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Hybrid Propulsion System Analysis for A Solar Powered Offshore Supply Vessel

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Abstract- This project focuses on the analysis of a solar-powered hybrid propulsion system for an Offshore Supply Vessel (OSV). The study explores the integration of solar energy into traditional diesel-electric propulsion to reduce fuel consumption and emissions. The system's performance is evaluated under specific conditions, including the vessel's speed of 14.5 knots and solar specifications such as 24V energy storage and a solar panel output of 380W. The Energy Efficiency Design Index (EEDI) is calculated for two operational scenarios: one where the vessel runs solely on diesel-electric propulsion for 10 hours daily over five days, and another where the operation is split evenly between solar and diesel-electric propulsion. The study leverages the average sunlight hours in Rivers State to optimize solar power usage, aiming to reduce greenhouse gas emissions and improve fuel efficiency. The results demonstrate the potential benefits of hybrid propulsion systems in improving operational efficiency and sustainability for offshore vessels. The analysis revealed that the total EEDI that will be produce for diesel generator only will be 949.1gCO$_2$/ton-mile. Also, the findings suggests that the EEDI when the propulsion system alternates between diesel and solar energy for 5 hours each reduces across all speeds compared to the diesel-only system. For example, at 14.5 knots, the EEDI decreases from 35.07 gCO2/ton-mile in the diesel-only case to 17.43gCO2/ton-mile in the solar-hybrid system. This underscores the environmental benefit of integrating solar power with diesel engines to achieve cleaner operations, especially at higher speeds. In terms of specific fuel consumption (SFC) of the diesel-only propulsion system compared with the solar-hybrid propulsion system at varying vessel speeds. The data shows that as vessel speed increases, the SFC also rises for both systems, but the hybrid system consistently exhibits lower fuel consumption. For example, at 14.5 knots, the diesel system consumes 176 g/kWh, while the hybrid system reduces this to 175 g/kWh.

Indexed Terms- EEDI, SFC, Hybrid Propulsion, Ship Resistance, Energy Demand

I. INTRODUCTION

Over the past years, due to issues such as air pollution and rising fossil fuel prices, governments, industry and researchers try to find a suitable alternative for conventional maritime transport. It was thought of that hybrid propulsion system on small tug boats, yachts and ships are one of the key technology developments in the maritime industries. for this reason, the need for installation of solar-hybrid propulsion system on marine vessels is necessary. The background of this study focuses on the analysis of solar powered hybrid propulsion systems for Marine vessel utilizing offshore support vessel also known as (OSV) as a comprehensive case study. These vessels transport equipment and personnel (crew) to and from offshore facilities, often operating in harsh and demanding environmental conditions [1].

Given the high operational costs and environmental concerns associated with traditional diesel-powered propulsion systems, there has been an increasing focus on exploring alternative and more efficient propulsion technologies for such solar-hybrid propulsion systems. Hybrid propulsion is any propulsion system that includes two or more sources of propulsion in one design, which can be used together or alternately [2].

According to Geertsma [3], hybrid propulsion systems combine conventional diesel engines with electric motors and energy storage devices, such as batteries or ultra-capacitors. These systems offer several advantages over traditional propulsion systems, including improved fuel efficiency, reduced emissions, and greater operational flexibility. They added that to enforce these advances, the International Maritime Organization (IMO) should impose the

MARPOL Regulations increasingly stringent restrictions on ship's emissions.

Notti and Sala [4] stated that due to the ease of system modification and relatively low cost, many considerations are being made to improve the ship's propulsion system in a hybrid manner in the form of combining the solar powered system to a hybrid propulsion system. This process involves striking a balance between performance, efficiency and cost, while considering factors such as the vessel's operational profile, expected power demands, and environmental conditions.

Offshore supply vessel (OSV) is a ship specially designed to supply offshore oil and gas platforms and other offshore installations. They typically range from 50 to 100metres (160 to 330 ft) in length and are distinguished by the large open deck area used to store supplies and house equipment and to allow for efficient loading and offloading. The primary function for most of these vessels is logistic support and transportation of goods, tools, equipment, and personnel to and from their destination. However, the successful implementation of these systems requires a thorough understanding of the vessel's operational requirements, careful system design and optimization, and the development of robust control strategies that can adapt to dynamic and challenging operating environments [5].

Aboud and Ali [6]defined a propulsion system as a system that a ship depends on in travelling and maneuvering in the existence of different types of waves, which reduce the efficiency of the system. This propulsion takes place due to the thrust produce that moves the vessel forward. As the vessel moves through fluid whether air or water it is acted upon by four forces which are lift, weight, thrust and drag. These Propulsion systems consist of the main engine, gear box, shaft, bearings and propeller. Hybrid propulsion systems, which combine traditional diesel engines with electric motors and energy storage devices, have emerged as a promising solution for improving the efficiency and reducing the emissions of marine vessels during operation.

In 2022, international shipping alone accounted for nearly 3% of the world's GHG emissions. The transportation sector, including shipping is responsible for about 20.2% of the world's total CO_2 emissions, making it the second-largest contributor to global carbon pollution. The Attainment of environmental quality is it through air or water pollution, remains germane for economics worldwide [7].

The present study is devoted to the effects of shipping on environmental emissions. Focusing on the effects of shipping on environmental emissions is particularly important due to its contribution to increasing emissions of greenhouses gases in recent times [8]

The integration of hybrid propulsion system in maritime transportation is a sustainable approach for emissions reduction, fuel consumption and reduction of vibration/noise. This optimization was written by many authors one of which is Dastjerdi [9] (John, 2004). Who demonstrated that hybrid electric vessel could provide an answer to the ever-increasing need for lowering- pollution and fuel-efficient forms of personal transport.

The integration of solar power in maritime transportation is a sustainable approach to reduce the environmental of vessels, from ferries to cargo ships. For instance, Smith [8] demonstrated that solar-assisted propulsion systems can substantially decrease fuel consumption and emissions in a passenger ferry. This research provides essential insights into the benefits of solar power adoption in maritime applications, which can be applied to a solar-powered hybrid propulsion system for an offshore supply vessel.

According to Haung, [10] energy storage plays a critical role in balancing demand and supply in renewable energy systems, especially for intermittent energy sources like solar or even wind. The study emphasized that storage systems can help smooth out these discrepancies between production and consumption, improving grid reliability and stability. This is particularly relevant in regions where solar power serves as a replacement for coal or natural gas-fired power plants. A life-cycle analysis by Pellow [11] demonstrated that solar systems with integrated energy storage dramatically lower the carbon footprint of electricity generation. Somes types of Energy storage system are batteries, Lithium-ion batteries are the most common form of energy storage in solar power systems due to their high energy density, long cycle life, and decreasing cost. Lithium-ion batteries are particularly well-suited for residential solar systems because they offer a balance of efficiency, cost, and durability.

II. MATERIALS AND METHODS

Solar Panel Formulation

Also, Beyond the stated design power rating of the solar panel, the real electrical output (Esp) generated by the panel was determined using the relation;

$Esp = ICS \times \eta_{sp} \times A_{sp}$ (1)

Where:

ICS = Solar Constant (depends on geographical location)

η_{sp} = Design Efficiency of Solar Panel

A_{sp} = Surface Area of Solar Panel

Power of Electric motor

$Pm = V \times I$ (2)

Integration of solar Power in hybrid propulsion systems by Analyzing the Power Requirements and Solar Input

The Solar-powered hybrid propulsion system for offshore supply vessels offers a sustainable solution by combining renewable solar energy with traditional diesel engines. This integration allows for a reduction in fuel consumption, emissions, and overall operational costs, making maritime operations more efficient and environmentally friendly. Solar panels installed on the vessel harness solar power, which is stored and utilized alongside conventional energy sources to drive the vessel. The diagram illustrating the configuration and operation of this hybrid system is shown below, detailing the interaction between the solar panels, energy storage system, and propulsion mechanisms.

Solar system design involves the sizing of the various components that make up the solar system (solar panel, charge controller, battery bank, rectifier and inverter) required to meet up the energy demand of the system. [12]

In order to properly size the battery bank, one most first of all obtain the average energy demand and the day of autonomy of the storage. Hence, the estimated energy storage of the bank is obtained using the following expression:
Hence, the estimated energy storage of the bank is obtained using the following expression:

$E_{est} = E_d \; x \; D_{aut}$ (3)

Where;

E_{est} is Estimated Energy Storage

E_d is the Average Energy Demand

D_{aut} is the Day of Autonomy

Safe energy storage is essential for efficient and reliable power management systems, particularly in renewable energy applications. It can be calculated using this formula:

$E_{safe} = \frac{E_{est}}{DOD}$ (4)

Where;

E_{safe} is Safe Energy Storage

DOD is Depth of Discharge

The Total Battery Capacity can be gotten by

$C_{tb} = \frac{E_{safe}}{V_b}$ (5)

Where;

C_{tb} is the Total Capacity of the battery bank in ampere-hours

V_b is the battery rated DC voltage

According to the power needed we have to calculate the number of batteries that will be used. This can be calculated by;

$N_{td} = \frac{C_{td}}{C_b}$ (6)

Where;

Ntb is the total number of batteries in the bank

Cb is the Capacity of Selected battery

Assuming the number of batteries that are connected in series we use

$N_{bs} = \frac{V_{dc}}{V_b}$ (7)

The Average Energy Demand

$E_{RD} = \frac{E_d}{\eta_b \eta_i \eta_c}$ (8)

Where;

E_{rd} is Daily Average Demand

$\eta_{b \text{ is}}$ Battery Efficiency

η_i is Inverter Efficiency

η_c is Charge Controller Efficiency

The average peak power is obtained by;

$$P_{ave,peak} = \frac{E_{RD}}{T_{sh}} \quad (9)$$

Where; Pave,peak is Average Peak Power

Tsh is Average Sun Hours

To estimate the total DC current of the system Idc is given by;

$$I_{dc} = \frac{P_{ave.peak}}{V_{dc}} \quad (10)$$

Where; Idc Total DC current of the system

V_{dc} DC voltage of the PV array

If the number of modules in series is needed it can be gotten by;

$$N_{sm} = \frac{V_{dc}}{V_{rm}} \quad (11)$$

Where;

N_{sm} is the number of modules in series

V_{rm} Rated DC voltage of the module

Similarly, the number of modules in parallel

$$N_{pm} = \frac{I_{dc}}{I_{rm}} \quad (12)$$

Where;

N_{pm} Number of modules in parallel

I_{rm} rated current of the modules

To Estimate the total number of modules that forms the array is determine by;

$$N_{tm} = N_{sm}\ x\ N_{pm} \quad (13)$$

To estimate number of panels needed we use:

$$Number\ of\ panel = \frac{Daily\ energy\ consumption(kWh/day)}{Daily\ energy\ production\ per\ panel(\frac{kWh}{day})} \quad (14)$$

Where;

$$\text{DEP}\ \left(\frac{\text{kWh}}{\text{day}}\right) = \text{SPRW x ASH} \quad (15)$$

DEP is Daily energy production per panel

SPRW is Solar panel rated wattage

ASH is Average sun hours

Ship Resistance Analysis

Considering that the vessel's speed is also dependent on the resistance and the proportion force is proportional to ship's speed. (Mohsen et al., 2020). Hence it can be illustrated as follows:

$$P_x = R_x\ x\ V_x \quad (16)$$

Where;

P_x = the electric motor' power in KW

R_x = the vessel resistance in N

V = the shipping speed in m/s

$$P_m = \frac{Estimated\ Power}{Propulsion\ Efficiency} \quad (17)$$

P_m = the motor power Kw

Ship's resistance is represented as (Mohsen et al., 2020)

$$R_x(V_x) = C_T(V_x)\frac{\rho_s}{2}V_x^2 S \quad (18)$$

Where;

ρ_s = mass density

S = the wetted surface of the ship

C_T = the total resistance coefficient

The wetted surface area

$$S = L \times B \times C_{wp} \quad (19)$$

C_{wp} is assumed between the range of 0.7 – 0.85 for a typical vessel

$$C_F(V_x) = \frac{0.075}{(log_{10}R_x(V_x)-2)^2} \quad (20)$$

The above is the frictional resistance coefficient (C_F)

$$R\_n(V_x) = \frac{(V_x\ \ x\ \ L)}{v} \quad (21)$$

R_n = Reynolds Number

$$R_T = R_f\ x\ R_r \quad (22)$$

Where: R_T = total hull resistance

R_f = frictional resistance

R_r = Residuary resistance

Note: since the particular type of OSV used is a low or medium speed vessel. Its residuary resistance is typically 10-20% of the total resistance. Therefore; for this vessel we will use 15%.

Therefore;

$$R_r = 0.15\ x\ R_f \quad (23)$$

Fuel Consumption Analysis

The formula below can be used to find the mass of fuel consumption for a specific output power of the diesel generator. (Mohsen *et al.,* 2020).

$$M_x^F = SFOC\ x\ P_x^{DG} \quad (24)$$

Where; P_x^{DG} = the output power of the diesel generator in (KW)

M_x^F = the fuel consumption in (g/h)

Emission Analysis

The Energy Efficiency Design index (EEDI) is a regulatory measure set by the International Maritime Organization (IMO) to establish a standard for emissions reduction in the maritime industry.it serves as a benchmark for the energy efficiency of new ships, ensuring that they meet specific criteria to minimize fuel consumption and greenhouse gas emission. The EEDI encourages innovation in ship design and propulsion systems to achieve higher efficiency levels. The formula used to EEDI is as shown below.

$$EEDI = \frac{P.ME\ x\ SFC\ x\ C_f}{DWT\ x\ V_S}(gCO_2 ton - mile) \quad (25)$$

P.ME = O.75 x MCR

Where;

P.ME = Power of Main Engine

SFC = the specific fuel consumption

DWT = the dead weight

MCR = the maximum continuous rating

C_f is the carbon conversion factor is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The different C_F value of the various types of fuels is as shown below

Table 1: Reference value of C_F for different fuel type [13]

Type of Fuel	Reference	Carbon Content	CF(t-CO2/t-Fuel
1. Diesel/Gas	Oil ISO 82I7 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquefied Petroleum Gas (LPG)	Propane butane	0.819	3.000000
		0.827	3.030000
5. Liquefied Natural Gas (LNG)		0.75	2.750000

Determination of Average Energy Demand

In order to estimating the average energy demand for the above-mentioned vessel specification, state that the Vessel speed (V_s)=14.5knot and length overall (L) =83.4m, kinematic viscosity, ν can be gotten from the ITTC Recommendation procedures at 20^0C. Therefore $\nu=1.00034\ x\ 10^{-6} m^2/s$

V=14.5 x 0.5144 =7.46m/s

Therefore, from equation (21)

$R_n = \frac{7.46\ x\ 83.4}{1,0034\ x10^{-6}}$ = 619956069.4

Fractional resistance coefficient,

$C_f = \frac{0.075}{(Log619956069.4-2)^2}$ = 1.626 x 10^{-3}

wetted surface area, $S = L\ x\ B\ xC_{wp}$ = 1050.84m^2

frictional resistance,

$R_f = 0.5\ x\ 1.626\ x10^{-3}\ x\ 1025\ x\ 7.46^2\ x\ 1050.84$ = 48733.62N

$R_r = 0.15\ x\ 48733.62\ = 7310.04N$

Total hull resistance,

$R_T = 48733.62 + 7310.04 = 56043.7N$

Effective Power,

$P_E = 56043.7\ x\ 7.46 = 418085.73W\ or\ 418.1kW$

Assuming propulsion efficiency is 0.85 since the boat will be propelled at a speed of 14.5knot. Therefore, the power of the motor will be:

$P_m = \frac{418.1}{0.85} =$ 491.87kW

In this work we will use the data collected from NIMET for the average sunlight hour in Rivers State [14] to be around 4.5 -5.5hrs. let's take the average sunlight hours to be 5hrs and both the battery efficiency and charge controller efficiency to be 90% and depth of discharge is 80%

Average Energy Demand,

E_d=491.87 x 5 = 2459.3kWh

Estimated energy storage, E_{est}=2459.3x1 = $2459.3kWh$

Safe energy storage, $E_{safe} = \frac{2459.1}{0.8} = 3074.1kWh$

Total capacity of the battery needed if the battery bank has a DC voltage of 24V,

$C_{td} = \frac{3074.1x1000}{24}$ = 128090A.h

If the selected battery is 573A.h the number of batteries to be connected in series will be 224

Determination for the Number of Panel need for the vessel specification

Recall that from table 3.2 the solar panel rated output wattage is 380W, And the estimated average sun light is 5hrs/day

Therefore, to determine the daily energy production per panel is

Daily Energy Production per panel $\left(\frac{\text{kWh}}{\text{day}}\right) =$ 0.38 x 5 = $1.9kWh/day$

$Daily\ energy\ consumption\left(\frac{kWh}{day}\right) = \frac{2459.3}{0.9\ x\ 0.9X0.9}$

$= 3373.53kWh/day$

$Number\ of\ panel = \frac{3373.53kWh/day}{1.9kWh/day} = 1776panels$

Determination of the EEDI that will be produced in 5days when run for 10hrs at different speed

Since we are trying to analyze the EEDI to be produced, the Power of the diesel generator and fuel and consumption will increase with the vessel's speed. Therefore, as the speed of the vessel increases; the power will in by an addition between 600-750Kw, While the specific fuel consumption will increase by 1g/kWh or decreases by 1g/kWh as the vessel's speed increases or decreases.

Note: since the specific fuel consumption is not known and not stated by the manufacturer it is assumed to be 211g/kwh for 14.5knot.

Hence the analysis from the given data using spread sheet can be summarized in the table below.

Table 2: Energy Efficiency Design Index (EEDI) for Diesel Generator at Various Vessel Speeds

Power (Kw)	SFC(g/kWh)	Time(hrs)	Cf (t-CO2/t-Fuel)	CO_2 (gCO_2)	Speed (knot)	Distance (Dnm)	EEDI (gCO2)
3600	176	10	3.21	20338560	14.5	145	35.07
4000	177	10	3.21	22726800	15.5	155	36.66
4400	178	10	3.21	25140720	16.5	165	38.09
4800	179	10	3.21	27580320	17.5	175	39.4
5200	180	10	3.21	30045600	18.5	185	40.6

From Table 2 the total EEDI = 35.07+36.66+38.09+39.4+40.6= 189.82gCO_2/ton-mile

Therefore, in 5days, Total EEDI that will produce becomes for diesel generator only will now be 189.82x 5 = 949.1gCO_2/ton-mile

Determinations of EEDI to be producing 5days if the estimated 10hrs voyage is shared equally between the main engine and renewable energy

Since the generator is supposed to run for 5hrs while the renewable energy will work for the remaining 5hrs. Therefore, there will be a decrease in specific fuel consumption, in this work we will assume that the decrease will be by 1g/kWh from the initial 10hrs SFC. But the power of the engine will increase as the vessel speed increases. Using the data below, the analysis results can be summarized as shown in table 3 below.

Given: D=145nm, T=5hrs, Cf =3.21 t-CO2/t-Fuel, P= 3600kW, SFC =175g/kWh, V_s =14.5knot

Table 3: EEDI for Combined Diesel and Solar-Hybrid Propulsion System

Power(kW)	Time(hrs)	SFOC(g/kWh)	Cf(t-CO2/t Fuel)	Vessel Speed (knot)	Distance(nm)	EEDI($gCO_2/ton-$mile)
3600	5	175	3.21	14.5	145	17.43
4000	5	176	3.21	15.5	155	18.23
4400	5	177	3.21	16.5	165	18.94
4800	5	178	3.21	17.5	175	19.59
5200	5	179	3.21	18.5	185	20.19

From Table 3 the total EEDI = 17.43+18.23+18.94+19.59+20.19= 94.38gCO_2/ton-mile

Hence, the total EEDI that will produce in 5day will be = 94.38x 5 = 471.9gCO_2/ton-mile

Determination of the Daily energy consumption for the remaining 5hrs per day for 5days

Table show the summary of energy consumed by the vessel at different speed of operation

Table 4: Daily Energy Consumption at Different Vessel Speeds for Hybrid Propulsion System

Vessel Speed (knot)	Total Resistance(N)	Motor Power (kW)	Running hours (hrs)	Energy demand (kWh)	Daily Energy consumption ($\frac{kWh}{day}$)
14.5	56043.7	491.87	5	4259.3	3373.33
15.5	63411.1	594.57	5	2972.9	4078.00
16.5	71386.6	713.03	5	3565.1	4890.40
17.5	79625.4	843.1	5	4215.5	5782.53
18.5	88470.1	990.9	5	4954.3	6796.05

Therefore, the total daily energy consumption is 24920.30

III. RESULTS AND DISCUSSION

The amount of the EEDI emission that will be produced in 5days when running a diesel generator for 10hrs at different vessel speed is as shown in figure 1. The result determined for running both the diesel generator and Renewable energy for a total of 10hrs with along same distance with varying speed that is, the voyage is supposed to be done for 10hrs, but in other to reduced emission and specific fuel consumption it now shared between the normal electric propulsion system and the renewable propulsion system (Figure 1)

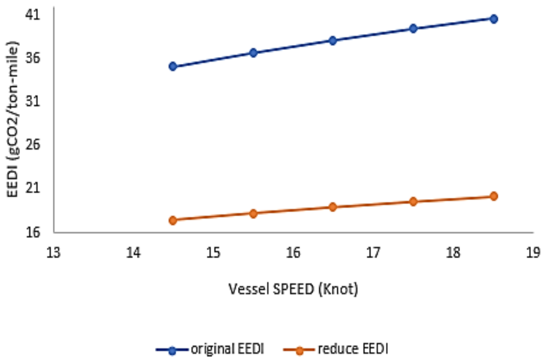

Fig. 1: Comparison of EEDI at Various Vessel Speeds for Diesel Propulsion and EEDI Reduction with Solar-Hybrid Propulsion System at Various Vessel Speeds

Comparing the results for the both cases, it clearly shows that there was reduction due to the fact that the electric-propulsion was not run for 10hrs but instead for 5 hours due to the help of the renewable energy system installed.

The estimation of the energy that will be consumption in 5 hours using different vessel speed and hull resistance is also properly detailed in figure 2. The Energy Efficiency Design Index (EEDI) of a diesel-powered propulsion system at different vessel speeds. The EEDI increases as the vessel's speed rises, highlighting the greater fuel consumption and CO2 emissions produced at higher speeds. For instance, at 18.5 knots, the EEDI peaks, showing the most inefficient energy use, whereas lower speeds such as 14.5 knots have a more favorable EEDI. This showcases how speed plays a critical role in determining the vessel's environmental impact.

The chat in figure 1 above also shows the EEDI when the propulsion system alternates between diesel and solar energy for 5 hours each. The hybrid system demonstrates a clear reduction in EEDI across all speeds compared to the diesel-only system. For example, at 14.5 knots, the EEDI decreases from 35.07 gCO2/ton-mile in the diesel-only case to 17.43gCO2/ton-mile in the solar-hybrid system. This underscores the environmental benefit of integrating solar power with diesel engines to achieve cleaner operations, especially at higher speeds.

Figure 3 and 4 is an illustration of the relationship between specific fuel consumption (SFC) and the rate of EEDI of the case study vessel. Figure 3 shows that for a diesel Propulsion system and figure 4 for that of a Hybrid propulsion system

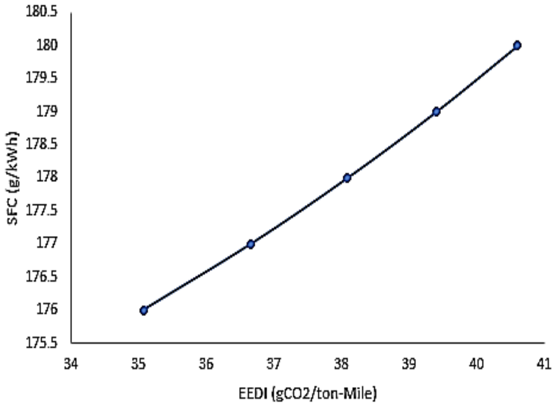

Fig. 3: Specific Fuel Consumption vs Vessel Speed for Diesel

This graph compares the specific fuel consumption (SFC) of the diesel-only propulsion system with the solar-hybrid propulsion system at varying vessel speeds. The data shows that as vessel speed increases, the SFC also rises for both systems, but the hybrid system consistently exhibits lower fuel consumption. For example, at 14.5 knots, the diesel system consumes 176 g/kWh, while the hybrid system reduces this to 175 g/kWh.

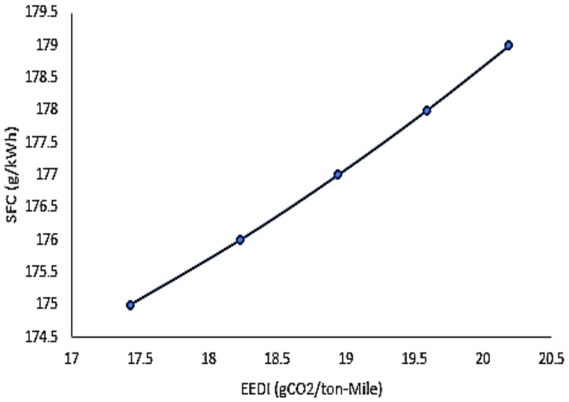

Fig. 4: Specific Fuel Consumption vs Vessel Speed for Hybrid Propulsion

This reduction as observed becomes more pronounced at higher speeds, with the hybrid system saving more fuel, indicating the efficiency gains achieved by incorporating solar power, especially in high-speed operations. This highlights the hybrid system's ability to reduce fuel usage and environmental impact across different operating conditions.

Figure 5 below highlights the relationship between total vessel resistance and speed for the hybrid propulsion system. As vessel speed increases, so does the total resistance, with the highest value of 88,470 N occurring at 18.5 knots.

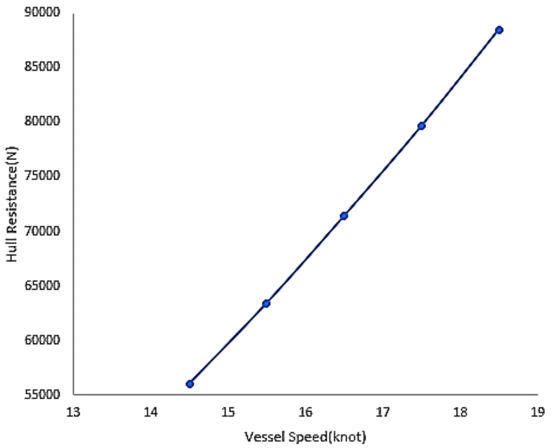

Fig. 5: Total Resistance vs Vessel Speed for Hybrid Propulsion System

The data shows that as resistance rises, the power demand on the hybrid system also increases, which directly affects fuel consumption and energy storage requirements. This resistance-based analysis helps in optimizing speed and energy management for maximum efficiency.

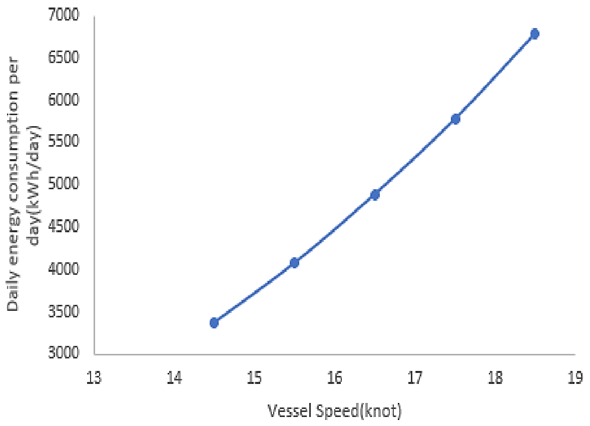

Fig. 6: Daily Energy Consumption of Hybrid Propulsion at Different Vessel Speeds

The chat in figure 6 illustrates the daily energy consumption of the hybrid propulsion system at different vessel speeds. As expected, the energy demand increases with speed, with 18.5 knots requiring 6796.05 kWh/day, while 14.5 knots only require 3373.33 kWh/day. The analysis shows that although higher speeds provide faster transportation, they result in significantly higher energy consumption, reinforcing the trade-off between speed and fuel efficiency.

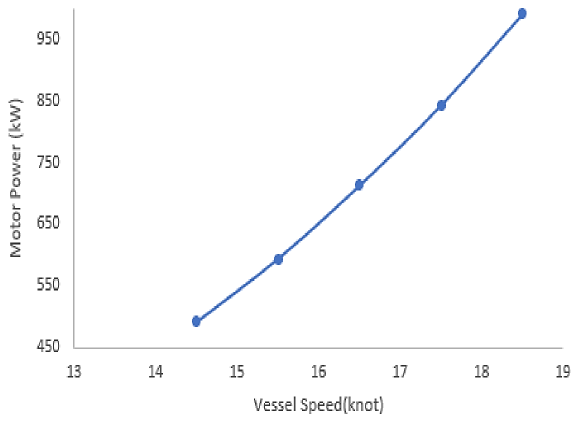

Fig. 7: Motor Power Requirements for Hybrid Propulsion Across Vessel Speeds

Figure 7 presents the motor power needed to operate the hybrid propulsion system at various speeds. At 14.5 knots, the motor power requirement is 491.87 kW, while at 18.5 knots, it surges to 990.87 kW. This clear upward trend illustrates the increased demand for energy as speed rises, which is crucial for planning both fuel and solar energy storage needs for long-distance voyages.

CONCLUSION

Judging from the result obtained from the analysis gotten from the previous chapters it shows that if a renewable energy which is the solar energy installed with a hybrid propulsion system to run for stipulated hours due to the average sunlight energy, capacity of the batteries, and daily energy consumption needed. The results abstained for the assumed number of days clear proves that solar energy can drastically reduce fuel consumption and emission for each day at different speed because instead of the normal conventional hybrid electric propulsion system to run alone throughout the voyage for 10hrs, it is now shared between both the solar energy and the conventional hybrid electric propulsion system with the aim to reduce emission, fuel consumption, maintenance cost and most importantly reduce the effect of Green-House-Gas on the environment.

In summary, this research contributes to the ongoing efforts to develop sustainable maritime technologies by showcasing the technical and environmental benefits of solar-powered hybrid propulsion systems. It paves the way for further innovations in reducing fuel dependency, lowering emissions, and enhancing the energy efficiency of marine vessels, thus contributing to the broader goals of decarbonizing the maritime sector.

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