Study of Catamaran Fishing Vessel Based on Solar Energy

P I Santosa¹, E Pranatal¹

¹ Naval Architect Department, Institute of Technology Adhi Tama Surabaya, Indonesia
pramudya05@itats.ac.id

Abstract: Projected temperature that will be felt by world community will increase 7.5°C hotter in 2070, meaning that world community is threatened to live in extreme temperatures an average of 34°C in next 50 years. This prediction can occur if a reduction in greenhouse gas emissions fails to be carried out simultaneously. On or hand, impact of soaring crude oil prices on world market has been felt by all walks of life so it is necessary to create alternative solutions to dependence of fuel to get through difficult times. In sea transportation sector, use of fuel for motorized ships is not only uneconomical but also not environmentally friendly. Dependence on fossil fuel energy has led to development of energy-efficient ship concepts that use alternative energy sources in moving ships. This is anticipated by use of solar energy in form of Electricalboats (Eb) which are applied as fishing vessels. This paper presents a study of efficient use of solar energy in Eb as a boat driver that does not utilize fuel for development of environmentally friendly fishing vessels. Technical analysis is done through testing ship model in Towing Tank and results are explored with Naval Architectories. In conclusion, there is a potential for fuel consumption savings of up to 90% when compared to ships that only use conventional engines.

Key words: Solar, energy, Efficiency

1. Introduction

Projected temperature that will be felt by world community will increase 7.5°C hotter in 2070 meaning that world community is threatened to live in extreme temperatures an average of 34°C in next 50 years, this prediction can occur if reduction in greenhouse gas emissions fails to be carried out simultaneously, [2] Behind a threat to a certain condition there is an opportunity, namely utilization of solar energy.

Potential of solar energy sources in Indonesia reaches an average of 4.5 kWh per square meter per day because of Indonesia's geographical location in equatorial region so that Indonesia's territory will always be illuminated by sun for 10-12 hours a day and shine around 2000 hours per year, so Indonesia is classified as a rich source of solar energy, [4].

On or hand, impact of soaring crude oil prices on world market has been felt by all walks of life which makes it even more burdensome. In response to this, austerity movements in various sectors are needed by creating alternative solutions to dependence on fuel to overcome difficult times, [6].

In sea transportation sector, ship operations are always associated with economic problems (operational costs) and environment (level of pollution that occurs due to ship operations), [7]. Reduction of engine power (and fuel requirements) can be met since design phase by creating an efficient hull design and propulsion system, [9].

Catamaran hull has a large deck area, small obstacles, stability and good ship motion (seakeeping). This means that catamaran hull has potential to reduce amount of propulsion and exhaust emissions that occur, [12]. Whereas fulfillment of need for an efficient propulsion system can be created with use of alternative energy, such as: Hybrid Engine Ships, Solar Electric Ships, Sailboats, Solar Electric Ships, Hybrid Engine Ships, [8].
At present fishing vessels are still urgently needed to support and maintain food security for billions of people in this world, [10]. In operation of fishing vessels must be absolutely safe because even in bad weather ship must work, so problem of total obstacles, driving force, fuel consumption, stability and seakeeping are very important issues, [11]. Meanwhile, number of fishing vessels using catamaran hulls is still very limited. Catamaran hull is very suitable to be used as a fishing vessel, [14].

![Figure 1. Electrical boats Configuration.](image)

Figure 1. Electrical boats Configuration.

Figure 1 shows configuration of a Solar Electric Boat, where concept of energy conversion in configuration is to convert solar energy into thrust needed to move a ship through propeller.

2. Methods

This research was conducted through testing ship model in Test Pool and results were explored with Naval Architect oily. This research is continuing and all material data information uses results of previous research to support scientific / academic and its application, [15].

2.1. Ship Resistances Testing

Main measurements of catamarans and results of ship resistance experiments in Towig Tank using lots of data from experiments conducted at ITS, [14].

![Table 1. Main Particulars](image)

| Parameter | Catamaran | Demihull |
|-----------|-----------|----------|
| LWL (m)   | 14.5      | 14.5     |
| B (m)     | 7.118     | 1.318    |
| H (m)     | 1.44      | 1.44     |
| d (m)     | 0.694     | 0.694    |
| CB        | 0.434     | 0.434    |
| Displ. (t)| 11.8      | 5.9      |

![Figure 2. Testing of ship resistances](image)

Figure 2 shows Ship resistances Test (RT) using a test model in test pond, results of which are used to develop Solar Electric catamaran fishing vessel configurations.

2.2 Data Exploration

• Ship Movement oily

![Figure 3. forces acting on ship's propulsion system](image)

Figure 3. forces acting on ship's propulsion system
Figure 3 shows forces acting on ship's propulsion system when operating. Ship can move forward because of thrust ($T$) that is sufficient to resolve ship resistances ($R_T$) at a certain service speed ($V_S$), [5].

\[ T > R_T \quad \text{or} \quad T - R_T > 0 \quad (1) \]

Where: $T$ is Thrust (kN) and $R_T$ is Ship Resistances (kN).

\[ R_T = \frac{1}{2} \rho C_T (WSA) V^2 \quad (2) \]

\[ T = \frac{R_T}{(1-t)} \quad (3) \]

where: $t = k_R \cdot wt$ \hspace{1cm}(4)

\[ wt = -0.0458 + 0.3745 C_B^2 + 0.1590 D_w - 0.8635 Fr + 1.4773 Fr^2 \quad (5) \]

\[ D_w = \frac{B}{\rho^\eta} \sqrt{\frac{\rho^\eta^3}{D}} \quad (6) \]

where: $t$ is thrust deduction factor for single screw, $k_R$ is 0.5 for thin rudder.

Use formulae of Engine Power, [5]:

Effective power ($P_E$) = $R_T \cdot V_S$ \hspace{1cm}(7)

Delivered power ($P_D$) = $P_E / \eta_D$ \hspace{1cm}(8)

Quasi propulsive coefficient ($\eta_D$) = $\eta_P \cdot \eta_H \cdot \eta_R$ \hspace{1cm}(9)

Service power ($P_s$) = $P_D / \eta_T$ \hspace{1cm}(10)

There are several arrangements of power transmission that are often used on ship propulsion systems:

- **Geared Drives**
  \[ \eta = -0.98 \]
  \[ \eta_T = -0.98 \]

- **Electric Drives**
  \[ \eta_p = -0.89 \]
  \[ \eta_T = -0.96 \]

![Diagram of Engine Power Components](image)

**Figure 4. Transmission Components of Eb Propulsion System**

Figure 4 shows efficiency values for each transmission component of ship propulsion system. Amount of mechanical efficiency in gearbox arrangement (Geared Drives), which serves to reduce and reverse rotation of motor drive, is 98 percent. Whereas ship's driving system that uses Electric Drives has a mechanical efficiency value of 89 percent.

Installed power ($P_I$) = $P_s + \text{Margin}$ \hspace{1cm}(11)

Margins (roughness, fouling, wear) 15 – 20% depend to ship routes.
• **Photovoltaic (PV)**

  Use following formula, [13]:

  \[
  \text{Power requirement: } P = V \times I
  \]

  \[
  P_{\text{max}} = V_{\text{oc}} \times I_{\text{sc}} \times FF
  \]

  \[
  \text{Fill Factor: } FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}
  \]

  \[
  P \text{ watt peak} = PV \text{ area} \times PSI \times \eta_{pv}
  \]

• **Ship Stability**

  Stability is ability of a ship to return to its initial position after experiencing heels caused by external forces i.e: waves or wind.

  \[
  GM = KB + BM - KG
  \]

  \[
  GZ = GM \sin \theta
  \]

  Stability requirement for catamarans is that angle $\phi$ at maximum GZ value must not be less than or equal to 10º (HSC, 2000).

• **Ship motion (Seakeeping)**

  Seakeeping is motion response of ship when it receives a disturbance from external due to wave blows or in or words is one aspect of hydrodynamics that studies behavior of ships on waves, [1].

  \[
  \text{Waves} \quad \rightarrow \quad \text{Ship} \quad \rightarrow \quad \text{Ship motions}
  \]

  Figure 5. Illustration of ship’s response

  Figure 5 shows an illustration of ship's response, where waves as input hit ship, causing dynamic movement of ship as its output.

  Response Amplitude Operators (RAO) calculated by, [1]:

  \[
  RAO_{\omega} = \frac{\zeta}{\zeta_a}\]

  where: $\zeta$ is Amplitude of ship motion response, $\zeta_a$ adalah Amplitude of sea waves.

### 3. Results and Discussion

| Run No. | V (Knots) | Fr | S/L = 0.2 | S/L = 0.3 | S/L = 0.4 |
|---------|-----------|----|-----------|-----------|-----------|
| 1       | 5.788     | 0.250 | 1.821 | 1.659 | 1.659 |
| 2       | 6.218     | 0.268 | 2.141 | 1.851 | 2.061 |
| 3       | 6.677     | 0.288 | 2.443 | 2.239 | 2.348 |
| 4       | 7.051     | 0.304 | 2.852 | 2.678 | 2.947 |
| 5       | 7.560     | 0.326 | 3.460 | 3.568 | 3.547 |
| 6       | 8.032     | 0.347 | 4.467 | 3.954 | 3.766 |
| 7       | 8.384     | 0.362 | 4.844 | 4.345 | 4.341 |
| 8       | 8.818     | 0.380 | 5.149 | 4.790 | 4.662 |
| 9       | 9.233     | 0.398 | 5.807 | 5.592 | 5.515 |
| 10      | 9.813     | 0.423 | 7.101 | 6.448 | 6.138 |

Table 2. shows values of catamaran resistance test results in Towing tank, n from this data will be developed as a basis for determining need for propulsion.
• Selection of Engines and Electric Motors

Installed engine power (PI) is 60 kW with a total efficiency (PE / PI) of 54%. engine used is 2 x 30 kW or 2 x 43 hp.

![Image of engine]

Type : Hybrid Beta Marine 43
Power engine : 43 hp max at 2,800 rev/min
Motor alternator : 45 Amp, 12 Volt
Fuel consumption:10 Lt/hr (at continuous Rating)
Dimensi: L 978 mm, B 622 mm, H 740 mm, Weight: 243 Kg

Figure 6. Hybrid diesel engine with specifications

Figure 6 shows a hybrid diesel engine, where engine is equipped with an alternator motor that is able to provide power as an Electric Drive to move ship and as a Generator to supply electricity to battery.

Table 3. Results of data development

| No | Parameter          | Simbol | Hasil | Units |
|----|--------------------|--------|-------|-------|
| 1  | Resistances        | $R_T$  | 6.138 | kN    |
| 2  | Thrust             | $T$    | 6.685 | kN    |
| 3  | Electricmotor      | $P_m$  | 12/45 | V     |
| 4  | Voltage            | $V$    | 30    | kV    |
| 5  | Current            | $A_H$  | 55    | m$^3$ |
| 6  | Quantity           | $A_H$  | 150   | A     |
| 7  | Weight             | $W$    | 850   | kg    |
| 8  | Connection         | $t_{use}$ | 6 - 8 | h     |

Table 3. shows a resume of $Eb$ propulsion system data development results which was carried out through testing ship model in Towing Tank and n results were explored with Naval Architect ories.

Table 4. Results of ship performance data evelopment

| No | Parameter          | Symbol | Results | Units |
|----|--------------------|--------|---------|-------|
| 1  | Displacement       | $\Delta$| 11.8   | ton   |
| 2  | Lightweight        | $LWT$  | 7.361  | ton   |
| 3  | Payload            | $DWT$  | 4.439  | ton   |
| 4  | Cubic number       | $CUNO$ | 55.04  | m$^3$ |
| 5  | Cargo hold Capacity| $Cap.$ | 8.5    | m$^3$ |
| 6  | Fish cargo         | $W_c$  | 2589   | kg    |
| 7  | Gross tonnage      | $GT$   | 15     | tonnage|
| 8  | Nett tonnage       | $NT$   | 3.03   | tonnage|
| 9  | Weight of PV Eqpt. | $W_m$  | 669    | kg    |
| 10 | Weight of Ship Eqpt.| $W_{SE}$ | 727   | kg    |
Table 4. shows a resume of Ship Performance data development results as an literary analysis by Naval Architect theories.

In general, normal operation of fishing vessels according to Hind, JA. [3], are: (1) Departure from port, (2) Outward bound), (3) On fishing ground, (4) homeward bound, and (5) arrival at port.

Figure 7 shows an operational simulation of a Solar Electric Catamaran Fish Boat. In its operations, fishing vessels must be absolutely safe (very seaworthy indeed), even in bad weather ship must work.

Figure 8 shows work scheme of Solar Electric Catamaran Fish Boat (Eb) system which can be explained in detail as follows: Solar panels placed above canopy and deck of ship function to capture solar energy and convert it into electrical energy, stored in batteries. Solar panels that have an area of 80 m$^2$ are capable of producing electrical power of 1.67 kW with a charging time for 1.1 hours / batt. Charging a battery with a capacity of 30 kW is also done through an alternator electric motor (45 Amp, 12 Volt) which is available under diesel engine power and only takes 1 hour. Power stored in battery will be used to supply electric motor and rotate propeller as an Electric Drive, so ship can move forward due to thrust generated by propeller. A 30kWh battery can provide electricity for 6 to 8 hours. In addition, this Eb does not produce exhaust emissions and is not noisy so it does not interfere with operation of ship when fishing, beneficial and environmentally friendly.
Figure 9. shows the relationship between rpm and power and torque produced by an Electric Motor. Torque is very closely related to thrust (thrust). more engine rpm value increases, greater engine power generated so that need for thrust (thrust) will increase as well. When engine speed is 2800 rpm, power value is 30 kW with a torque of 108 Nm. But when engine speed drops to around 1650 rpm, power used is only about 21 kW and torque produced is around 128 Nm. Similarly, when engine speed drops to around 900 rpm, power used is only about 8 kW so torque value drops to around 105 Nm.

Figure 10. shows the relationship between rpm and power and speed. Ships (Vs) more engine rpm value increases, greater engine power and Ship speed.

Economic value of fuel use on fishing vessels is shown in Figure 11 below, [14].

Figure 11. Relationship between Vs - FC - T at 60 kW power

Figure 11. shows a graph of relationship between ship speed (Vs) - fuel consumption (FC) - thrust (T). To reach official speed Vs 9.8 knots with a driving force (P) of 60 kW, thrust of ship (T) of 6,685 kN requires a fuel consumption (FC) of 57.9 liters / hour. So it can be said that economic value of speed of ship (Vs) of 9.8 knots, thrust (T) of 6,685 kN is equivalent to cost of fuel consumption of 57.9 liters / hour. efficiency of engine drive transmission system is 0.98, while electric motor drive is 0.89. If economic value of engine drive (fossil energy) used is equated with economic value of electric motor drive (solar energy) obtained is speed of engine driving boat Vs of 1 knots is equivalent to speed of boat moving fish solar panel Vs about 0.9 knots, it can be simply concluded that solar energy needed to drive a ship of 1 knots is equivalent to fuel consumption of 5.3 liters / hour.

The results of Eb catamaran fishing vessel static stability calculation (in various operational conditions), are as shown in Table 5.

Table 5. Eb stability requirement according to Fishing Vessels (Safety Provisions) Rules 1975 and HSC annex 7. IMO 2016

|     | deport | p-fg | fg | F-p | p-aort | m.deg | m.rad | m | pass |
|-----|--------|------|----|-----|--------|-------|-------|---|------|
| 1   | Area’s ≤ 30° | 25.837 | 25.86 | 25.8 | 28.5 | 28.6 | ≥ 7.4274 | pass |
| 2   | Area’s ≤ 40° | 0.851 | 0.824 | 0.80 | 0.84 | 0.83 | ≥ 0.090 | pass |
| 3   | Area’s between30°-40° | 0.214 | 0.200 | 0.19 | 0.21 | 0.21 | ≥ 0.050 | pass |
| 4   | Minimum GZ ≥ 30° | 1.640 | 1.570 | 1.54 | 1.65 | 1.61 | ≥ 0.200 | pass |
| 5   | Maximum GZ | 22 | 21 | 23.5 | 23 | 22 | ≥ 10° | pass |
| 6   | Initial GM | 7.111 | 7.434 | 6.61 | 6.18 | 6.33 | ≥ 0.150 | pass |
While the results of Response Amplitude Operator (RAO) for heave and pitch movements are as presented in Figures 12 and 13.

![Figure 12. Heave Motion](image1)

![Figure 13. Pitch Motion](image2)

Catamaran motion is very dependent on choice of distance between hull (S/L) and on distance S/L = 0.2 RAO value is 18% smaller than S/L = 0.4 in direction of wave 120°, as obtained in [16].

4. Conclusions

Application of solar energy on catamaran fishing vessels is very useful (Eb) and has potential of cost savings of around 90% fuel consumption, also can reduce greenhouse gas emissions. This work is a portrait of a study of development of energy efficient fishing vessels and reducing air pollution.

5. References

[1] Bhattacharya, R., 1972, Dynamics Of Marine Vehicles, A Wiley Interscience Publication: John Wiley and Sons, New York.
[2] Chi Xu, Timothy A. Kohler et al, 2020, Future of Human Climate Niche, journal Proceedings of National Academy of Sciences, PNAS May 26, 2020 117 (21) 11350-11355; first published May 4, 2020 https://doi.org/10.1073/pnas.1910114117
[3] Hind, JA., 1982, Stability and Trim of Fishing Vessels - second edition, Fishing News Book Ltd, Farnham, Surrey, England.
[4] Kement rian ESDM, 2010, www.esdm.go.id
[5] Molland AF et al., 2011, Ship Resistance and Propulsion – Practical Estimation of Ship Propulsive Power, ISBN:978-0-521-76052-2 Hardback, CUP, USA.
[6] Presiden RI, Peraturan Presiden (PERPRES) Nomor 47 Tahun 2017 tentang Hemat Energi bagi Masyarakat.
[7] Santosa PI et al, 2017, Kapal Ikan Katamaran : Tinjauan Aspek Kebutuhan Energi, Fungsi dan Performa Kapal yang Ramah Lingkungan, Disertasi –MT093350, repository.its.ac.id 4112301001-Dissertation
[8] Santosa PI et al,2017, A Study into Development of More Energy Efficient and Less Polluted Fishing Vessel, International Journal of Engineering Research & Science (IJOER), ISSN: 2395-6992, Vol-3, Issue-10, October- 2017, https://www.adpublications.org/a-study-into-development-of-more-energy-efficient-and-less-polluted-fishing-vessel/
[9] Santosa PI, 2019, Configuration of Solar Sail Catamaran Fishing Vessel, Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering, Volume 19 Issue 3 Version 1.0 Year 2019, Type: Double Blind Peer Reviewed International Research Journal, Publisher: Global Journals, Online ISSN: 2249-4596 & Print ISSN: 0975-5861, https://engineeringresearch.org/index.php/GJRE/article/view/1961/1892.
[10] Santosa PI et al, 2019, Configuration of Engine-Sail Catamaran Fishing Vessel, IOP Conf. Series: Materials Science and Engineering, DOI:10.1088/1757-899X/462/1/012008, https://iopscience.iop.org/article/10. 1088/1757-899X/462/1/012008/pdf, https://ui.adsabs.harvard.edu/abs/2019MS%26E..462a2008S/abstract
[11] Santosa PI, 2019, Techno-Economic Review: Use of Solar Sail On Catamaran Fishing Vessel, SSRG International Journal of Mechanical Engineering (SSRG-IJME) – Volume 6 Issue 7 – July 2019 ISSN: 2348 – 8360 www.internationaljournalssrg.org, https://www.researchgate.net/publication/336053021

[12] Santosa PI, 2020, Study of fish Catamaran ship based on fossil energy, Jurnal Kelautan Vol.13, No. 1, 2020, https://journal.trunojoyo.ac.id/jurnalkelautan/article/view/6141/4488

[13] Tiwari, GN., Dubey, S., 2010, Fundamentals of Photovoltaics Modules and its Applications, Published by Royal Society of Chemistry, Cambridge CB4 0WF, UK.

[14] Utama IKAP et al, 2010, Development of Catamaran Fishing Vessel, IPTEK, Journal for Technology and Science, Vol.21, No.4.

[15] Utama IKAP et al., 2010, Experimental and CFD Investigation into Drag Characteristics of Catamaran Fishing Vessel, Proc, Regional Conference on Mechanical and Aerospace Technology (RCMeAe), Bali, Indonesia,

[16] Utama IKAP et al., 2011, An investigation into resistance/powering and seakeeping characteristics of river catamaran and trimaran, Makara Seri Teknologi, Vol 15, No, 1.