

Design and Development of Electric-Powered Workboat for Hydro-Floating Solar Hybrid System

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Abstract

This study presents the design and development of an electric-powered workboat for application in a hydro-floating solar hybrid system, with the objective of supporting the operation and maintenance of such systems through efficient and environmentally friendly transportation. The research addresses key design challenges, including stability, maneuverability, and the integration of renewable energy sources. Computational Fluid Dynamics (CFD) simulations were employed to analyze resistance, wave patterns, and effective power, while Maxsurf software was used to evaluate vessel stability. The results indicate that the electric-powered workboat achieves a maximum speed of 21 km/h and demonstrates optimal energy efficiency at operating speeds of 18–19 km/h. In addition, assessments of noise levels, wave patterns, and environmental performance were conducted within the context of the Hydro-Floating Solar Hybrid System at Sirindhorn Dam. The findings confirm the feasibility and effectiveness of electric-powered workboats utilizing renewable energy sources, highlighting their potential contribution to sustainable waterway transportation infrastructure.

Keywords Electric-powered boat; Floating solar; Zero emission transportation; CFD

1 Introduction

The increasing demand for sustainable energy solutions has led to the development of hydro-floating solar hybrid systems in Thailand (Electricity Generating Authority of Thailand, 2021). These systems integrate the advantages of hydroelectric and solar power to optimize energy production and efficiency. Workboats are necessary for the operation and maintenance of such systems and have traditionally been powered by diesel engines. However, the envi-

ronmental impacts of diesel propulsion have accelerated the shift toward electric-powered alternatives.

Hydro-floating solar hybrid systems have attracted significant attention for their capacity to optimize the use of water sources in renewable energy generation. Vourdoubas (2023) emphasized the efficiency gains achieved by integrating solar panels with existing hydropower infrastructure. This dual-source approach not only enhances overall energy output but also mitigates the instability associated with solar power. In addition, studies by Chen et al. (2024), Mehadi et al. (2021), and Fagertröm et al. (2024) demonstrate the potential of such systems to minimize land-use conflicts and strengthen the sustainability of national energy portfolios.

Patil et al. (2017) indicated that hydro-floating solar hybrid systems installed on reservoirs, lakes, and canals offer improved energy conversion efficiency due to natural panel cooling, while simultaneously reducing water evaporation and algae growth. Recent studies on floating photovoltaic systems indicate that surface coverage can modify local hydrodynamics by attenuating wave energy, thereby influencing structural loads and operational stability (Haas et al., 2020). Huang et al. (2024) showed that waves induce heave and pitch motions of floating solar panels, leading to continuous incline-angle variation and measurable power losses of up to approximately 13% compared with calm-water conditions. These indicate that service

Article Highlights

- An electric-powered workboat was designed and developed for operation within hydro-floating solar hybrid systems.
- Hull form, stability, and resistance results were evaluated using CFD and validated with empirical methods, ensuring reliable hydrodynamic performance.
- The propulsion system was optimized based on resistance and effective power analysis, resulting in an efficient twin-motor with verified operational performance.
- An energy storage system was developed to support operating requirements, covering a travel range of approximately 50 km under real operating conditions.

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and maintenance workboats operating near hydro-floating solar hybrid system should be designed to generate minimal wake and wave disturbance to avoid inducing motions that could compromise structural stability and energy production efficiency.

The transition toward electric-powered workboats has been facilitated by development in battery technology and electric propulsion systems. Lithium-ion batteries, identified by Reddy et al. (2020) as the current standard, are favored for their high energy density, long cycle life, and declining costs. Furthermore, the emerging development of solid-state batteries offers the prospect of even greater performance improvements (Zhao et al., 2019).

The effective energy management strategies for electric and hybrid ships can significantly improve energy efficiency and operational performance by optimizing power distribution between propulsion systems and onboard energy storage (Soleymani et al., 2015). The optimization of energy management and power allocation can reduce energy consumption and extend the operational range of electric boats by coordinating propulsion demand and battery usage (Han et al., 2014).

Electric motors, such as direct current (DC) motors, synchronous motors, permanent magnet synchronous motors, induction motors, and acyclic motors, provide high efficiency and reliability, as noted by Kirtley et al. (2015). Their compact size and low maintenance requirements make them particularly well-suited for marine applications. In addition, the integration of energy management systems, which optimize power distribution and battery utilization, further strengthens the feasibility of electric-powered workboats.

Hull resistance prediction method to support the efficient design of electric vessel was studied by comparing the theories and CFD (Ahlstrand and Lindbergh, 2020). The recent study of hull form optimization methods presents the support techniques such as CFD-based refinement and multi-object algorithm can reduce resistance force and improve energy efficiency for modern vessels (Tadros et al., 2023). Similarly, Cheng et al., (2024) applied CFD-driven hull line optimization and reported measurable reductions in drag coefficients through iterative shape refinement.

The environmental benefits of electric workboats are considerable. Koričan et al. (2022) reported that electric propulsion eliminates greenhouse gas emissions and pollutants such as nitrogen oxides and particulate matter, thereby improving both air and water quality. Moreover, noise pollution—a major concern associated with diesel engines—is substantially reduced, as demonstrated by Andersson et al. (2024).

Operational advantages include lower energy costs and reduced maintenance requirements, as electric motors contain fewer moving parts than internal combustion engines. Skomedal and Espeland (2021) reported that electric work-

boats can deliver performance comparable to, or even exceeding, that of conventional vessels in terms of speed and maneuverability—capabilities that are particularly critical in confined and variable operating environments.

Designing electric workboats involves addressing several unique challenges. Stability and maneuverability are particularly critical, as these vessels must operate near working areas. Takamasa and Hazaku (2013) highlighted the importance of developing hull forms capable of operating effectively in both calm and wave conditions, as well as selecting propulsion systems, such as waterjets, that are suitable for environments with underwater ropes attached to buoys and that minimize the risk of harming marine life.

Energy autonomy is another key consideration in the design of electric workboats. Incorporating renewable energy sources, such as flat-top solar panels, allows energy to be stored in battery systems, thereby reducing dependence on shore-based charging (Sunaryo and Ramadhani, 2018). Moreover, strategic management of battery charging and discharging processes can improve operational efficiency and extend battery lifespan (Spagnolo et al., 2012).

Several case studies highlight the successful implementation of electric-powered workboats. The Amsterdam canal fleet, documented by Jacobs et al. (2018), demonstrates the feasibility of large-scale electric vessel deployment in urban environments. Similarly, the adoption of electric workboats in Norway's aquaculture sector illustrates their effectiveness and potential role in advancing the future of fish farming (Frith, 2019).

The literature highlights the potential of electric-powered workboats to enhance the sustainability and efficiency of hydro-floating solar hybrid systems. Advances in battery technology, electric propulsion, and energy management with monitoring graphical user interface systems have made electric workboats a viable alternative to conventional diesel-powered vessels. By addressing design considerations specific to the operational requirements of these hybrid systems, electric workboats can effectively support the maintenance and operation of renewable energy infrastructure while aligning with broader environmental objectives.

2 Material and methods

2.1 Conceptual design

Generating clean electricity through floating solar energy represents a crucial objective for cost-effective renewable energy utilization in Thailand (Sapthanakorn and Salakij, 2021). The Hydro-Floating Solar Hybrid Project at Sirindhorn Dam in Ubon Ratchathani province, Thailand, serves as a pilot initiative that integrates floating solar power with an existing hydroelectric plant

This project has a generation capacity of 45 MW, contrib-

uting to a reduction in greenhouse gas emissions (CO_2)—a major driver of global warming—by approximately 47 000 tons per year. It occupies an area of 1 216 000 m^2 and comprises 144 420 installed solar cells (Mawong, 2024). The floating pontoons are constructed from high-density polyethylene (HDPE), a material commonly used in water supply pipes, which is resistant to UV radiation and safe for aquatic organisms and the surrounding environment. The floating structures are stabilized by a bottom-anchoring mooring system at a water depth of 30 m. The solar cell arrays are divided into seven separate clusters, positioned at a distance from the pier.

The workboat is the service vessel suitable for operation within the hydro-floating solar hybrid project. The round-trip travel distance from the pier to the installation site is approximately 9 km, as illustrated in Figure 1.



Figure 1 The hydro-floating solar hybrid project with the round-trip distance at sirindhorn dam

The adoption of emission-free and environmentally sustainable watercraft is a fundamental principle of this project. This decision aligns with the project's objectives and offers the potential to reduce energy costs. Accordingly, an electric workboat powered entirely by clean energy was selected. The vessel is designed to perform multiple functions—including operations, maintenance, and educational tours for the public—within the project's operating environment. To meet these requirements, a monohull configuration was chosen (Rönnebrand, 2022), featuring a shallow draft, a length of 20.2 meters, a beam of 4.6 meters, and two propeller drives positioned to avoid interference with the underwater tether system. This design enhances both maneuverability and operational safety. The estimated weight and carrying capacity of the vessel are presented in Table 1, with an approximate displacement of 22.7 tons and a design speed of 20 km/h.

2.2 Hull design

The monohull configuration was designed to accommodate a payload of approximately 22.7 metric tons, with

Table 1 Weight estimation for the workboat

Lists	Weight (kg)
1. 40 passengers $\times$ 90 kg	3600
2. Boat structure	8000
3. Electric propulsion system	1000
4. Energy Storage System	2150
5. Furniture	1000
6. Air conditioning system	1000
7. Loads	5950
Total	22700

principal dimensions of 20.2 m in length, 4.6 m in breadth, and 0.72 m in draft, and is capable of achieving a maximum operating speed of 20 km/h. The calculated Froude number ($F_r = V / \sqrt{gL}$) is 0.39, indicating operation within the displacement regime (Yousefi et al., 2013). Within this scope, the round-bilge hull form was identified as the most suitable design (Castaldi, 2020). Although vessels of this type may experience stability challenges at higher speeds, the addition of bilge keels can effectively reduce rolling motion (Tupper, 2013). A schematic representation of the hull form for the electric-powered workboat is provided in Figure 2.

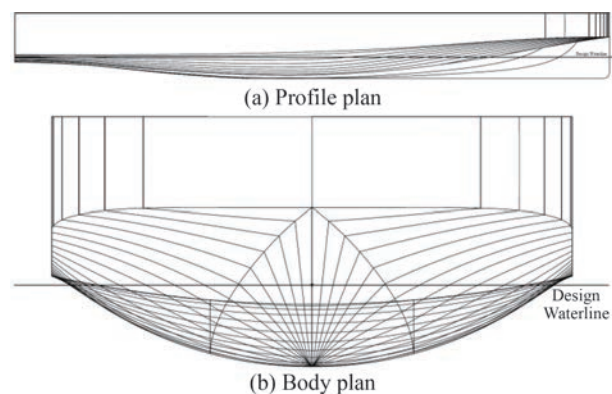


Figure 2 Line plan of hull design

2.3 Stability

Stability is a fundamental aspect of boat design, reflecting the vessel's ability to maintain equilibrium and resist capsizing when subjected to external forces. As noted by Hanzu-Pazara et al. (2016), achieving adequate stability requires a careful balance of several factors, including hull geometry, weight distribution, and metacentric height. These parameters interact dynamically with external influences such as waves, wind, and passenger load, highlighting the necessity of thoroughly understanding the vessel's stability profile.

In Naval Architecture, several critical parameters govern stability and ensure safe operation. One of the most

important is the metacentric height (GM), which represents the distance between the metacenter (M) and the center of gravity (G) of the vessel (Mégel and Kliava, 2010). Another key measure is the righting arm curve, which characterizes the vessel's stability response by describing the relationship between heel angle and the restoring moment (Pawłowski, 2005). Modern boat design increasingly relies on advanced computational tools and simulations to assess stability characteristics and ensure compliance with international regulations and industry standards (Abbas et al., 2021).

This research utilized Maxsurf software to compute a range of parameters for the analysis of ship stability. The hydrostatic characteristics of the electric-powered workboat, presented in Figure 3, provide the foundation for understanding its intact stability behavior. The righting arm (GZ) curve under lightship condition (Figure 4) demonstrates strong intact stability characteristics. The GZ value increases steadily with heel angle, reaching a maximum of approximately 1.86 m at a heel angle of about 36.9° , as summarized in Table 2. This large maximum righting arm significantly exceeds the IMO minimum requirement of 0.2 m, indicating a strong restoring capability (Surendran and Reddy, 2003).

Under full-load conditions (Figure 5), the GZ curve exhibits a similar shape, although with a slightly reduced maximum righting arm of 1.76 m occurring at a heel angle of approximately 36.5° . This reduction is expected due to the upward shift of the center of gravity caused by payload and onboard equipment. Nevertheless, the full-load GZ values remain well above IMO requirements, and the range of positive stability is preserved.

2.4 Resistance simulation

Resistance is a critical factor in boat design, as it strongly influences the performance and efficiency of marine vessels under varying operating conditions. According to Carlton (2012), ship resistance comprises the combined forces acting on a vessel as it moves through water, including frictional resistance, wave-making resistance, and air resistance. Frictional resistance results from the interaction between the hull and the surrounding water and is affected by hull form, surface roughness, and speed. Wave-making resistance arises from the generation of waves at the bow and stern, requiring careful hull and appendage design to minimize drag. Air resistance also contributes to total resistance, with aerodynamic features playing an important role in reducing drag and improving energy efficiency.

The accurate calculation of resistance is essential in boat design, as it directly affects performance, energy consumption, and operating costs. Various approaches have been developed for resistance prediction. Empirical methods, which rely on regression analyses of experimental data, remain widely applied for practical estimations (Islam et al., 2022). More advanced approaches include numerical simulations such as computational fluid dynamics (CFD) (Song et al., 2020) and potential flow theory (Pacuraru, 2019), which provide detailed insights into complex hydrodynamic interactions between the hull and water. In addition, towing tank experiments remain a valuable source of empirical data for validating resistance predictions and refining hydrodynamic performance assessments (Lovato et al., 2022).

This study employed Flow-3D, a CFD software widely used for simulating ship resistance (Deshpande et al., 2020;

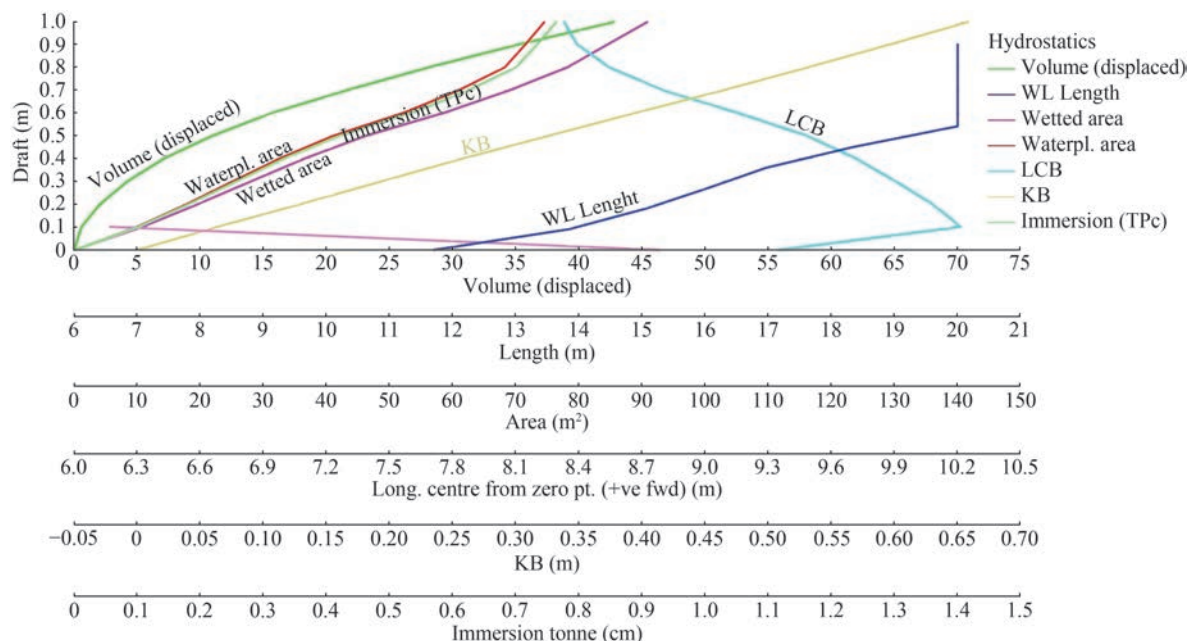


Figure 3 Hydrostatic curve of the workboat

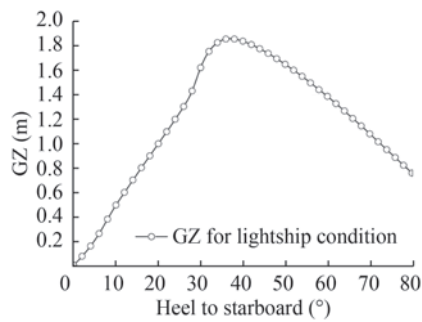


Figure 4 GZ curves at lightship condition

Table 2 Stability analysis results

Criteria	IMO code	Full load	Light ship
Area under GZ curve until 30°	0.055 mrad	21.082 mrad	22.387 mrad
Area under GZ curve until 40°	0.09 mrad	38.215 mrad	40.494 mrad
Area under GZ curve between 30° and 40°	0.03 mrad	17.133 mrad	18.107 mrad
Max. righting arm	> 0.2 m	1.76 m	1.862 m
Angle of max. stability	> 25°	36.5°	36.9°
GM	> 0.15 m	2.76 m	2.751 m

Note: mrad is milliradian and represent 1/1000 of a radian.

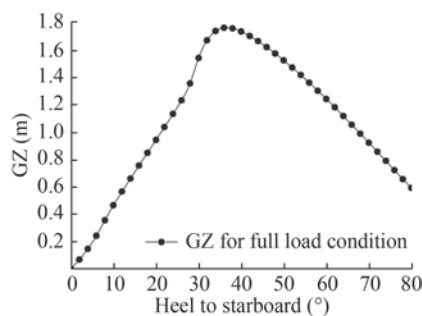


Figure 5 GZ curves at full load condition

Muk-Pavic et al., 2006). Flow-3D is based on the Navier-Stokes equations for fluid motion and incorporates models for turbulence, multiphase flows, and free-surface dynamics. Using a combination of finite volume and finite difference methods, the software discretizes the governing equations to accurately capture complex flow behaviors across diverse engineering applications.

A key feature of Flow-3D is the FAVOR (Fractional Area/Volume Obstacle Representation) mesh scheme, which enables precise representation of solid boundaries by embedding fractional area and volume obstacles within the computational domain (Flow Science, 2014). This immersed boundary approach allows fluid flow around complex geometries to be simulated with improved accuracy and efficiency. The software also integrates a robust free-surface

model capable of resolving phenomena such as waves, splashing, and surface tension effects. The Volume of Fluid (VOF) method is applied to track and capture the motion of fluid interfaces, ensuring reliable representation of multiphase flow dynamics.

For turbulence modeling, Flow-3D employs advanced approaches such as Reynolds-Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES), which allow accurate prediction of turbulence properties including turbulent kinetic energy, eddy viscosity, and turbulent length scales.

The simulation was initiated by defining a free-surface problem and specifying the boat's hull with displacement corresponding to the design. The hull was modeled with coupled motion, allowing free movement in the heave and pitch directions. To capture turbulent flow behavior, the Large Eddy Simulation (LES) turbulence model was selected.

The computational domain was defined based on the vessel's length ($L = 20$ m), extending $1.5L$ upstream, $2.5L$ downstream, $2.5L$ laterally on each side, and a water depth of $1.5L$ (Song et al., 2019). The domain was discretized into smaller volumes using the FAVOR mesh scheme, which generated four mesh blocks around the ship model to provide varying mesh resolutions. This multi-block approach helped reduce overall simulation time, as illustrated in Figure 6. The boundary conditions applied in the simulation are summarized in Table 3.

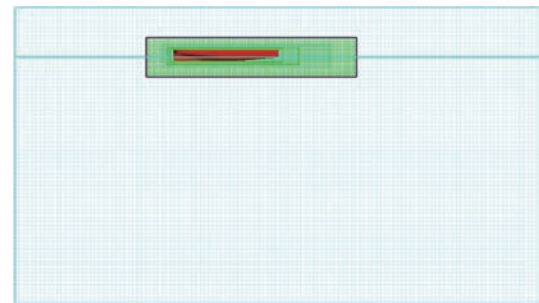


Figure 6 The domain for workboat model in Flow-3D

Table 3 Boundary conditions

Boundary type	Location	Conditions
Inlet	$-x$	Velocity (m/s)
Outlet	$+x$	Pressure outlet (N/m^2)
Bottom	$-z$	Wall
Upper	$+z$	Symmetry
Left side	$-y$	Symmetry
Right side	$+y$	Symmetry

A systematic grid refinement study was performed to verify that the numerical solution is independent of the mesh resolution. Four meshes containing 3.21, 4.11, 6.36

and 7.27 million cells, respectively, were generated by progressively refining the grid around the hull and the free surface. For each mesh, the steady resistance at the design speed of 20 km/h was computed. As shown in Figure 7, the difference in total resistance between the two finest meshes (6.36 and 7.27 million cells) is only 0.64%, indicating that the solution is essentially grid converged. The mesh with 6.36 million cells was therefore adopted for all subsequent simulations as it provides a good compromise between numerical accuracy and computational cost.

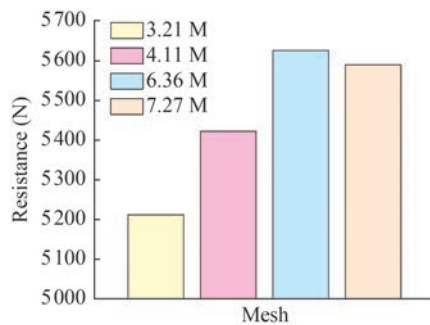


Figure 7 Numerical results obtained using different meshes

The resistance of the workboat was evaluated using CFD simulations in Flow-3D and the results are shown in Figure 8. For comparison, the empirical Holtrop-Mennen method is also applied. At the design speed of 20 km/h ($F_n \approx 0.39$ for $L = 20.2$ m), the CFD model predicts a total resistance of 7.65 kN, while the Holtrop method gives 6.30 kN, i.e. an underestimation of about 18%. This discrepancy is not unexpected, since Holtrop-Mennen is a semi-empirical formulation calibrated primarily for conventional seagoing displacement ships (Holtrop and Mennen, 1982; Holtrop, 1984), and its accuracy is known to decrease when applied to shallow-draft hulls and operating conditions that fall near or outside the limits of the underlying statistical database, such as transition-speed regimes (Nikolopoulos and Boulougouris, 2019).

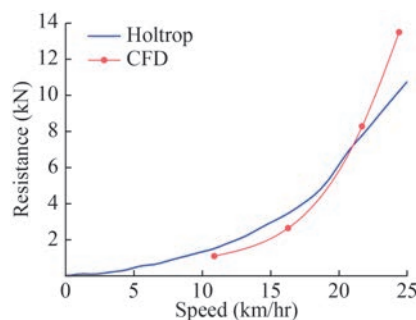


Figure 8 Hull resistance at different speeds

In contrast, the CFD approach solves the free-surface flow around the actual hull geometry and appendages, allowing the viscous and wave-making components of resis-

tance, as well as sinkage and trim effects, to be captured more faithfully than in a purely statistical method (Deshpande et al., 2020). The resulting free-surface elevation shown in Figure 9 exhibits relatively low wave heights and a rapid decay of the wave train toward the stern, which is consistent with the low wave-making characteristics required for safe operation near the floating solar arrays. Together with the grid-refinement study and the comparison with full-scale power measurements, the Holtrop comparison therefore supports the use of the CFD results as the primary and more reliable basis for resistance and effective-power prediction in this work, while the empirical method is treated as a conservative consistency check on the order of magnitude of the resistance.

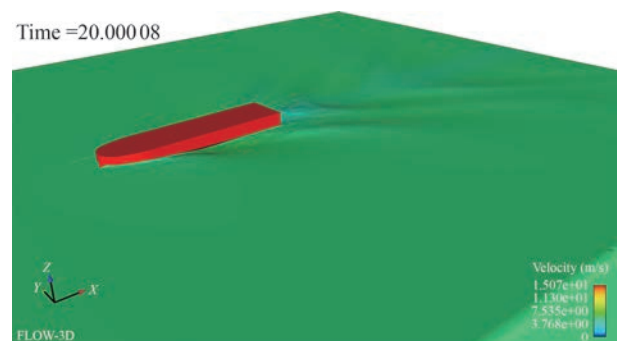


Figure 9 Wave pattern at speed 20 km/h

2.5 Electric propulsion

Electric propulsion systems have emerged as a preferred choice for watercraft, offering significant advantages in terms of efficiency, reduced emissions, and operational flexibility. As highlighted by Kolodziejcki and Michalska-Pozoga (2023), these systems utilize electric motors powered by onboard energy sources, including integrated renewable resources, shore-based charging connections, and battery storage systems, to drive the propeller and propel the vessel. By eliminating the reliance on conventional fuel-burning engines, electric propulsion substantially reduces greenhouse gas emissions and contributes to improved air quality in maritime transportation. In addition, electric propulsion is characterized by low noise levels (Andersson et al., 2024), reduced maintenance requirements, and precise operational control, making it well-suited for a wide range of vessel types, including ferries, passenger boats, and workboats.

The effective power (P_e) of an electric boat is an important parameter in designing an electric propulsion system for optimizing its performance and efficiency in waterborne operations. Determining the effective power of an electric vessel involves the calculation of the power required to overcome various resistances, such as hydrodynamic drag, wave-making resistance, and the unique elements of electric propulsion mechanisms like battery effi-

cacy and motor efficiency. Accurate calculation of effective power is therefore essential for the design and operation of efficient and environmentally friendly electric boats. The effective power is related to the total resistance and boat's velocity according to the following equation (Nurachman and Imfianto, 2018)

$$P_E = R_T \times V \quad (1)$$

Here, R_T denotes the total resistance (kN) and V represents the vessel's speed (m/s). As specified in Section 2.4, the CFD simulations predict a bare-hull resistance of 7.65 kN at the design speed of 20 km/h (5.56 m/s). Following Rawson and Tupper (2001), appendage resistance for conventional workboats typically accounts for about 10% of the bare-hull resistance; this percentage is adopted here to account for the rudder, shafts and other underwater fittings. The corresponding total resistance including appendages is therefore

$$R_T = 1.10 \times 7.65 \text{ kN} \approx 8.42 \text{ kN}$$

Substituting $R_T = 8.42 \text{ kN}$ and $V = 5.56 \text{ m/s}$ into equation (1) yields an effective power of

$$P_E \approx 8.42 \times 5.56 \approx 46.8 \text{ kW}$$

Installed power (P_I) denotes the total rated power of the motors installed on the electric workboat and represents the maximum available propulsion power under normal operating conditions. It is obtained from the effective power (P_E) by accounting for losses associated with hull efficiency, propeller efficiency and the electric drive system. The required installed propulsion power can be calculated as follows (Nurachman and Imfianto, 2018):

$$P_I = \frac{P_E}{\eta_h \times \eta_p} \quad (2)$$

$$\eta_h = \frac{1 - t}{1 - w} \quad (3)$$

where P_E is the effective power, η_h is the hull efficiency and η_p is the overall propulsion efficiency excluding hull effects, t is thrust deduction, and w is wake fraction.

The electric-powered workboat examined in this study employs a twin-screw configuration, for which the thrust deduction and wake fraction were taken as $t = 0.10$ and $w = 0.175$, respectively (Solutions, 2018). These values fall within the typical range reported for displacement workboats and small passenger vessels with moderately fine stern forms and twin propellers and are therefore not case-specific tuning parameters but representative design values. The hull efficiency was calculated as $\eta_h = 1.09$, which is consistent with values reported for similar twin-screw arrangements in standard naval architecture refer-

ences (Rawson and Tupper, 2001; Solutions, 2018).

The propulsion system consists of an induction motor directly coupled to the propeller shaft, eliminating the need for a gearbox and reducing mechanical transmission losses. The motor efficiency (η_M) of approximately 0.90 is based on manufacturer data for commercially available 55 kW three-phase squirrel-cage induction motors operated close to their nominal load (Siemens, 2016), and lies within the typical range of 0.88–0.94 reported for marine electric drives (Kirtley et al., 2015; Kolodziejewski and Michalska-Pozoga, 2023).

The inverter efficiency (η_{inv}) of 0.97 is taken from the data sheet of a standard marine vector-control drive (Delta, 2010) and is consistent with the 0.96–0.99 range commonly adopted in electric-propulsion design studies (Kolodziejewski and Michalska-Pozoga, 2023).

The open-water propeller efficiency (η_o) of approximately 0.60 was derived from the Wageningen B-series characteristics (Barnitsas et al., 1981) for a propeller geometry and loading comparable to the present design, and lies within the usual 0.55–0.65 range for such propellers.

When combined, these parameters yield an overall propulsion efficiency of $\eta_p = 0.524$, which can therefore be regarded as typical for an electric twin-screw workboat of this size and speed regime rather than an optimistic estimate. Taken together, these values provide a consistent and realistic basis for the installed-power calculation of the electric propulsion system.

Based on the effective power of approximately 46.8 kW and the adopted propulsion efficiencies, the required input power to the electric propulsion system can be estimated. The overall propulsion efficiency $\eta_p = 0.524$ accounts for the propeller, motor and inverter losses, while the hull efficiency is $\eta_h = 1.09$. The corresponding required input power is therefore

$$P_I \approx 46.8 / (1.09 \times 0.524) \approx 82 \text{ kW}$$

To provide an adequate power margin for additional losses, environmental variations and possible hull fouling, the propulsion system was designed to incorporate two 55 kW induction motors ($2 \times 55 \text{ kW} = 110 \text{ kW}$), ensuring sufficient capacity to achieve and maintain speeds greater than 20 km/h. This installed power corresponds to a margin of roughly 34% above the required input power (P_I).

In conventional ship design practice, sea and service margins of about 15%–30% of the calm-water power are commonly adopted to account for such uncertainties; in the present case, the slightly higher margin arises from the use of commercially available standard motor ratings, for which a pair of 55 kW machines was selected instead of a lower, non-standard size. The resulting margin is therefore conservative but still regarded as reasonable for an electric workboat operating under the given environmental and

operational conditions.

The arrangement of the electric propulsion system is shown in Figure 10, where a low-speed induction motor is directly connected to the propeller shaft to minimize losses associated with gearbox transmission.

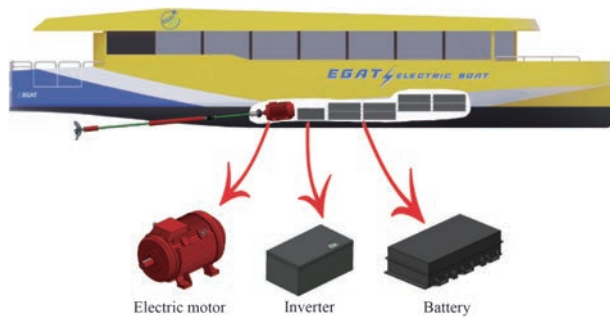


Figure 10 The arrangement of electric propulsion system

The functionality of the electric propulsion system depends on an inverter that integrates several components: a Micro Control Unit (MCU), a drive unit, and a power electronic unit, as shown in Figure 11. The MCU processes input signals from the throttle and transmits control signals to the drive unit, which governs the operation of the power electronic unit. The power electronic unit converts direct current (DC) supplied by the battery pack into three-phase alternating current (AC) to drive the electric motor, which is directly connected to the boat's propeller shaft. The motor operates within a speed range from idle up to a maximum of approximately 985 rpm.

2.6 Energy calculation

Determining the power consumption of an electric watercraft is a critical step in developing efficient and environmentally sustainable aquatic transportation systems. Spagnolo et al. (2012) highlighted the importance of accurately predicting energy usage to improve the operational effectiveness of electric marine vessels. Such evaluations must include the daily energy requirements of the battery to ensure safe operation under both normal and emergency

conditions.

The primary factor influencing energy consumption projections is the overall efficiency of the propulsion system, which depends on motor efficiency, battery capacity, hull resistance, operational speed, and additional auxiliary energy demands. Furthermore, external factors such as environmental conditions, route characteristics, and variations in payload must also be considered. Accurate estimation of energy consumption is therefore essential to ensure reliable and safe performance of electric boats.

This study considers two primary energy systems employed in electric vessels: the electric motors used in the propulsion system to achieve the required speed, and the various electrical apparatuses supporting onboard operations. The operational target of the electric workboat is to complete approximately four trips per day, covering a total distance of about 40 km, with each trip lasting roughly one hour. The estimated energy consumption per charge is 130.78 kWh, as presented in Table 4.

To ensure reliable performance, the battery capacity was calculated based on an 80% Depth of Discharge (DoD), resulting in an estimated requirement of 163.48 kWh. Accordingly, a Nickel Manganese Cobalt (NMC) lithium battery pack with a storage capacity of 214.9 kWh was selected for the vessel's energy storage system. The cabin air-conditioning system is powered separately, using battery power recharged by solar cells, and is independent of the propulsion battery system. It should be noted that the auxiliary energy consumption for this system is not quantified in this study.

2.7 Electric-powered system

Electric-powered boat systems typically consist of electric propulsion motors, energy storage systems such as batteries or fuel cells, and auxiliary loads. With advancements in battery technology, these vessels can achieve higher energy efficiency, lower emissions, and quieter operation compared to conventional combustion engine-powered boats.

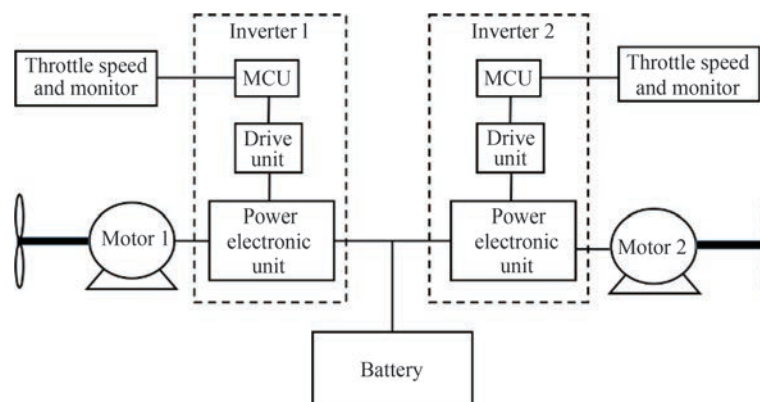


Figure 11 Electric propulsion diagram of workboat

Table 4 Energy consumptions

Items	Quantity (set)	Power (W)	Time (hr.)	Energy (kWh)
Motor	2	30 095	2	120.38
Steering	1	600	4	2.4
Bilge pump	4	240	0.5	0.48
Shaft seal pump	2	240	4	1.92
Lighting	40	20	4	3.2
Navigation	1	200	4	0.8
Display	1	200	4	0.8
Ventilation	2	100	4	0.8
Total				130.78

The design of electric-powered workboat systems must account for factors including optimal battery capacity, propulsion motor efficiency, charging infrastructure, and overall system integration. The schematic diagram in Figure 12 illustrates the electrical system of the workboat, which includes two 55 kW induction motors controlled by an inverter that regulates motor speed via throttle input. The energy storage system is based on a Nickel Manganese Cobalt (NMC) lithium battery pack configured as two parallel strings of 22P88S cells. The system operates at a voltage of 325.6 V, a current of 660 A, and provides a total capacity of 214.9 kWh.

The battery system can be charged either through a 175 kW DC fast charger or a 12 kW onboard charger (OBC). In addition, DC–DC and DC–AC converters are integrated to supply power to the vessel's onboard electrical equipment.

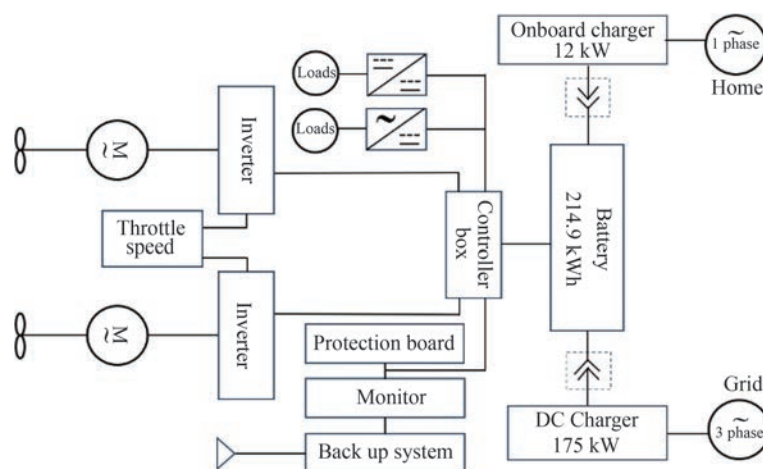
All electrical loads were supplied through the power management system. Each unit is capable of basic self-management functions, including redundancy, fault tolerance, and diagnostics. The system is also designed to be easily scalable. In this study, multiple communication protocols were employed and categorized into two levels:

high-level and low-level. The WebSocket protocol was used for high-level communication between units, while low-level communication was implemented for microcontrollers, microprocessors, sensors, and actuators.

2.8 Monitoring and data-logging system

In this work, the measurement and display system was developed as a web-based application, which the display unit functions simultaneously as both the server and client. The display unit communicates directly with the battery module via the CANBUS network, while the vessel speed and positional data are obtained from the GPS system through the NMEA0183 protocol. For power meters and gas sensor modules, data acquisition is handled independently by a measuring client, which transmits the collected information to the server over a TCP/IP network. Communication between the measuring client and the power meters as well as gas sensor modules is implemented through the MODBUS protocol, ensuring standardized and reliable data exchange. The overall system architecture and interconnections are illustrated in Figure 13.

This configuration is integrated with the gas monitoring system, which includes two sensor modules installed in the battery room. Each module incorporates two sensors: Carbon Monoxide (CO) and Hydrogen Fluoride (HF). The carbon monoxide sensor (ZE07-CO), a thermal catalytic type with a resolution of 0.1 ppm, provides both analog and Universal Asynchronous Receiver/Transmitter (UART) output. The hydrogen fluoride sensor (ME3-HF), with a sensitivity of 0.4 $\mu\text{A/ppm}$, requires an amplifier circuit for proper interfacing. To support this, a custom-made PCB was developed to perform signal amplification and communication interfacing. An analog front-end (LMP91000) was selected for integration with the HF sensor, while an 8-bit AVR Atmega1609 microcontroller was employed for programming and data acquisition. Data from the LMP91000 were acquired via SPI communication, whereas

**Figure 12** Schematic of electrical system of workboat

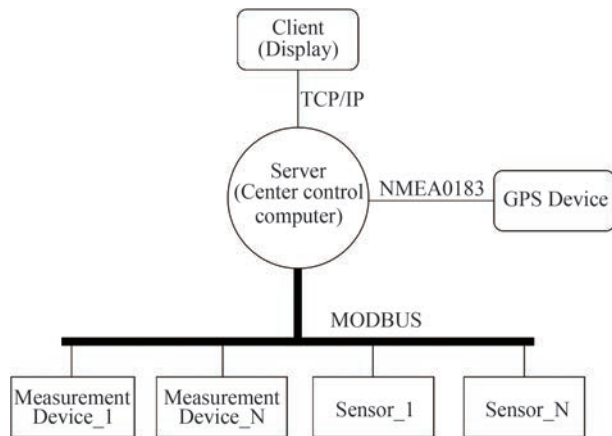


Figure 13 Communication detail

temperature and CO data from ZE07-CO were read via UART. All sensor data were subsequently published through the MODBUS protocol, enabling seamless integration with the measuring client's communication framework.

To prevent catastrophic battery system failure, a stand-alone monitoring system, dependent of the main computer (instrument cluster), was implemented to disconnect of the power relay from the battery module when necessary. A mini-program was developed and deployed on a Raspberry Pi 3 single board computer (SBC), which was integrated with a custom printed circuit board (PCB) designed to extend peripheral connectivity. The SBC communicates with two gas sensor modules via MODBUS protocol, acquiring gas concentration and temperature data at 1000 ms interval. The monitoring program was developed using the Node.js framework, a widely adopted Javascript-based runtime environment, and communicates with instrument cluster through SOCKET.io.

The instrument cluster was developed using a 12.1 -inches sunlight readable touch monitor (1000 cd/m²), powered by an Intel J1900 2.0 GHz processor, 2 GB DDR3 RAM, and 32 GB SSD. Ubuntu 14 selected as the operating system, with Server, CANBUS, Global Navigation Satellite System (GNSS) applications deployed on this platform. User Interfaces (UI) was accessible via HTTP through a web browser, while the Electron framework was employed to implement the Graphical User Interface (GUI) as a desktop application.

The UI webpages, illustrated in Figure 14, consist of four main sections: overview, map, log, and setting. For the client side, the React framework—a widely used cross-platform framework for web and UI development—was selected. On the server-side, the Express framework was employed to manage application features, including REST API.

Application Programming Interfaces (APIs) for data and functionality sharing between independent programs were implemented simple HTTP protocols, and SOCKET.io bidirectional and low latency communication. This config-



Figure 14 Monitoring Graphical User Interface of the electric-powered workboat

uration enables secure interaction between programs without requiring codes-level integration. The Node.js framework, a widely adopted JavaScript-based runtime environment, was selected as the API framework for its lightweight structure and real-time capabilities.

Parameters such as current, voltage, power, temperature, and location were stored in a database. To meet requirements for rapid deployment, simplicity, and lightweights operation, MongoDB was chosen. As a popular open-source, document-based, and JSON-like binary data database, MongoDB offers scalability and flexibility well-suited to the system's needs.

3 Results and discussion

The electric-powered workboat features a monohull structure constructed from lightweight aluminum to optimize energy efficiency. The propulsion system and energy storage unit are housed within a ballast compartment equipped with ventilation and cooling systems. The specifications of the electric-powered workboat are presented in Table 5.

Table 5 Specification of the electric-powered workboat

Items	Details
1. Size	Length = 20.2 m, Breadth = 4.6 m
2. Draught	0.72 m
3. Full loads	22700 kg
4. Material	Aluminum
5. Passenger	40 PAX
6. Speed	20 km/hr
7. Propulsion	Induction motor 55 kW × 2
8. Battery	Lithium NMC 214.9 kWh
9. Life cycle	> 4000 times
10. Distance	50 km
11. Time for charging	Quick charge < 1 hr

The electric-powered workboat was assessed and implemented within the Hydro-Floating Solar Hybrid System at Sirindhorn Dam, as shown in Figure 15. The propulsion system demonstrated efficient responsiveness to acceleration changes, and reversing could be executed promptly due to the direct coupling between the propulsion system and the propeller shaft, eliminating the need for a reduction gearbox. Maneuverability was further enhanced by the steering system's ability to achieve a small turning radius, supported by the use of twin independent propeller shaft drive systems.



Figure 15 Electric-powered workboat at the hydro-floating solar hybrid system

Operational performance evaluations confirmed that the workboat can reach a maximum speed of 21 km/h with an electrical power input of up to 120.6 kW, while the most energy-efficient operation was obtained at speeds of 18–19 km/h with a power demand of approximately 66–68 kW. These measured power levels are of the same order of magnitude as the 82 kW installed power estimated from the CFD-based analysis, providing further confidence in the sizing of the propulsion system and the validity of the numerical model.

As discussed in Section 2.5, the CFD-based total resistance, including a 10% allowance for appendage resistance, is 8.42 kN at 20 km/h, giving an effective power of about 46.8 kW and a required installed propulsion power of approximately 82 kW when the adopted hull and propulsion efficiencies are applied. The installed propulsion power of 2×55 kW (110 kW) therefore provides a conservative but reasonable margin above this requirement.

Figure 16 presents the relationship between remaining battery capacity (%) and travel distance (km). The results show that at operating speeds of 12 km/h, 16 km/h, and 19 km/h, the expected travel ranges are approximately 59 km, 57 km, and 56 km, respectively.

Examinations revealed that the workboat's propulsion system produced an average noise level of approximately 69.1 dB within the cabin area. Observations also indicated that the vessel generated only minor waves amplitude at the stern and dissipated rapidly, as shown in Figure 17. This ensured that the waves did not interfere with the floating solar platforms and other operational systems. This

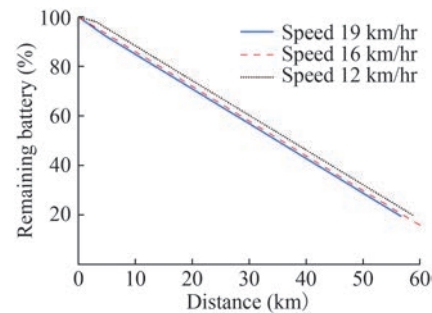


Figure 16 The remaining battery percentage (%) versus the distance journey (km)



Figure 17 Wave pattern generated by the electric-powered workboat during sailing test

characteristics are particularly important for hydro-floating solar farms, where excessive wave impact could affect the stability of floating photovoltaic structures and increase stress on mooring lines. The hull form of the electric-powered workboat was designed hull form to reduce the wave pattern, which suitable to minimize wave generation, making it suitable for operation in hydro floating solar farm environments.

As expected, the operation of the electric-powered workboat produced no air emissions, thereby eliminating environmental impacts associated with conventional fuel combustion. In addition, the charging infrastructure is supplied by renewable energy sources, including hydroelectric and solar power. Consequently, the electric-powered workboat is capable of supporting multiple functions within the Hydro-Floating Solar Hybrid Project, representing a key strategy for advancing sustainability and mitigating greenhouse gas emissions.

4 Conclusions

This study focused on the design and development of an electric-powered workboat for application in hydro-floating solar hybrid systems. The proposed vessel combines a lightweight aluminium monohull, a twin-screw electric propulsion system and a lithium NMC battery pack, and has been implemented and tested at the Hydro-Floating

Solar Hybrid Project at Sirindhorn Dam. The design process integrated conceptual design, hull form development, stability assessment, resistance prediction using CFD, propulsion system configuration, energy calculations and system integration.

The CFD-based resistance analysis, including a 10% allowance for appendage resistance, yielded a total resistance of 8.42 kN at the design speed of 20 km/h, corresponding to an effective power of approximately 46.8 kW and a required installed propulsion power of about 82 kW. On this basis, an installed propulsion power of 2×55 kW (110 kW) was selected, providing a conservative but reasonable margin above the calculated requirement. Sea trials confirmed that the workboat can reach a maximum speed of 21 km/h, with efficient operation at 18–19 km/h requiring only 66–68 kW of electrical power. The measured power levels are consistent with the CFD-based predictions, lending additional confidence to the validity of the numerical model and the sizing of the propulsion system.

The energy storage system, consisting of a 214.9 kWh NMC battery pack, provides practical travel ranges of approximately 56–59 km over the tested speed range, which exceeds the nominal design distance of 50 km. The measured interior noise level of about 69.1 dB and the small waves observed during operation indicate that the electric workboat offers improved onboard comfort and limited hydrodynamic impact on the floating solar arrays compared with conventional diesel-powered workboats. In addition, the absence of local exhaust emissions and the use of renewable hydro and solar energy for charging demonstrate the potential of electric-powered workboats to contribute to low-emission and sustainable waterborne transportation within such hybrid energy projects.

It should be noted that the present work is based on steady-state CFD simulations in calm water and on sea trials conducted under relatively benign environmental conditions. Future research could extend the analysis to include different loading conditions, a wider range of operating speeds and environmental factors, as well as long-term battery ageing effects and lifecycle cost assessments. Despite these limitations, the results clearly indicate that the developed electric-powered workboat is technically feasible and operationally effective for supporting the Hydro-Floating Solar Hybrid System, and they provide a useful reference for the design of similar vessels in other renewable energy applications.

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declare that are relevant to the content of this article.

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