

DESIGN ANALYSIS OF SOLAR-ELECTRIC PROPULSION SYSTEM OF A TOUR BOAT

INEGIYEMIEMA, M.^{1*} – NITONYE, S.¹ – KOKO, A. S.¹

¹ *Department of Marine Engineering, Rivers State University, Port Harcourt, Nigeria.*

**Corresponding author
e-mail: Nitonye.samson[at]just.edu.ng*

(Received 02nd July 2024; revised 07th October 2024; accepted 16th October 2024)

Abstract. This project aims to develop a solar-powered propulsion system for tour boats by harnessing solar energy using strategically positioned photovoltaic (PV) panels and electric propulsion motors. An energy storage system with advanced batteries to store excess energy from the PV panels to enable continuous operation at sunset or on cloudy days was designed. Suitable PV panels for adequate power generation were chosen to match the energy requirements for propulsion system, navigational systems, and other services on board. Canonical equations were used to model the parameters for motor characteristics, vessel speed, resistance components, and power requirements. With a 0.3 kW/m² output power density and 90 kW total power need, 300 m² of solar panels was required. Consequently, 56 and 110 batteries for 24 and 48 hours, respectively, were needed when cruising at 18 knots with a total electric load of 50 kW. Implementing the research findings, recreation boats' operators will be able to utilize the abundant solar energy, for environmentally conscious and sustainable marine transportation to ameliorate the hazards of fossil fuel-powered vessels.

Keywords: *solar energy, propulsion systems, resistance, power, vessel speed*

Introduction

The use of solar energy to power boats has been gaining momentum since the energy crises of the 1970s. The advent of efficient solar cells has enabled the development of solar-powered motorboats with an extensive range, akin to sailboats. At the heart of a solar-powered propulsion system lie high-efficiency photovoltaic (PV) panels strategically positioned on the boat's surface to maximize sunlight exposure. An energy storage system, comprising advanced batteries, acts as a reservoir, storing excess energy during abundant sunlight, ensuring a continuous power supply even without sunlight. This stored electrical energy is converted into mechanical energy by an efficient electric motor, propelling the boat while minimizing energy losses during operations. The electric motor, a crucial part of the propulsion system, uses the magnetic fields produced by the stator and rotor to convert electrical energy into mechanical energy. The boat will move because of the interaction between the magnetic fields produced by the rotor, which is installed on a spinning shaft, and the stator, which is made up of wire coils connected to the power supply (Djalab et al., 2024; Papade et al., 2023). Furthermore, the project encompasses a comprehensive evaluation of the environmental impact and sustainability of the solar propulsion system. By reducing the reliance on traditional fossil fuels, the project aims to contribute significantly towards the reduction of carbon emissions, promoting environmental sustainability. Careful consideration is given to the local ecosystem, ensuring the solar-powered boat does not adversely impact marine life or the surrounding environment. The design considerations encompass several factors, such as the integration of PV panels into the boat's design without compromising aesthetics or functionality. All components are designed to withstand the

tough marine environment, which includes exposure to saltwater, humidity, and a range of weather conditions. Durability and weather resistance are of the utmost importance. Efficiency and power management are equally crucial, with considerations for weight distribution, aerodynamics, and the implementation of tracking systems for the PV panels to maximize sun exposure throughout the day.

Safety features and redundancy mechanisms are meticulously incorporated into the system to ensure the boat's safe operation, encompassing emergency shutdown procedures and backup power sources. Moreover, the economic viability and commercialization aspects are addressed through a thorough cost-benefit analysis, evaluating initial setup costs, maintenance expenses, and potential long-term savings on fuel. Exploring potential markets for solar-powered tour boats and partnerships with tourism companies and local governments interested in sustainable transportation solutions further reinforces the holistic approach of this project (Tercan et al., 2021). The work aims to design and develop a solar propulsion system for a tour boat that is powered by an electric motor. It will conduct a comprehensive analysis for the most suitable photovoltaic panel capable of generating adequate power for the tour boat. It meticulously designs and develops an efficient propulsion system tailored specifically for the vessel, ensuring optimal performance and functionality. It performs hydrodynamic analysis of the vessel's resistance and power characteristics, using canonical models; and undertakes a rigorous evaluation to determine the requisite number of batteries that can store and retain sufficient energy for 48 hours, thereby enabling the uninterrupted operation of the propulsion system (Nitonye et al., 2017).

Different types of propulsion systems

Ships can maneuver across the water by using propulsion forces. Although few propulsion systems were available in the past, various new systems have been developed in the current era that can be used on other vessels. Some of the different propulsion systems used in ships are diesel propulsion, wind propulsion, nuclear propulsion, fuel-cell propulsion, and bio-diesel fuel propulsion. Others are Gas Turbine Propulsion, Diesel-Electric Propulsion, Solar Propulsion, Water-jet Propulsion, and Combined Plant (Ogar et al., 2018; Noosomton and Charoensuk, 2015).

Components of the solar-electric propulsion system

A solar-electric propulsion system utilizes solar cells to convert the sun's radiant energy into electricity. This conversion is achieved through a principle known as the "photoelectric effect". While a single solar cell generates a relatively modest amount of power, approximately 1-2 watts, multiple cells are combined into larger units called panels to generate more substantial power outputs. This concept paved the way for the development and widespread adoption of solar panel technology in various applications, including marine propulsion. Now, there are three primary categories into which solar cell technologies can be roughly divided: amorphous silicon and thin-film materials, polycrystalline (semi-crystalline), and monocrystalline (single-crystal construction). Furthermore, commercial development of a more modern and unknown solar technique called organic photovoltaic is underway. Because of their distinct physical, chemical, manufacturing, and performance qualities, each of these technologies is well suited for particular uses and operational settings (Tamunodukobipi et al., 2018; Mahmud et al., 2014; Gevorkian, 2008). Essentially, a 100-watt monocrystalline solar panel should

have the same power output as a 100-watt polycrystalline panel and a 100-watt amorphous panel. The primary difference lies in the amount of surface area occupied by the panel. To achieve a power rating of 100 watts, amorphous panels require a significantly larger surface area compared to monocrystalline panels (*Table 1*).

Table 1. Solar crystalline materials.

PV technology	Capacity (MW)	Percentage of total
Mono-crystalline	306	56.15
Polycrystalline	162	29.72
Amorphous	33	6.06
All others	44	8.07
Total	545	100

Photovoltaics (PV)

Using semiconducting materials that display the photovoltaic effect—a phenomenon explored in physics, photochemistry, and electrochemistry—photovoltaics (PV) is the process of turning light into electricity. Commercial applications of the photovoltaic effect include the production of electricity and photosensors (Bazilian et al., 2013). Photovoltaic systems use solar modules, which are made up of many solar cells that produce electricity. PV systems can be floating, wall-mounted, rooftop-mounted, or placed on the ground. The mounting system can track the sun's path across the sky with a solar tracker or it can be fixed. Because photovoltaic technology emits far less carbon dioxide than fossil fuels, it helps prevent climate change. One of the main benefits of using solar photovoltaics as an energy source is that, once installed, it emits no greenhouse gases or pollutants during operation. The main element used in it, silicon, is widely available in the Earth's crust and is scalable to suit changing power needs. However, additional expansion may be limited by other materials needed, such as silver, in the fabrication of PV systems. Competition for land usage, the requirement for energy storage devices or worldwide distribution via high-voltage direct current power lines (resulting in extra expenses), and the unpredictable nature of power generation—which needs to be balanced—are some other significant restrictions (Soto et al., 2010).

Solar charge battery controller

For solar power systems that use batteries, a solar charge controller is an essential part. Controlling the amount of power that goes from the solar panels to the batteries is the main job of the solar charge controller. Batteries that have been overcharged may have a much shorter lifespan and, in extreme circumstances, become unusable. The simplest charge controllers only keep an eye on the battery voltage, open the circuit, and stop charging when the voltage reaches a predetermined point. The circuit might be opened or closed by older charge controllers using mechanical relays to start or stop the batteries' power supply.

Rechargeable battery

The inclusion of a rechargeable battery is crucial for this project. Its primary function is to store the electrical energy generated by the solar panel. This stored energy ensures the system's uninterrupted operation during hours of darkness or low light conditions when the solar panel's power generation capabilities are limited or non-existent. In solar

systems that employ batteries as energy storage units, it is essential to incorporate a power control mechanism. This power control device serves as a switching component that prevents the stored energy within the battery from reversing its flow back into the solar panel during periods when the panel is no longer generating power. Consequently, this measure safeguards the battery from rapid depletion, thereby extending its operational lifespan (Spagnolo et al., 2012).

Diode

A diode is an electronic component whose primary function is to permit the flow of electric current in one direction while blocking it in the opposite direction. It operates akin to an electronic check valve. In the context of this project, the diode serves the purpose of preventing the backflow of voltage from the battery.

DC motor speed controller

Speed control of a DC motor is a crucial aspect in various applications. By regulating the motor's speed, it becomes possible to vary its rotational velocity according to the specific requirements and desired operations. The speed control mechanism finds its use in scenarios such as controlling the movement of robotic vehicles and regulating the motion of motors in elevators, where different types of DC motors are employed. Unlike mechanically driven systems, the DC motor speed control acts as an electronic gearbox, providing precise control over the motor's speed.

Electric motor

For the U.S. Navy, the idea of electric propulsion is not new. Electric propulsion was originally used in 1913 on the Navy Collier Jupiter, which was eventually transformed into the U.S.S. Langley, the country's first aircraft carrier. Alternating Current (AC) propulsion motors and steam-powered turbine generators were used in Langley's propulsion system. The U.S.S. New Mexico and five other battleships that followed adopted electric drive because of this propulsion system's performance. Turbo-electric drives were also installed on the Navy's second and third aircraft carriers, the USS Lexington and USS Saratoga. Electric motors can be categorized into three main types: Induction motors, Synchronous motors, and Direct current motors.

Shaft propulsion and shafting

The shafting of a vessel is responsible for transmitting the output power from the engines (power source) to the propeller, which propels the ship hull. The system is designed to withstand transient loads on the vessel and prevent any harmful vibrations within the vessel's structure. The shaft propulsion system, the propeller is usually powered by variable-speed motors. The horizontal motors can be connected directly to the shaft, providing a simple and mechanically strong solution, or they can be linked through a gear mechanism, which allows for a higher rotational speed of the motor and a more compact design. The shaft line propulsion is always combined with rudders, and with the aid of high-lift rudders, the shaft propellers can also provide a certain degree of transverse thrust. The propeller is typically controlled by a fixed pitch propeller (FPP), which offers a simple and robust propeller design. In some applications, a controllable pitch propeller (CPP) may be employed. While other types of propulsion systems exist,

such as the Azimuth Thruster and the Podded propulsion, this project utilizes the shaft propulsion system (Odokwo et al., 2022).

Shaft bearing

The shafting between the main engine and the propeller is supported in a straight line by shaft bearings. These bearings go by numerous names within the ship, including Line Shaft bearings, Steady bearings and Spring bearings. If the bearings are found in the stern tube, they are referred to as Stern Tube Bearings; if they are found in struts, they are called Strut Bearings. These bearings support the outboard sections of the shafting. Oil or saltwater can be used to grease outboard bearings. A main thrust bearing transfers the propeller thrust to the hull.

Materials and Methods

The analytical approach was utilized incorporating mathematical and engineering formulas, graphs, charts, and software for result validation. The purpose of propulsion selection or design is to obtain an optimal configuration based on the engine's capabilities concerning speed, torque, and power. The model solar boat and dimensions are shown in *Table 2* and *Figure 1* respectively

Table 2. Main dimensions of the scaled model.

S/N	Parameters	Quantity
1	Length Overall (LOA)s	2.0 m
2	Length of Waterline (LWL)	1.9 m
3	Length Between Perpendicular (LBP)	1.8 m
4	Breadth Mould [(BMD)]_m	0.30 m
5	Designed Draught (Tm)	0.10 m
6	Depth (Dm)	0.33 m
7	Surface Wetted Area (Sm)	0.75 m ²
8	Designed Speed (Vm)	2.04 knots
9	Mass Displacement(Δm)	4.3017 tons
10	Volume Displacement (∇m)	0.040 m ⁻³
11	Transverse Projected Area (AT)m	1.0 m ²
12	Propeller Diameter (DP)m	0.10 m
13	Seawater Kinematic Viscosity (v_sw)	1.18831 x 10 ⁻⁶
14	Density of Seawater (ρ_sw)	1026 kg/m ³
15	Block coefficient [(C_B)]_m	0.07
16	Shaft Efficiency (η_s)	0.98
17	Quasi-propulsive Efficiency (η_D)	0.68
18	Wake fraction (w)	0.3
19	Trust deduction factor (t)	0.18
20	Thrust (T)	2.807
21	Air Resistance Coefficient (C_air)	0.0030 or 3x10 ⁻³
22	Model-Ship Correlation (CA)	0.0004
23	The density of Air (ρ_air)	1.305 kg/m ⁻³
24	Temperature of Seawater	15°C
25	Length ratio (λ)	106



Figure 1. Model of the Solar Tour Boat.

Energy consumption analysis

Conduct a thorough analysis of the energy consumption requirements for the boat, including navigation equipment, lighting, communication devices, and other electrical loads. This analysis will provide the foundational data for subsequent calculations.

Solar panel power calculation

Employ the formula Eq. (1), is to determine the optimal power output required from the solar panels. This calculation will lay the groundwork for sizing the solar array.

$$\text{Solar Panel Power} = \frac{\text{Daily Energy Consumption}}{\text{Solar Insolation}} \quad \text{Eq. (1)}$$

Solar panel quantity calculation

Utilize the formula Eq. (2), is to ascertain the quantity of solar panels necessary to meet the boat's energy demands. This step ensures the scalability and efficiency of the solar power system.

$$\text{Number of Solar Panels} = \frac{\text{Solar Panel Power}}{\text{Individual Solar Panel Power}} \quad \text{Eq. (2)}$$

Solar panel current calculation

Calculate the current output of each solar panel using the formula Eq. (3). This calculation is crucial for ensuring compatibility with the electrical system and downstream components.

$$\text{Solar Panel Current} = \frac{\text{Solar Panel Power}}{\text{Solar Panel Voltage}} \quad \text{Eq. (3)}$$

Battery size calculation

Determine the required battery capacity using the formula Eq. (4). Parameters to be calculated for the Design will include the Resistance of the Tour Boat, the Effective

Power (PE), the Electrical Power Delivered to the Propeller (PD), and the Hull Efficiency (nH). others will include the Motor Shaft Power (Ps), Thrust Power Generated by the Motor (PT), the Electrical Power Delivered by Solar Panel (Esp), and the Torque Generated by the Motor (T).

$$\text{Battery Capacity} = \frac{\text{Daily Energy Consumption} \times \text{Autonomy Days}}{\text{Battery Voltage}} \quad \text{Eq. (4)}$$

Resistance of the tour boat

The total resistance for the hull of the Tour boat, which the vessel will experience as it moves through the wind and water body, is estimated using Gertler's chart method and ITTC method.

Calculating the total resistance of the scaled model

The used of formulation from Eq. (5) to Eq. (10):

$$R_{Tm} = R_{TBH} + R_{air} + R_{app} \quad \text{Eq. (5)}$$

$$R_{TBH} = C_{TBH} \times \frac{1}{2} \times \rho_{sw} \times S_m \times V_m^2 \quad \text{Eq. (6)}$$

$$C_{TBH} = C_{FM} + C_{RM} + C_A \quad \text{Eq. (7)}$$

$$C_{FM} = \frac{0.075}{(\log R_e - 2)^2} \quad \text{Eq. (8)}$$

$$R_e = \frac{V_m \times L_{wl}}{\mu} \quad \text{Eq. (9)}$$

$$F_n = \frac{V_m}{\sqrt{g \times L_{wl}}} \quad \text{Eq. (10)}$$

Where; R_{Tm} =total resistance of the tour boat model, R_{TBH} =total bare hull resistance, R_{air} =Air resistance and R_{app} =The resistance offered by appendages, C_{TBH} = Coefficient of total bare hull resistance, C_{FM} = Coefficient of frictional resistance of tour boat model, C_{RM} = Coefficient of residuary resistance and C_A = Model-ship correlation coefficient, R_e = Renold's number, V_m = Speed to tour boat model, L_{wl} = Length of the waterline of the tour boat model and μ = Seawater kinematic viscosity, C_{RM} is gotten from the Gertler series chart, F_n = Froude number, g = Acceleration due to gravity, V_m = Speed of tour boat model.

Calculating the air resistance

The used of formulation from Eq. (11) To Eq. (12):

$$R_{air} = C_{air} \times \frac{1}{2} \times \rho_{air} \times S_T \times V_m^2 \quad \text{or} \quad R_{app} = 2.5\% \text{ of } R_{TBH} \quad \text{Eq. (11)}$$

$$R_{Tm} = R_{TBH} + R_{air} + R_{app} \quad \text{Eq. (12)}$$

Effective power of the tour boat model

The used of formulation Eq. (13):

$$P_E = R_{Tm} \times V_m \quad \text{Eq. (13)}$$

Delivered power of the boat model

The used of formulation from Eq. (14) To Eq. (18):

$$P_D = P_{out} \quad \text{Eq. (14)}$$

$$P_{out} = P_s = P_{in} \times \eta_m \quad \text{Eq. (15)}$$

$$P_{in} = V \times I \quad \text{Eq. (16)}$$

$$E_{sp} = I_{cs} \times \eta_{sp} \times A_{sp} \quad \text{Eq. (17)}$$

$$A_{sp} = 2(lw + lh + hw) \quad \text{Eq. (18)}$$

Where; P_D = Power delivered to the propeller, P_{out} = The power output of the electric motor, P_s = Shaft Power, P_{in} = Input power, η_m = Efficiency of the motor, V = Voltage and I = Current, E_{sp} = Electric Power delivered by Solar Panels, I_{cs} = Solar constant (depends on the geographical location), η_{sp} = Design Efficiency of the Solar Panel, A_{sp} = Surface Area of Solar Panel.

Shaft power of DC motor for the tour boat model

The used of formulation Eq. (19):

$$P_s = \eta_m \times V \times I \quad \text{Eq. (19)}$$

Where; η_m = motor efficiency, V = Voltage and I = Current.

Hull efficiency of the tour boat

The used of formulation Eq. (20):

$$\eta_m = \frac{P_E}{P_T} = \frac{R_T \times V_m}{T \times V_A} \times \frac{R_T / T}{V_A / V_m} \times \frac{1-t}{1-w} \quad \text{Eq. (20)}$$

Where; t = thrust redundant factor, w = wake fraction, V_m = speed of the tour boat, V_A = Advanced velocity, R_T = Total resistance, and P_T = Thrust power.

Thrust power generated

The used of formulation Eq. (21) to Eq. (22):

$$P_T = T \times V_A \quad \text{Eq. (21)}$$

$$V_A = V_m(1 - w) \quad \text{Eq. (22)}$$

Where; T = Thrust and V_A = Advanced Velocity, V_m = the design speed of the model and w = wake fraction.

The torque generated by the DC motor (τ)

The used of formulation Eq. (23) to Eq. (25):

$$P_{out} = \tau \times w \quad \text{Eq. (23)}$$

$$\omega = \frac{RPM \times 2\pi}{60} \quad \text{Eq. (24)}$$

$$\tau = \frac{P_{out}}{w} \quad \text{Eq. (25)}$$

Where; τ = the torque generated by the motor and ω = angular speed, RPM = Revolution per minute (speed) of the motor,

Calculation of torque produced at various motor efficiencies

The used of formulation Eq. (26):

$$\tau = \frac{I \times V \times \eta_m \times 60}{RPM \times 2\pi} \quad \text{Eq. (26)}$$

Calculation of motor torque at various inputs current

The used of formulation Eq. (27)

$$\tau = \frac{I \times V \times \eta_m \times 60}{RPM \times 2\pi} \quad \text{Eq. (27)}$$

Calculation of thrust power delivered at various model speeds

The used of formulation Eq. (28):

$$P_T = T \times V_A \quad \text{Eq. (28)}$$

Results and Discussion

In this research, the values of the motor speed and model design speed are varied to determine their impact on the motor torque generated and the thrust power delivered. Hence the graphs of motor speed against torque, motor efficiency against torque, input current against torque, and model speed against thrust power delivered are plotted (Table 3). From the analysis, an increase in the RPM of the DC Motor decreases the torque produced by the Motor.

Table 3. Calculation for shaft power and motor efficiency.

Current (A)	Voltage (V)	Angular speed (ω)	Speed (rpm)	Motor eff.	Shaft power
10	12	3000	0.46	55.2	0.18
15	12	3000	0.46	82.8	0.26
20	12	3000	0.46	110.4	0.35

25	12	3000	0.46	138.0	0.44
30	12	3000	0.46	165.6	0.53

Torque and shaft power versus input current

For a fixed voltage across terminals, the torque developed by the motor is directly proportional to the input current. Since power has a linear relationship with power when the rpm of the motor is constant, then the graph of shaft power against input current should be linear. These are justified by *Figure 2*. At 10A, the torque developed 0.18 Nm and the corresponding power produced is 55.2W. Similarly at 30A, the corresponding torque and shaft power are 0.53Nm and 165.6W, respectively.

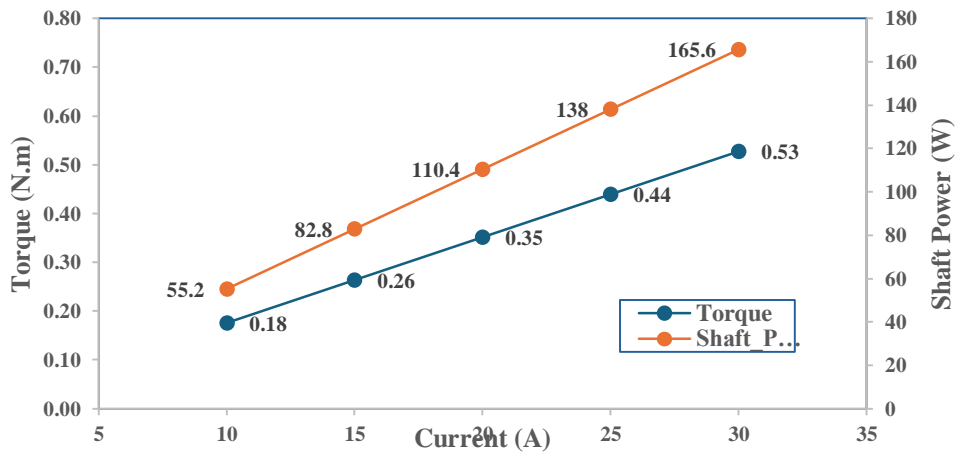


Figure 2. Variation of torque, shaft power with input current.

Torque developed versus motor speed

Figure 3 shows the variation of torque developed with motor speed when the power produced is maintained constant. The graph displays a negative parabolic curve from left to right. The torque developed decreases inversely as the motor speed when the power produced is invariant. At the maximum speed of 3000rpm, the torque developed is 0.13Nm, being the least. Conversely, at the lowest speed of 1000rpm, the torque becomes 0.38Nm, being the maximum. This implies that higher torque is achievable when the speed is lowest for a constant output power, and vice versa. Analysis results of *Figure 4* show that, for a fixed electrical power input, the torque and shaft power increase linearly with improved motor efficiency. In other words, any improvement in motor efficiency directly impacts proportionally to the shaft power and torque developed.

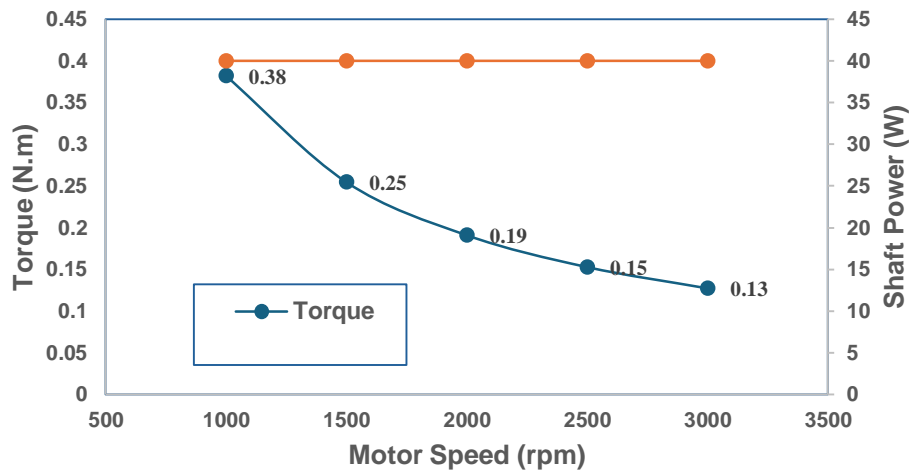


Figure 3. Variation of torque, with the motor speed at constant shaft power.

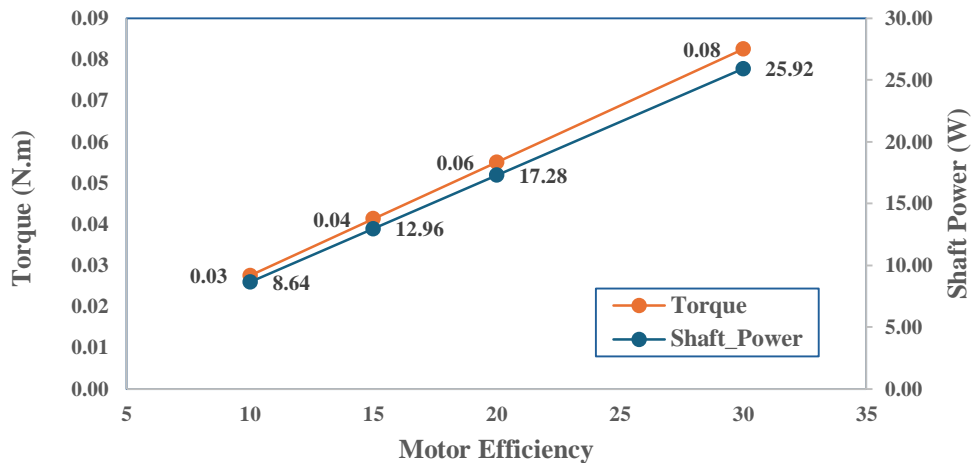


Figure 4. Variation of torque, shaft power with motor efficiency.

Relationship between vessel speed and coefficients of total resistance

The graphs in *Figure 5* shows that the coefficients of total resistance decrease with increasing speed and approach the x-axis asymptotically. However, it was observed that the values of frictional resistance coefficient are smaller than those of residuary resistance. This is true because of the large Reynolds number due to low kinematic viscosity and the large length of vessel. Because of the large influence of the residuary resistance, the total resistance coefficient almost follows the same contour as the latter.

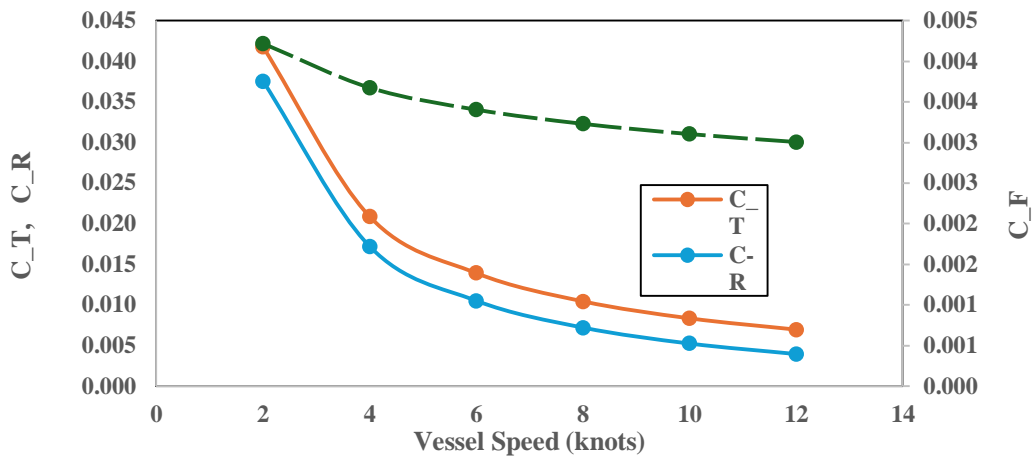


Figure 5. Total resistance coefficients of the vessel.

Relationship between vessel speed and components of total resistance

Figure 6 displays the components of the total resistance of the vessel plotted against its speed. The frictional resistance and residual resistance are significantly larger than the air resistance. This is because the vessel has a small superstructure which is also streamlined to the air current. However, the dominating frictional and residuary resistances are not of the same magnitudes as the vessel’s speed rises. At low speeds, the frictional resistance is dominant until about 27 knots where the two curves intersect. Beyond 27 knots, the residuary resistance becomes dominant because increasing waves induced resistance. The resultant curves are all parabolic and consistent with the characteristics of the components of the total resistance of tour boats. Conversely, the plots of total resistance and shaft power against the vessel’s speed describe a parabolic and cubic curve with speed respectively. At the peak speed of 30 knots, the total resistance is 2.94kN while the corresponding power is 45.44kW. At the cruise speed of 18 knots, the total resistance and the developed power are 0.94kN and 8.72kW, respectively (Figure 7).

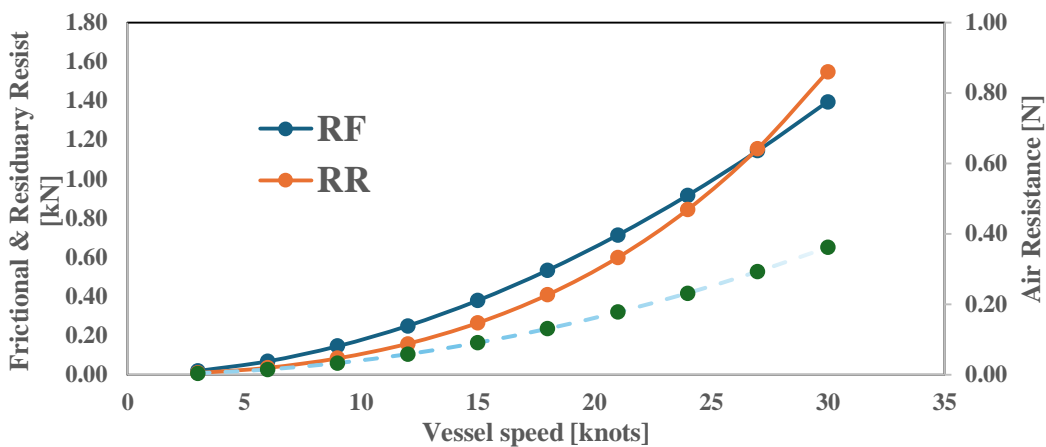


Figure 6. Components of the total resistance of the vessel.

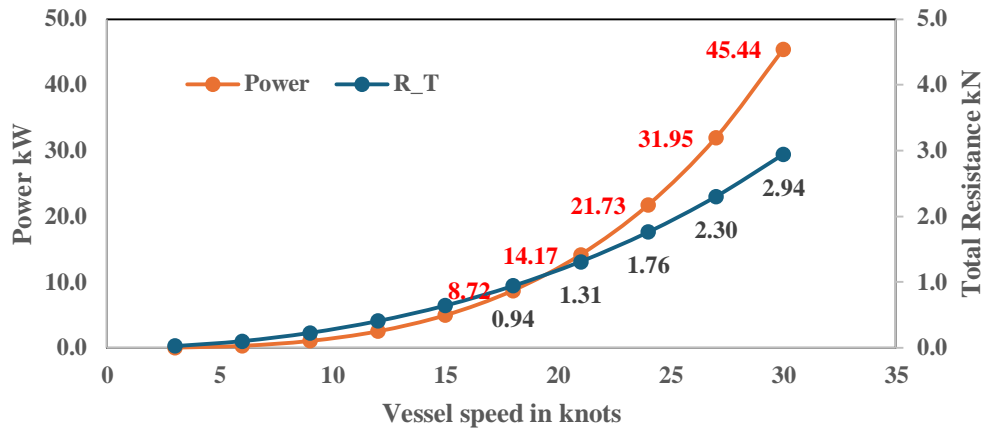


Figure 7. Vessel's total resistance and propulsive power.

From the analysis result, an increase in the speed of the vessel leads to a corresponding increase in the thrust power delivered (This implies that the thrust power produced varies directly proportional to the speed of the model. If the panel output power density is 0.3kW/m^2 , for a total power requirement of 90kW , then the solar panel surface area is 300m^2 . This implies that at the vessel speed of 30knots and propulsive power of 45.44kW , there is a redundant power of about 44.56kW for ship services, neglecting transmission and winding losses. Correspondingly, the number of $12\text{V}/200\text{A}$ batteries of capacity 200 A.hr with a discharge current of 40A , servicing a load of 90kW for 24 hrs , is $(N_{battery} = \frac{90 \times 1000 \times 24}{10.8 \times 200 \times 10} = 100)$. Considering a cruise speed of 18 knots , propulsive power of 8.72 kW and a total electrical load of 50kW (with redundancy of 41.28kW for ship services), then the number of batteries is 56 for a 24hrs discharge and 110 for 48 hrs discharge.

Conclusion

A solar-powered propulsion system for a small tour boat was designed to ensure a zero-pollution system of nautical navigation and maritime operations. Firstly, an extensive analysis was carried out to select the most appropriate photovoltaic panel configuration capable of generating sufficient power to drive the tour boat effectively. After evaluating various panel options, an optimal configuration of mounting flexible panels on the topmost deck was chosen. Secondly, a thorough design and development process was undertaken to create an efficient propulsion system tailored specifically for the vessel, ensuring optimal performance and functionality. The resulting system incorporates a carefully selected motor and drivetrain combination to maximize efficiency and meet the operational demands of the small tour boat. Thirdly, the research investigated the relationships between various parameters of the solar-powered propulsion system, including motor characteristics, vessel speed, resistance components, and power requirements. It also analyzed the vessel's speed, resistance, and overall electrical load to determine the number of batteries and the configuration of photovoltage panels using empirical equations. Fourthly, a rigorous evaluation was conducted to determine the required number of batteries and their capacity to store and retain enough energy for 48 hours , thereby enabling the uninterrupted operation of the propulsion system. With the output power density of 0.3kW/m^2 and a total power

requirement of 90kW, the solar panel surface required was 300m². Consequently, the number of 12V/200A batteries needed for 24hrs was 100. Similarly, at a cruise speed of 18 knots and a total electrical load of 50kW, the number of batteries was 56 for a 24hrs discharge and 110 for a 48hrs discharge. Therefore, the results in this study, when properly implemented, can significantly contribute to the advancement of sustainable and eco-friendly marine transportation vessels that will provide valuable design guidance, optimization, and implementation of eco-friendly boats

Acknowledgement

This research is self-funded.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

REFERENCES

- [1] Bazilian, M., Onyeji, I., Liebreich, M., MacGill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D., Zhengrong, S. (2013): Re-considering the economics of photovoltaic power. – *Renewable Energy* 53: 329-338.
- [2] Djalab, A., Djalab, Z., El Hammoumi, A., TINA, G.M., Motahhir, S., Laouid, A.A. (2024): A comprehensive Review of Floating Photovoltaic Systems: Tech Advances, Marine Environmental Influences on Offshore PV Systems, and Economic Feasibility Analysis. – *Solar Energy* 277: 17p.
- [3] Gevorkian, P. (2008): Solar power in building design: the engineer's complete design resource. – *United Diversity Library* 506p.
- [4] Mahmud, K., Morsalin, S., Khan, M.I. (2014): Design and fabrication of an automated solar boat. – *International Journal of Advanced Science and Technology* 64: 31-42.
- [5] Nitonye, S., Adumene, S., Howells, U.U. (2017): Numerical design and performance analysis of a tug boat propulsion system. – *Journal of Power and Energy Engineering* 5(11): 80-98.
- [6] Noosomton, J., Charoensuk, J. (2015): The New Propeller Design 3 Blades Type on 18o Skew Angle and Testing Cavitation of Tailing Thai Boat. – *International Journal of Engineering Research* 4(5): 258-264.
- [7] Odokwo, V.E., Theophilus-Johnson, K., Nitonye, S., Ogbonnaya, E.A. (2022): Influence of Optimized Propulsive Efficiencies on Decarbonization of Ship Emission. – *Journal of Newviews in Engineering and Technology (JNET)* 4(2): 18-28.
- [8] Ogar, O.B., Nitonye, S., John-Hope, I. (2018): Design analysis and optimal matching of a controllable pitch propeller to the hull and diesel engine of a CODOG system. – *Journal of Power and Energy Engineering* 6(03): 53-74.
- [9] Papade, C.V., Kulkarni, S.S., Kulkarni, S.P., Dindure, K.N. (2023): Design and Analysis of Iot-Based Twoseater Solar Boat. – *International Journal of Engineering Applied Sciences and Technology* 8(1): 237-248.
- [10] Soto, J.F., Seijo, R.G., Formoso, J.F., Iglesias, G.G., Couce, L.C. (2010): Alternative sources of energy in shipping. – *The Journal of Navigation* 63(3): 435-448.
- [11] Spagnolo, G.S., Papalillo, D., Martocchia, A., Makary, G. (2012): Solar-electric boat. – *Journal of Transportation Technologies* 2(2): 144-149.

- [12] Tamunodukobipi, D., Samson, N., Sidum, A. (2018): Design analysis of a lightweight solar powered system for recreational marine craft. – World Journal of Engineering and Technology 6(02): 441-456.
- [13] Tercan, Ş.H., Eid, B., Heidenreich, M., Kogler, K., Akyürek, Ö. (2021): Financial and technical analyses of solar boats as a means of sustainable transportation. – Sustainable Production and Consumption 25: 404-412.