DESIGN AND CORRELATION ANALYSIS OF SOLAR IRRADIANCE AND PROPULSION POWER FOR A SOLAR-POWERED BOAT IN NIGERIA MARITIME UNIVERSITY WATERWAY

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Abstract

The viability of the use of solar powered boat for passenger transportation within Nigeria Maritime University (NMU), specifically between Okerenkoko and Kurutie towns, two communities separated by water with 0.270 nautical miles apart, is studied. The solar boat was designed based on engineering specifications with solar power integration for power propulsion. The boat, nicknamed SPB-Rose, has a 6.5m overall length and a 10-passenger seating capacity with a PV solar panel of $0.6615m^2$. It is found that it is a viable solution to operate a solar- powered boat with a solar energy source in this location. Though the sunshine hours are limited to between daily mean of 3.1hrs (1706.69 Wh) in August and 6.2hrs (3878.74 Wh) in November, the implication is that the vessel operation is limited to the range of these daily hours only. It is important to note that even a cruising speed of 0.5knots, it takes about 30mins to sail and convey staff and students between communities under consideration against the present 20mins using internal combustion engine boats. It is suggested that to use the vessel all day, it may be necessary to include a shore-based recharge system with extra batteries for backups at low sunshine hours at NMU.

Keywords: Solar Irradiance, Solar-powered boat, Sunshine hours, electric propulsion

I.   Introduction

Globally, there is a growing focus on renewable and sustainable energy sources, which has resulted in notable advancements in a number of industries, including maritime transportation. One such invention is the solar-powered boat, which provides an eco-friendly substitute for conventional fossil fuel-powered boats (Tamunodukobipi et al., 2018). By using solar energy to power electric motors, these boats lower their operating expenses and greenhouse gas emissions. One excellent way to reduce fuel costs and its impact on the environment's health is through the use of solar electricity. The utilization of energy from sunlight is dependent on its ease of access and suitable technology. The rate at which solar energy is utilized has no influence to its accessibility; thus, cannot be exhausted (Hamidat et al., 2015). Renewable energy technologies have achieved major development thus far and have an enormous capability in Nigeria and may well contribute to reducing our general dependence on fossil fuel in addition to developing our country's security in view of their natural and far-sighted benefits (Hamidat et al., 2016). In Nigeria, the source of power on the speedboat depends only on the outboard spark-ignition engine, which uses fossil fuel.

Renewable energy on speed boat has been implemented in numerous cases as a measure to reduce emissions and noise from speedboat operations. This research aims at powering speedboat with the use of solar energy to meet vessels' power demands while in operation. This research is centered to proffering a solution to the towering cost of speedboat operation in NMU water ways due to the high cost of fuel consumption and maintenance. The objective of this research is majorly to evaluate, design and analyze the impact of SPB from sunshine duration data in NMU waterways. The work of Gupta et al. (2024) aimed at cleaning the water's surface using solar-powered boats in rivers. Its scalability and applicability to other kinds of water bodies, like lakes, ponds, and coastal areas, were not examined. (Hasan et al., 2022) investigated and evaluated the solar-electric boat's design approach for river transportation powered by direct sunlight. The project was meant to be a quick excursion around rivers where, during the summer, public transportation is extremely polluted. Considering that this boat is utilized in sunny conditions, it is feasible to comprehend how much energy it uses and to keep planning the electric boat and energy management/storage system. The research of photovoltaic (PV) system sizing was the primary goal of the work. First, in order to acquire an effective solar photovoltaic system, the ship size estimate is evaluated based on the current ship design. The goal of Hasan et al.(2022) was to devise a plan for better ship design that, in comparison to current ships, gives higher PV output and smaller battery weight. The reliability and performance of the solar-electric boat in many weather scenarios, such as cloudy/rainy days and the winter months, were not considered. (Setiyobudi et al., 2023) conducted a study in Rembang Regency, Indonesia, on the application of solar photovoltaic (PV) and wind turbines for a 14-metre BSC (Blue Swimming Crab) fishing vessel. This study addressed the application of renewable energy sources and their economic implications in meeting onboard electrical needs. This study considered the operating system scenario for a BSC that was stranded in the Java Sea for seven days. The computation findings indicate that 22,960Watt-hours of solar PV and wind turbine energy can be used as electrical energy. 20units at 100 Ah, 12 Volts of battery are needed. Using this technique has the benefit of reducing operational costs by 16%, which can raise fishermen's earnings by 11%.

Göksu & Yüksel (2023) researched the construction of a solar-powered boat which used a system dynamics approach-based simulation to examine the impacts of form-related and environmental factors on power consumption and battery duration. One of the findings of

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Göksu & Yüksel (2023) is that the best way to use the boat is to navigate at no trim angle because the rising trim angle of the boat actually reduces the time it takes for the batteries to discharge. The use of alternative solar panel technologies, such as flexible solar panels, bifacial panels, or cutting-edge materials like perovskites, may have advantages or efficiency gains that were not examined by Göksu & Yüksel (2023). Ivon (2022) analyzed the widespread notion that electric boats are not economically advantageous. Information about all-electric cargo ships (as of 2021, accessible on the internet) was acquired. The main dimensions, speed, and battery capacity of the sample vessels were utilized to determine their relative cargo transit efficiency. The efficiency of electric ships was compared to that of fuel-powered vessels using varying routes and speeds. It has been demonstrated that electric ships are roughly 50% more profitable on short voyages and, if they steam slowly, similarly profitable on medium routes. Sharma & Syal (2021) presented two methods to develop innovative solar-powered boats. One is a hybrid PV-diesel system for a large boat, and the other is a PV-only system for a small boat. According to research findings, a boat with a hybrid system can use less fuel and emit less hazardous emissions. One difficult problem with the hybrid energy for the solar-powered boat system is that the hybrid system is highly complex since the voltage generated by photovoltaic cells needs to be regulated to match the voltage generated by a diesel engine in terms of amplitude, frequency, and phase. Another problem is that load management is necessary due to the low likelihood of PV output energy.

Nora & Ken (2020) examined solar boats for short-distance travel and entertainment. A tracking of maximum power points, battery management system, solar power charging, and overall system design were proposed. The work of Nora & Ken (2020) did not address scalability or commercial viability, instead concentrating on a low-cost, low-power architecture. Dutta et al. (2020) proposed the design of an electric boat with solar power charging for water transport in Bangladesh. The design included the installation of a solar charging station with a net metering system, where all the boats could be charged when needed instead of placing solar panels on each boat. The work of Dutta et al. (2020) ignored the possible advantages of directly installing solar panels onto individual boats in favor of a centralized solar charging station with a net metering scheme. Kulkarni et al. (2020) designed an electric boat that runs on solar power for use by tourists and travelers. The lead acid/lithium-ion batteries used in the boat can be charged at any time by photovoltaic modules mounted on a flat-top structure with the aid of a charge controller or battery management system. The concept is intended for quick trips around rivers and lakes, where summertime public transportation is particularly harmful. Asari et al. (2019) constructed a solar-powered boat by considering the solar panel's ability to collect solar energy, convert it into electrical energy, run motors, and store it in a battery. Additionally, a sun tracking device to optimize the solar gathering process is used by the solar-powered boat.

Syahrihaddin & Imfianto (2019) encouraged the traditional coastal fishing population in Indonesia to employ renewable and sustainable energy sources for their fishing operations. The work of Syahrihaddin & Imfianto (2019) did not address the practical difficulties in putting the suggested approach into practice in Indonesia's traditional fishing communities. Aijjou et al. (2019) provided a concrete illustration of how energy conservation might be implemented by installing solar panels on container ships. The usefulness and difficulties of installing solar panels for the production of auxiliary power on boarding a ship shows how solar energy from photovoltaic cells can be utilized to supplement auxiliary power on small container ships, at least to supply equipment needed for the ship's safety in the event of a mechanical failure.

Chao et al. (2018) showcased a solar-powered boat design that made use of a patented distributed PV power system, which consists of the PV power controller, power optimizer, and maximum power point tracking technology. Nasirudin et al. (2017) presented a methodology to design a solar-powered boat to identify the smallest possible photovoltaic (PV) system size. The work Nasirudin et al. (2017) is based on modelling and simulation with insufficient real-world performance validation. Rodrigues et al. (2016) presented the design and preliminary testing of a solar-powered fishing boat. The concept vessel is a monohull keel boat with an overall length of 4.2 meters that is propelled by an effective DC-DC interleaved boost converter. Kurniawan, (2016) examined and talked about the use of solar energy in ships. Using a catamaran boat with a flat top structure that allows space for solar panels is the greatest way to use solar energy on a ship. Of a truth, lately, there has been a global focus on renewable energy and a desire to avoid fossil fuels. Electric power is now the most effective method for maneuvering a boat. (Hossain et al. 2017).

There is no literature that indicates matching solar irradiance with propulsion power requirements of any SPB. The present work will contribute to modeling sunshine duration data to propulsion power for solar-powered boats.

2. System Description

A solar speedboat (SPB) called SPB-ROSE which includes a 1.5 kW solar PV, and a 440Ah battery bank. powers a boat with an electric motor rated at 1000 rpm. This system is ideal for traditional water boats. The SPB, measuring 6.5m in length and 3.2m in width, is composed of polyester material. It can accommodate up to ten passengers at once and is projected to travel between zero and twenty knots. Fig 1 displays the schematic and block diagram of the boat.
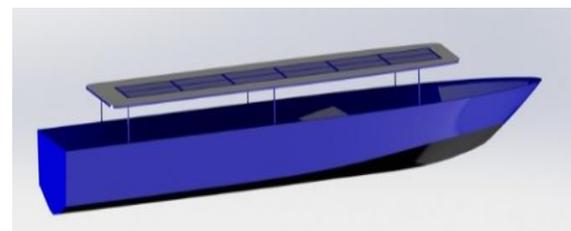

Figure 1. The schematic diagram of the SPB

3. Materials And Methods

Materials involved in the work include:

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1.5 kW solar PV
440Ah battery bank powers
An electric motor rated at 1000 rpm.

The installation of the solar photovoltaic (PV) panel allows to function as direct energy source for the proposed system Mehedi & Iqbal (2020). The PV power is managed by a 140A rated MPPT controller, whose output is coupled to the battery via a charge controller and a boost converter with a constant current (CC) of 25A and a constant voltage (CV) of 49V. The battery bank (BB) is linked to the DC relay. BB is connected to the Motor Speed Controller (MSC) via the 140A rated DC relay, which serves as an overcurrent prevention mechanism. It is suggested to place a manual motor ON/OFF switch between the motor and the speed controller. Ultimately, when the switch is in the ON position, the DC motor transfers mechanical rotary energy to the boat propeller through a coupler and shaft mechanism. The block diagram of the system description is shown in Fig. 2.

Boat dimensioning

Taking 40% of the boat's length into account, the SPB-ROSE dimension is 6.5m × 3.2m with a computed draft height of 0.37m. In fair weather, the general guideline for determining a boat's capacity, that is, its passenger capacity, is to assume that each person weighs an average of 68.5 kg. The Passenger capacity is expressed as:

$$Passenger\ capacity = \frac{L \times W}{15} = 14 \tag{1}$$

For this research, we have considered 10 passengers at a time which is equivalent to 685kg
Where;
L = Boat length in feet
W = Boat width in feet
The entire displacement of water by the boat at full load state must be determined in order to compute the power needed to move the boat at design speed.

$$Weight\ of\ displaced\ water = Total\ load \tag{2}$$
$$Total\ Load = Passenger\ weight + boat\ infrastructure\ weight\ battery\ weight \tag{3}$$
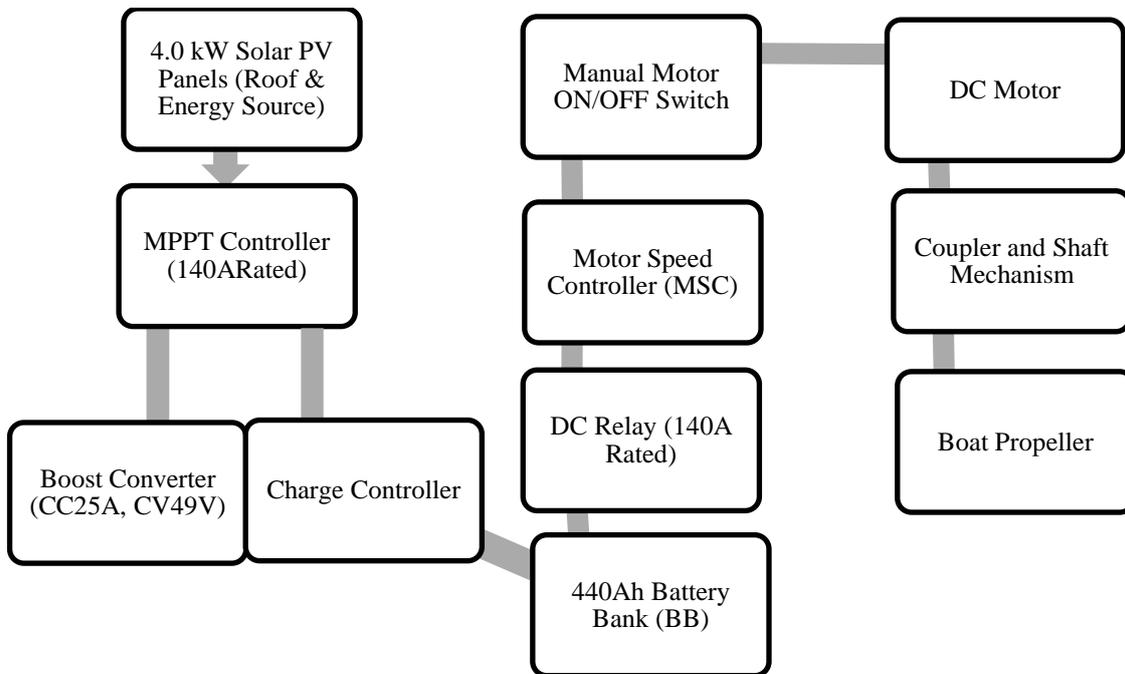$$Weight\ of\ displaced\ water = 2400kg \tag{4}$$

Figure 2. Block diagram showing schematics of system description

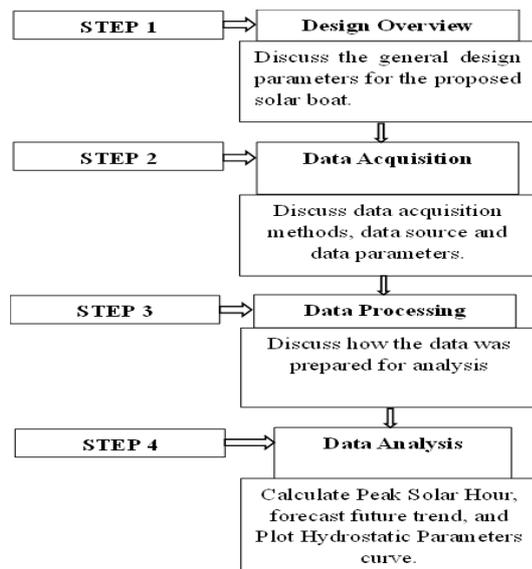The general methodology used in this work is shown in Fig. 3.

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Figure 3. Block diagram of the Proposed Method.

Solar boat's hull speed calculation
Since there are insignificant current or wind, the following Equation 5 specifies the likelihood of excessive drag, the conceptual boat speed, or the highest permitted safety speed :

$$Hull\ Speed = 1.34 \times \sqrt{LWL} \tag{5}$$

Where:
LWL = The length at the water line
The solar boat parameter is shown in Table 1 and details of the batteries in Table 2.

Table 1. Solar Boat Parameter

Boat Description	Parameter
Boat Hull Type	passenger boat (PB)
Boat materials	Fiber Glass Polyester materials
The gross weight of the boat (full load capacity)	2400kg (5291lb)
Passenger on board	10 people
Boat length	6.5m
Boat Midships	3.199m
Draft height (DH)	0.04m (0.13ft)
Boat depth	0.5m (1.64ft)
The displaced	1.713 tones
Wetted Surface (S)	9.079m^2
Maximum Hull speed	8.41knots
Considered Hull speed	0.5 knots

Table 2: The Specification/Details of the Batteries

Battery Description	Specifications/Details
Model	2YS-62P
Series	5000
Manufacturer	Surrette/Rolls
Type	Flooded- Dual Wall
Dimension	27.38" ×9" ×31.63"
Weight	570lb
Nominal Voltage	2V
Rated Capacity (24 hours)	4560AH

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Solar irradiance

Solar irradiance, the power per unit area received from the Sun in the form of electromagnetic radiation, plays a pivotal role in determining the effectiveness of solar energy systems. When using solar energy to charge two (220Ah) battery for a solar-powered speed boat, the amount of sunlight available each day will have a direct impact on the energy harvested, influencing the system's capacity to reach full charge.

The average solar irradiance on Earth varies depending on geographical location, time of year, weather conditions, and angle of incidence. However, a standard measure often used in calculations is 1000 W/m² on a clear day, assuming optimal conditions. To calculate the daily energy collected by a solar panel, we multiply the irradiance by the panel's area and its efficiency. For instance, if a solar panel has an efficiency (η) and an area (A), the power generated by the panel, (P), under direct sunlight is:

$$P = Solar\ irradiance \times A \times \eta \qquad (6)$$

$$Solar\ irradiance = SSH \times ISC \times T \qquad (7)$$

Where;
SSH = Sunshine Hour
Solar constant (ISC) = 1366w/m²
Atmospheric Transmittance (T) = 0.75, $\eta = 1$

Daily monthly average solar irradiance:

The average solar irradiance for each month was calculated by taking the mean of the monthly solar irradiance values for each year (2015–2020) shown in Appendix A.

Trend Analysis:
A time series trend analysis was performed on the monthly average solar irradiance data. PV array characteristic curve for various solar irradiances will also be analyzed. Correlation analysis was performed to relate the amount of solar power generated on a monthly daylight propulsion power requirements of the SPB-Rose

Data acquisition

This section discusses the data collecting process used for this study. Accurately projecting the performance, stability, and efficiency of the vessel and comprehending the consequences of utilizing solar power as the primary propulsion system all depend on the data needed for such a project

A number of crucial procedures were engaged in the data collection process to guarantee that the solar-powered boat's design was both effective and able to achieve performance goals. The subsequent actions were performed:

Solar Irradiance:
The assessment of solar energy resource in Delta State using Nigeria Maritime University as case study. Peak Sunshine Hour data shown in Table 3 was obtained from Nigeria Meteorological Agency (NIMET) from the year 2015 to the year 2020.

Table 3. Peak sunshine hour of NMU

Months	2015 (hrs.)	2016 (hrs.)	2017 (hrs.)	2018 (hrs.)	2019 (hrs.)	2020 (hrs.)
January	4.0	6.2	4.8	4.4	4.41	4.3
February	6.0	3.7	4.9	5.53	5.52	4.4
March	4.5	5	5.7	4.8	4.87	4.31
April	5.9	3.9	4.4	4.4	4.5	3.80
May	5.1	4.5	5.1	4.02	4.02	4.49
June	4.0	3.9	1.8	3.7	3.74	2.31
July	3.1	2.8	1.4	3.33	3.34	3.45
August	3.3	2.2	1.3	2.38	2.3	3.63
September	2.6	3.1	2.0	3.3	3.85	3.56
October	4.0	4.0	4.1	3.85	3.33	4.12
November	6.2	6.2	5.8	5.4	5.44	5.3
December	5.6	6.1	5.4	5.75	5.76	5.66

Source: Nigeria Meteorological Agency (NIMET)

Hull Geometry:

Maxsurf Modeler was used to define the hull geometry in the first phase of data collecting. Hull lines were produced using the vessel's anticipated displacement as well as its length, beam, and draft as the starting design parameters. The modeler made it possible to precisely adjust the hull's

shape, guaranteeing the best hydrodynamic performance with the least amount of resistance.

Hydrodynamic Data:
Resistance data were gathered using Maxsurf Resistance in order to assess the hull design's hydrodynamic

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efficiency. Numerous resistance elements, including residual and frictional resistance, were calculated at various rates. This information was crucial in figuring out the boat's power needs, which in turn affected how the solar power system was designed. The gathered information was checked against performance standards for comparable ships to make sure the hull shape would lead to the least amount of energy being used.

Total resistance and power

The effective power for the ship at its operating speed has to be determined in order to aid in the engine selection process. It was necessary to first determine the total resistance (R_T), as it is a function of the effective power. Given the ship's Froude number at different speeds and the prismatic coefficient, a relationship for the coefficient of residual resistance (C_R), coefficient of friction resistance C_F and coefficient of total resistance C_T were used with the C_R depending on the Froude's number as:

$$C_T = C_R + C_F \qquad (8)$$

$$R_T = 0.5 * p * S * V^2 \qquad (9)$$

Here, v denotes the ship's velocity, S denotes its wetted surface area, and ρ denotes the fluid's density (presumably salt water) that the ship is floating in. Equation 10 was used in this calculation to get the ship's wetted surface area S as:

$$S = C * SQRT(Vol.) * L \qquad (10)$$

Where C=Coefficient (depending on ship form), Vol.=Volume displacement of the ship and L =length of the ship.

Lastly, Equation 11 might be used to get the effective horsepower given the ship's total resistance.

$$P = R_T * V \qquad (11)$$

4. Results and Discussions

Results and analysis

The solar power and propulsion power of the SPB-Rose is shown in Table 4.

The daily mean sunshine hour in a month is averaged from Table 3.

The daily meaning solar irradiance (wh/m^2) in a month is calculated from Equation 7.

The power generated from the panel for the sunshine hour under consideration is calculated from Equation 6

SPB-Rose propulsion power required 0.5knot with wetted surface of 9.079m^2 of Table 1 (for the same sunshine hour) is calculated from Equations 9 and 10.

The total panel area was 0.6615 m^2 and a hull speed of 0.5m/s was used in calculating the SPB-Rose propulsion power requirement (for the same sunshine hour).

Table 4. Solar Power and Propulsion Power of the SPB-Rose

Month	Daily mean sunshine hour in a month	Daily mean solar irradiance in a month (wh/m2)	power generated from the panel (wh) for the sunshine hour	SPB-Rose propulsion power required @ 0.5knot (for the same sunshine hour)	Difference in power needs	% difference
Jan	4.69	4799.78	3175.05	2727.704	447.35	14.09
Feb	5.01	5131.04	3394.18	2913.816	480.37	14.15
Mar	4.86	4982.49	3295.92	2826.576	469.34	14.24
Apr	4.48	4593.18	3038.39	2605.568	432.82	14.25
May	4.54	4649.52	3075.66	2640.464	435.19	14.15
Jun	3.24	3321.09	2196.90	1884.384	312.52	14.23
Jul	2.90	2974.47	1967.61	1686.64	280.97	14.28
Aug	2.52	2580.03	1706.69	1465.632	241.06	14.12
Sept	3.07	3143.51	2079.43	1785.512	293.92	14.13
Oct	3.9	3995.55	2643.06	2268.24	374.82	14.18
Nov	5.72	5863.56	3878.74	3326.752	552.0	14.23
Dec	5.71	5851.6	3870.83	3320.936	549.90	14.21

The fifth column (difference in power needs) was found by subtracting the solar power generated from the SPB-Rose propulsion power needs for the same sunshine hour. Comparison of the solar generate-able power using efficient panels of total area 0f 0.6615m^2 installed onboard the SPB Rose and the propulsion power need of the marine craft (SPB Rose) at hull speed of 0.5knots and same sunshine hours is shown Fig. 4

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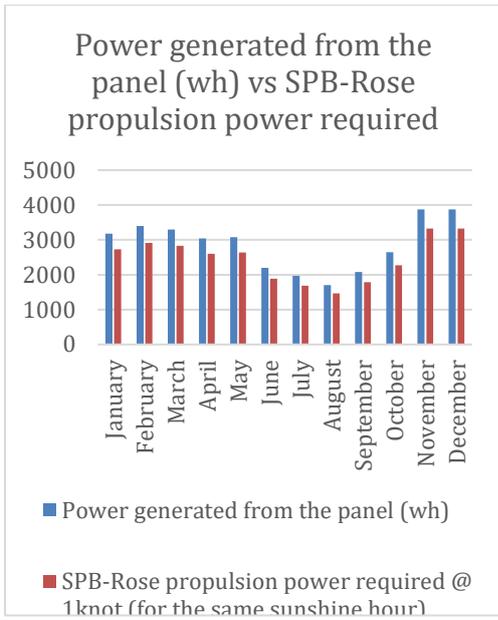**e-ISSN: 24085162; p-ISSN: 20485170; December, 2025: Vol. 10 No. 3 pp. 015 – 023**

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Figure 4. Comparing solar power generation on SPB Rose and her propulsion needs for the same sunshine hour

The yearly trend of solar irradiance and therefore, the solar power generate-able is shown in Fig.5 for the years under consideration.
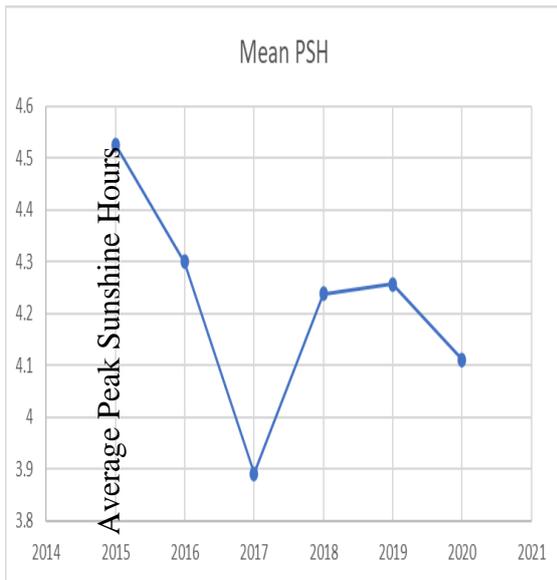

Figure 5. Average Peak Sunshine Hour (PSH) Trend (2015-2020)

The basic ship plan using the dimensions of the proposed solar powered boat and plots of the vessel's hull design are shown in Figure 6 to 8.
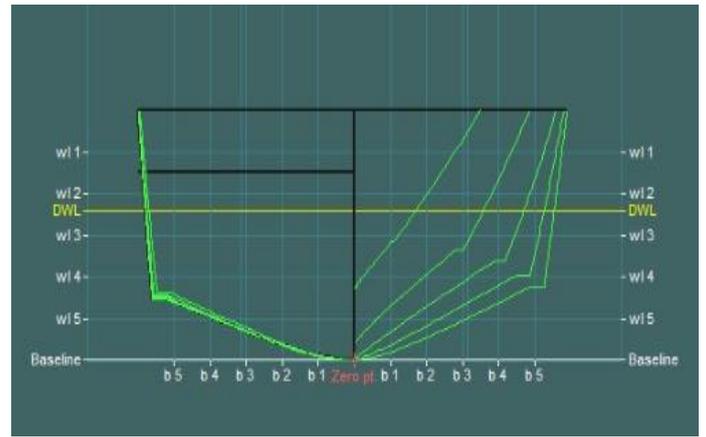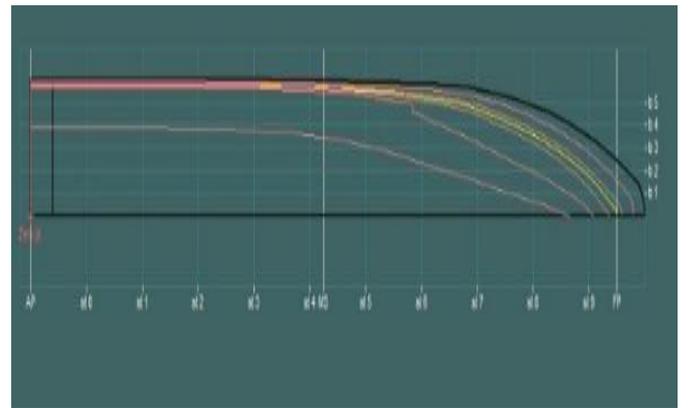

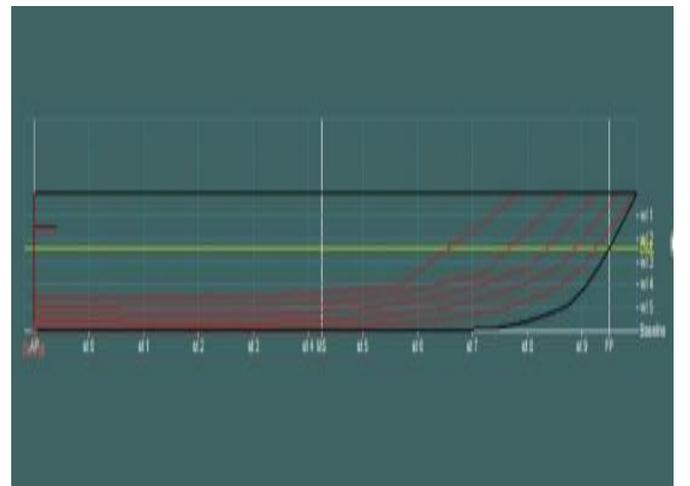Figure 6. Body Plan of the Solar Powered Boat

Figure 7. Half-breath Plan

Figure 8. Shear Profile of the Solar Powered Boat

Discussion of results

Table 3 describes the power generated from the panels and the propulsion power needs of the marine craft (SPB Rose) at 0.5knot for the same sunshine hour. It is found that within the same sunshine hours, the solar generated power for the SPB Rose is enough to power and propel the craft but only at within 0.5knot. This is represented in the bar chart of Fig 4. The blue bar represents the power generated from the panel and the red represents the SPB-Rose propulsion power required for the same sunshine hour.

From the Table 3 and Fig. 4. it can be seen that the highest propulsion power is obtained between November and

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March, coinciding with the period of dry season. On another hand, the lowest power is obtained between June and October, coinciding with the period of rainy season with the lowest in August.

Though the sunshine hour is adequate for propulsion power to sail passengers from Okerenkoko to Kurutie. The significance of this result is that for the craft to operate beyond the limited sunshine hours, there may be need to include a shore-based recharge battery system.

Fig.5 is an indication of very varying trend and may be attributed to climate change conditions. As has been described earlier, due to these large variations, planning a solar-powered propulsion system imply the need for adjustments in power storage or supplementary energy sources to maintain propulsion effectiveness across varying weather patterns.

Figs. 6 to 8 show the naval design estimates of the craft. The estimates and design made for the SPB Rose shown in Fig.1

As described by many authors in our review, it is found that operating the boat at lower speeds is likely more efficient and sustainable, given that less power is required. This could help in conserving energy, especially for a solar-powered vessel with limited energy storage. In this present work, it is observed that as the speed increases towards 2.5 m/s, the power requirements rise sharply. This could be a limitation for the solar powered board, as the energy generation from solar panels may not be sufficient to keep up with the power demand at higher speeds.

5. Conclusion
This research focused on the design and analysis of a solar-powered boat (SPB-ROSE) for the Nigeria Maritime University (NMU) waterways located in Niger Delta of Nigeria. With growing concerns over climate change, high fuel costs, and pollution caused by fossil-fueled boats, the study sought to explore solar energy as a sustainable alternative. Using sunshine duration data, hydrodynamic simulations, and MATLAB/Maxsurf modeling, the research successfully developed a solar-powered boat design capable of meeting propulsion demands. The findings confirmed that solar power is a feasible and effective energy source for speedboat operations in NMU's waterway, allowing for reduced fuel dependency, lower greenhouse gas emissions, and minimal environmental impact.

The study concludes that the integration of solar-powered generators into speedboat operations is a viable and sustainable alternative for NMU's waterway. Additionally, the resistance and power assessments aligned the solar-powered system with the boat's speed and propulsion needs, ensuring the design meets operational demands without compromising performance. The results demonstrate that NMU's waterways receive sufficient sunlight to maintain consistent solar-powered operation up to about 5hrs daily in some days. Transitioning to solar-powered boats not only reduces operational costs but also minimizes air and noise pollution, contributing positively to the environment and the overall sustainability goals of NMU.

To further support the adoption and effectiveness of solar-powered boat technology, the following recommendations are proposed:

Promote Solar-Powered Boat Policies: NMU and regional maritime authorities should develop policies encouraging the use of solar-powered boats, including potential subsidies or incentives for operators who transition from fossil fuels to renewable energy sources.

Curriculum Integration: NMU should integrate renewable energy studies into its maritime engineering programs, with a focus on solar-powered propulsion and sustainable boat design. This can develop the technical skills necessary for future professionals to contribute to eco-friendly maritime innovations.

Optimization of Battery and Power Management: Further research into advanced battery storage and power management systems would improve the SPB's performance, especially during periods of low sunlight. This can enhance reliability and operational hours.

Community and Stakeholder Engagement: Educating and engaging local stakeholders about the benefits of solar-powered boats could drive wider adoption and foster a sustainable energy culture within the maritime community.

Finally, this study provides an innovative framework for designing solar-powered speedboats tailored to the unique environmental and operational needs of any location of waterways under consideration and not just for NMU alone. By correlating solar irradiance data with propulsion power requirements, the research advances the understanding of renewable energy applications in marine transport.

6. Acknowledgements

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