32	0.88	0.36
Average Power (W)	27.21	18.20	7.46
Accumulated Power (Wh)	10.60	9.30	4.90
Rotational Speed (RPM)	2609	1349	580

Voltage is the electrical potential difference between two points in a circuit, measured in volts (V), and serves as a primary parameter in the direct control of DC motor speed [43]. The test results of the DC electric motor indicate that the average voltage received ranged between 20 V and 21 V. The detailed average voltage values were 20.64 V at high speed, 20.77 V at medium speed, and 20.45 V at low speed. Based on these results, the voltage values across different speed levels show minimal variation, indicating that the motor's voltage performance did not reach its maximum rated value of 24 V. The nominal 24 V DC motor voltage that decreased to around 20 V during operation is a common phenomenon caused by voltage drops within the system. A 24 V motor receiving only about 20 V during operation may result from several technical factors, including voltage reduction due to internal resistance within the power source, such as the battery, or within the cables and connectors, particularly when the motor operates under load.

This voltage drop phenomenon is supported by the study which examined voltage imbalance in power supply systems and found that operating a 24 V motor at 20 V can occur due to resistance-induced voltage loss within system components, especially in the controller and connecting cables [44]. Cable size significantly influences the current flow from the battery to the motor. Therefore, selecting the appropriate cable size and ensuring high-quality electrical connections are crucial to minimizing voltage losses and heat generation [45].

Current is the rate of change of electric charge per unit of time, measured in amperes (A) [46]. Based on the current parameter measurements, the recorded current values were relatively low. The average current at high speed was 1.32 A, at medium speed 0.88 A, and at low speed only 0.36 A. These results indicate that the two 12 V, 5 Ah batteries connected in series were not capable of fully supporting the motor's optimal performance, as the measured current remained significantly below the motor's nominal current of 14 A and the battery's nominal capacity of 5 Ah.

This reduction in performance can be attributed to several factors, one of which is the series configuration of the battery setup, which increases voltage but does not enhance current capacity [47]. Additionally, internal resistance within the batteries contributes to voltage drops when high current flows, thereby reducing the effective current delivered to the motor. The relatively small battery capacity and mismatch between current supply and motor demand may result in decreased motor performance, particularly under high-load operating conditions [48].

The rate at which energy is absorbed or delivered is referred to as power, while electrical power is the amount of electrical energy transferred per second, measured in joules per second or watts (W) [49]. Based on the electric motor power measurements, the power values fluctuated over time across the three speed conditions. At high speed, the average power consumption was 27.21 W, with a maximum of 32.34 W and a minimum of 20.8 W. At medium speed, the average power consumption was 18.20 W, the maximum reached 25.25 W, and the minimum was 14.56 W. At low speed, the average power consumption was 7.46 W, with a maximum of 10.25 W and a minimum of 6.12 W.

These power consumption fluctuations across different speeds indicate a direct correlation between the motor's operating speed and its energy consumption the higher the motor speed, the greater the power consumed [50]. The overall power performance of the motor was relatively low, primarily due to the suboptimal capacity of the batteries used. Therefore, upgrading the specifications of several internal components is necessary to enhance system performance.

Power accumulation, or total energy consumption, represents the total amount of power used over a specific period and is generally expressed in watt-hours (Wh) [51]. This parameter is crucial for illustrating the efficiency and energy demand of the electric motor during testing. Based on 15 minutes of measurement, the accumulated power showed an increasing trend with time and motor speed. At high speed, the total recorded energy consumption was 10.6 Wh, which, when extrapolated over one hour, equals approximately 42.4 Wh. At medium speed, the accumulated power was 9.3 Wh, equivalent to 23.25 Wh per hour, while at low speed, the recorded power consumption of 4.9 Wh corresponds to 19.6 Wh per hour. These differences indicate that the speed level influences the rate of energy consumption, consistent with the principle that higher rotational frequencies require greater energy input.

The performance of the electric motor can be analyzed through the power accumulation parameter, which represents the total energy consumed over a specific duration at various speed levels. Power accumulation serves as an essential reference for estimating the motor's energy requirements, particularly in planning power storage systems and improving operational efficiency. The variations in accumulated power across different speed conditions indicate that the output frequency controlled by the dimmer significantly affects energy consumption. As the motor's rotational speed and operational duration increase, the accumulated power tends to rise proportionally [52]. This finding demonstrates that the energy utilization characteristics of electric motors are dynamic and depend on both load and operating time. A comparison of power accumulation under three different speed conditions, illustrating the cumulative variation in energy consumption, is presented in Figure 3.

The propeller rotational speed performance of the electric motor system shows varying ranges under different conditions over time. The nominal specification of the electric motor is 2750 revolutions per minute (rpm). At high-speed conditions, the average rotational speed reached 2609 rpm, with the lowest value recorded at 2218 rpm and the highest at 2910 rpm. At medium speed, the average rotational speed was 1359 rpm, with a minimum of 1054 rpm and a maximum of 1653 rpm. Meanwhile, under low-speed conditions, the average rotational speed reached 580 rpm, with the lowest value recorded at 348 rpm and the highest at 418 rpm. The significant range of rotational speed across conditions indicates that the variation in frequency controlled by the dimmer functions effectively and has a direct influence on the motor's rotational speed.

The rotational speed performance of the electric motor under three different test conditions over time is indicate that the motor's rotational speed falls within a range close to its nominal specification, suggesting that it demonstrates relatively optimal performance. However, this test was conducted under no-load conditions, so further testing under loaded conditions is necessary to obtain more representative performance data corresponding to actual operational conditions. The rotational speed of an electric motor is strongly influenced by the applied load. In the context of a marine propulsion system, the motor experiences a decrease in rotational speed due to additional loads such as cargo weight, hydrodynamic drag, and mechanical friction. The rotational speed of ship propulsion motors typically ranges from 1250 to 2500 rpm under full-load conditions [53]. Therefore, the motor's speed characteristics should be re-evaluated under full-load conditions to assess its stability under varying loads, ensuring optimal performance during real-world applications.

The relationship between rotational speed, power, and current in the electric motor system shows that both power and current increase with rising speed. Test data indicate that at a low-speed condition with an average of 580 rpm, the power and current consumption were relatively low, reaching only 0.3 A and 7.4 W. At medium speed with an average of 1359 rpm, the power consumption reached 17.2 W and the current 0.8 A. At high speed, with an average of 2609 rpm, the power consumption was 27.21 W and the current 1.32 A. At the maximum rotational speed of 2910 rpm, the power consumption reached 32.34 W and the current 1.57 A. The increase in input frequency through the dimmer results in a corresponding rise in rotational speed and current in the motor [54].

Based on the regression analysis presented in Figure 3, the correlation coefficient between rotational speed and current was 0.8641, and between rotational speed and power was 0.8658. These values indicate a strong relationship between rotational speed and both power and current in the electric propulsion system. Power and current consumption tend to increase proportionally with the rise in rotational speed [55]. The graphical relationship between rotational speed, power, and current is illustrated in Figure 3.

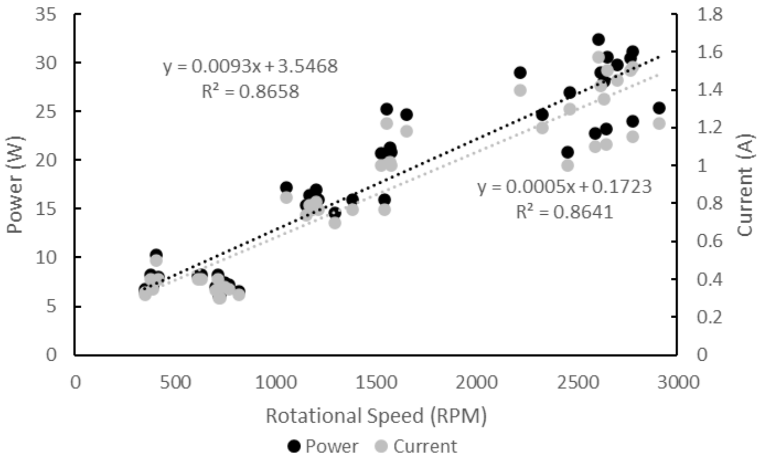

Figure 2 Correlation Between Rotational Speed, Power, and Current

The relatively low power and current performance suggest that the motor has not yet reached its optimal condition. An electric motor typically achieves its nominal current only when operating under full-load conditions [45]. This finding emphasizes the need for further enhancement of the internal system and subsequent testing under loaded propulsion system conditions to evaluate the motor's performance more comprehensively.

D. Estimation of Power Demand and Battery Capacity Requirements

A 24 V DC motor with a rated power of 250 W is expected to be operated for approximately 6 hours per day under variable operating conditions, with usage predominantly at high speed. Experimental results indicate that the motor's energy consumption varies significantly depending on the operational speed. Therefore, an accurate estimation of battery requirements necessitates the calculation of the total energy consumed by the motor over a daily duty cycle. Based on test results of maximum power accumulation at each speed level, the motor consumes 42.40 Wh per hour when operating at high speed, 37.20 Wh per hour at medium speed, and 19.60 Wh per hour at low speed. The estimation of a 6-hour daily usage cycle is derived from the average duration of fishing activities conducted by small-scale fishers [56], during which the motor is assumed to operate for 4 hours in high-speed mode, 1.5 hours in medium-speed mode, and 0.5 hours in low-speed mode. Accordingly, by aggregating the energy consumption for each operating mode as summarized in Table 5, the minimum total daily energy required by the motor is calculated to be 235.20 Wh. This value serves as a critical reference for determining the battery capacity necessary to support optimal motor operation.

After estimating the total daily energy demand in watt-hours (Wh), the next step is to convert this value into battery capacity expressed in ampere-hours (Ah), based on the motor system's operating voltage of 24 V. Incorporating a safety factor is a crucial aspect of battery sizing to ensure the availability of energy reserves and to maintain optimal battery lifespan. A safety margin of 20% is applied to account for unforeseen loads and fluctuations in power consumption during operation, resulting in an adjusted total energy requirement of 282.24 Wh. Given the system voltage of 24 V, the corresponding required battery capacity is approximately 11.76 Ah. This calculation forms the basis for determining appropriate battery specifications to ensure reliable and efficient operation of the propulsion system throughout the intended usage period. Compared to the currently employed battery configuration, two 12 V, 5 Ah batteries connected in series to provide 24 V with an effective capacity of 5 Ah, his capacity is clearly insufficient to meet the motor's energy demand over a 6-hour operating duration. Therefore, the use of a 24 V battery system with a minimum capacity of 12 Ah is recommended to ensure adequate power availability, prevent performance degradation during operation, and enable the propulsion system to operate optimally and reliably in accordance with the planned usage profile.

The requirement for an optimal propulsion system is a critical aspect of small-scale fishing vessel operations. Such vessels must operate under varying marine conditions, including ocean currents and waves, while maintaining stability and maneuverability during fishing and catch transportation activities. Small-scale fishing vessels generally have lengths ranging from 6 to 10 m and are typically employed for nearshore operations with operational durations of approximately 4 to 8 hours. Consequently, the propulsion system must provide sufficient power capacity to achieve cruising speeds of 5 to 8 knots, depending on payload and prevailing environmental conditions.

Experimental results obtained from the developed direct current (DC) electric motor prototype indicate that the motor operates within an optimal efficiency range. However, the power and torque output remain relatively limited when compared to the propulsion requirements of medium-sized fishing vessels. Based on power and energy analyses, the electric motor investigated in this study is more suitable for application in small vessels with capacities below 5 GT, such as traditional lightweight boats operating in relatively calm waters, including rivers, lakes, or sheltered coastal areas. The implementation of electric propulsion systems for fishing vessels operating in open-sea conditions would require substantial system upgrades, particularly in terms of increased motor power, battery capacity, and the integration of more advanced cooling and control systems. A gradual and staged approach to the adoption of electric propulsion technology is therefore recommended, allowing system implementation to be tailored to vessel characteristics and overall operational requirements.

IV. CONCLUSION

This study successfully developed a prototype electric propulsion system for small-scale fishing vessels by adapting a DC motor-based configuration and integrating essential components into a functional drivetrain. The system demonstrates initial operational feasibility at Technology Readiness Level (TRL) 2, indicating that the concept has been validated at an early experimental stage. Performance evaluation under different operating conditions confirms that motor output varies consistently with load and speed settings, reflecting stable electrical and mechanical behavior of the system. Despite this functionality, the overall performance remains limited, indicating the need for further optimization in component integration and energy efficiency. The estimated total energy requirement for a typical six-hour fishing operation is 282.24 Wh, with a recommended battery specification of 24 V and a minimum capacity of 12 Ah to support practical use. These findings suggest that low-cost DC electric motors, including those adapted from electric scooters, have potential as alternative propulsion systems for small-scale fishing vessels. However, further development is required to improve system efficiency, durability, and real-world performance. This study provides an initial empirical basis for the application of electric propulsion technology in small-scale fisheries and contributes to ongoing efforts to reduce dependence on fossil fuels and minimize environmental impacts.

ACKNOWLEDGEMENTS

The authors sincerely thank all those who contributed to this research, including mentors, colleagues, and laboratory staff for their support and assistance. Special appreciation goes to the young lecture program for funding this study, enabling its successful completion.

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