Design Concept of Catamaran Passenger Solar Power Boat for Gili Ketapang Island, Probolinggo - Indonesia

Ahmad Nasirudin[1] and Abdul Hamdan[1]

[1]Department of Naval Architecture, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, 60111 Keputih, Surabaya, Indonesia

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Abstract: Gili Ketapang is a small island with population of around 9,000 people. It is located at five miles north of Tanjung Tembaga Port, Probolinggo, Java Island. Gili Ketapang Island is one of tourism destinations in East Java. To get there, the residents and tourists use the diesel engine traditional wooden boats. Actually, the boats are not intended for passenger only but sometimes also used for fishing activities as fishing vessels. So, according to regulation, the aspects of safety are not fulfilled. Besides, by using diesel engine, the boats are noisy, smoky, and smelly which are not comfortable for passenger. Therefore, this study proposes a catamaran passenger solar boat concept which is fulfilled the aspect of safety and comfort for passenger. By using Parent Design method to determine the dimension and by using slender body method to estimate ship resistance, then the main dimension of the boat, motor power, battery capacity, and solar power are obtained. The safety aspects are examined by calculating its freeboard and stability. A lines plan, a general arrangement, and 3-Dimensional drawing of the boat are presented.

1 INTRODUCTION

Gili Ketapang is a small island where is located around five miles north of Probolinggo city, East Java, Indonesia. The area of Gili Ketapang is around 0.61 square kilometres with total population around 9,000 people.

Existing transportation from Gili Ketapang Island to Java and vice versa are diesel engine traditional wooden boats. The boats are not only used by residents but also tourists who want to visit Gili Ketapang Island as one of tourism destination. But, they are indicated not fulfilled the regulation, because they are not intended for passenger only but sometimes also used for fishing activities as fishing vessels.

Figure 1: Existing Boat

Besides, the boats use diesel engine as main propulsion, as a result they are noisy, smoky, and smelly which are not comfortable for passenger especially tourists. Therefore, this study is aimed to design a concept of passenger boat for Gili Ketapang Island by considering safety and comfort aspect by using catamaran hullform, electric motor, and solar power as additional electrical energy source.

2 METHODOLOGY

2.1 Data Collection

Two methods data collection are applied, survey on the location to get primary data and collecting data from articles, catalogues, and reports as secondary data. The primary data is related to the number of potential passengers across the route per-day and length of travel time. The secondary data is related to such as main dimension of reference boat, battery and solar panel specification, and effective solar irradiation.

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2.2 Payload Determination

Payload is determined by analysing the number of passenger crossing the route i.e. Tanjung Tembaga Port to Gili Ketapang Island and vice versa by using simple average method.

2.3 Main Dimension and Lines Plan Determination

Main dimension is determined by using Parent Design Approach and lines plan of the boat is generated by following the shape of reference boat.

2.4 Ship Resistance and Motor Power Estimation

Slender body method (Michell, 1898) is applied to estimate ship resistance at several speed conditions. Additional resistance is added by considering weather condition. Whilst, required motor power is calculated at service speed condition by considering total efficiency and NCR (Normal Continuous Rate) around 70% of MCR (Maximum Continuous Rate).

2.5 Battery Capacity and Solar Power Calculation

Required capacity of battery is calculated based on the motor power at desired speed and endurance of the boat during operation.

$$E_b = \frac{P_{B@NCR} x\ t}{DOD} \qquad (1)$$

where E_b is required capacity of battery energy in kilowatt-hour (kWh), $P_{B@NCR}$ is motor break power at normal continuous rate in kilowatt (kW), t is boat endurance in hour (h), and DOD is depth of discharge of the battery.

Solar power is calculated based on the area of the boat roof or number of solar panel, while the energy harvested by solar panel is calculated based on the power installed and effective sun irradiation (productivity) per-day.

$$E_{pv} = P_{pv} x\ p \qquad (2)$$

where E_{pv} is energy harvested by solar panel in kilowatt-hour (kWh), P_{pv} is solar power in kilowatt (kW), p is effective sun irradiation (productivity) in hour (h).

2.6 Lightweight and Deadweight Calculation

Lightweight is calculated based on the lightweight of reference boat without considering weight of existing motors, batteries, and solar panels then new weight of motor, batteries, and solar panel based on current calculation are added.

In this case, the deadweight is the number of passenger, crew, and weight of freshwater. As lightweight calculation, deadweight is also calculated based on the deadweight of reference boat then updated by current number of passengers and weight of freshwater.

2.7 Freeboard and Stability Evaluation

The required minimum freeboard of the boat is calculated by using Small Craft Code by MCA, UK and criteria of boat stability is taken from HSC (High Speed Craft) 2000 Code (International Maritime Organisation, 2000).

2.8 General Arrangement and 3-D Drawing

General Arrangement is drawn as final drawing after all calculations and evaluations are done then 3-D image is created based on general arrangement drawing.

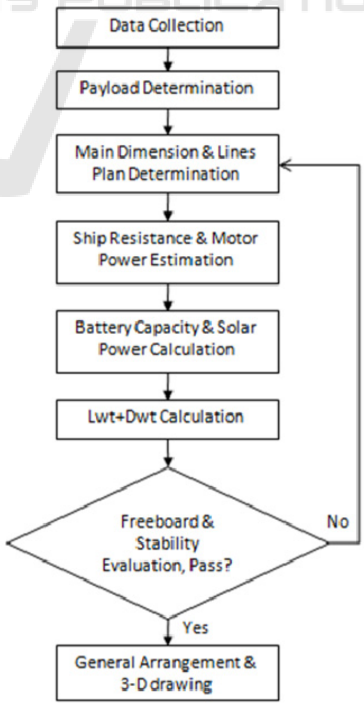


Figure 2: Flowchart of method

3 ANALYSIS AND RESULT

3.1 Payload Determination

The number of passenger is as a payload. Since, there has no official data, the number of passenger is taken from direct measurement on the location regarding to the number of passenger per-trip (boat). From the four days observation on the location has been known that there has around 10 trips a day. The peak time occurs in the morning and afternoon which has total around six trips. The payload is determined from the calculation of the average number of passenger during peak time i.e. around 46 passengers. The data collected and the average calculation result are shown in Figure 3.

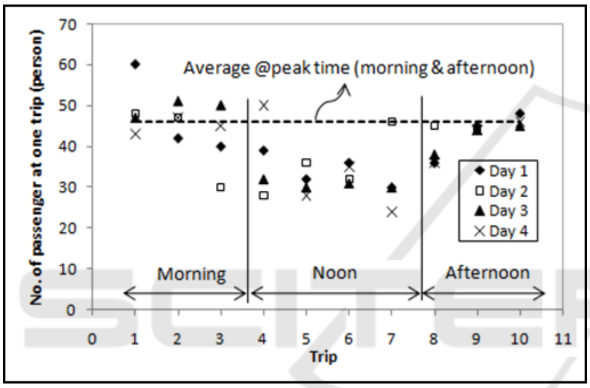


Figure 3: Payload calculation

3.2 Main Dimension

The main dimension of the boat is determined by using Parent Design Approach. This is the simplest method in the designing a boat which is taking directly the main dimension from a similar boat type as reference. The main dimension of the boat for this study is shown in Table 1.

Table 1: Main Dimension.

Item	Dimension
Lwl, Length water line	14.12 m
B, total Beam	5 m
b, breadth of demihull	1.48 m
T, draught	1.2 m
H, depth	2 m
Δ, Total displacement	21 ton

3.3 Lines Plan

Based on the main dimension, the lines plan is generated. The generation of lines plan is following the shape of the reference boat. The result of lines plan is shown in Figure 4.

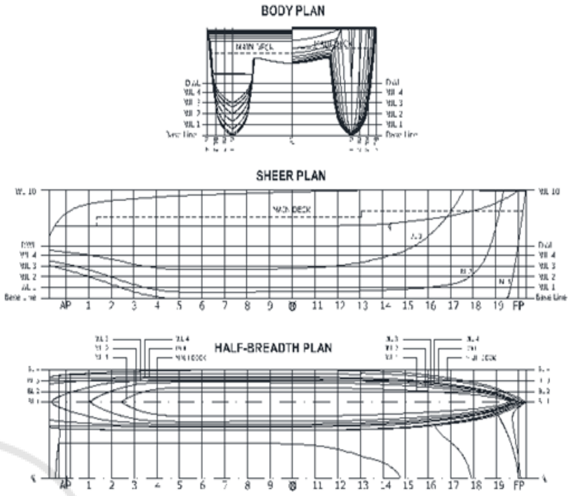


Figure 4: Lines Plan

3.4 Ship Resistance and Motor Power Estimation

Based on the data collected, the time travel duration from Tanjung Tembaga Port to Gili Ketapang Island is around 40 minutes by using the existing boats. With the distance of five nautical miles then the average boat speed can be known i.e. around 8 (eight) knots. By using slender body method [1], resistance of the boat with 8 knots speed is obtained around 3.05 kN. Based on the resistance value and the assumption of additional power for the weather effect is around 30%, the total propulsive efficiency is around 53%, then the break power of motor at NCR (Normal Continuous Rate) is obtained around 31 kW. The motor break power estimation at different speed is shown in Figure 3. With the typical electric motor which has NCR about 70% then the break power at MCR (Maximum Continuous Rate) can be known i.e. about 44 kW or 2x22 kW (catamaran). It means that, based on Figure 5, the maximum speed of the boat can be reach only around 9 knots.

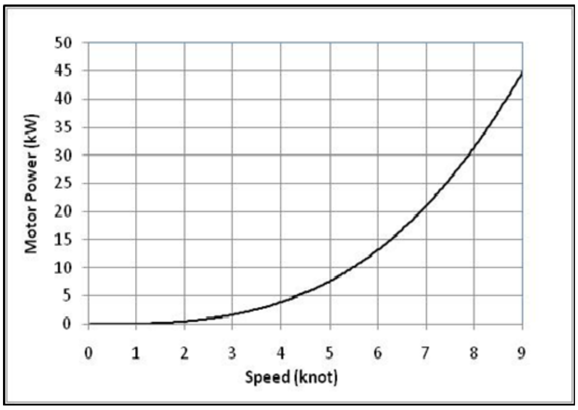


Figure 5: Motor Power

3.5 Battery Capacity Calculation

Battery capacity is calculated based on Equation 1. In this case, the boat endurance is planned along 240 minutes or around 4 hours which is equal to 6 trips (3 round trips). By using Lithium battery type which has capability of 80% DOD and based on Equation 2, the battery energy required is obtained around 155 kWh. This energy required is equal to 16 batteries with specification of 48 volt and 200 Ah capacities. If the boat is run at maximum speed 9 knots then the endurance of the boat is only 2.8 hours.

3.6 Solar Power Calculation

Solar power is calculated based on the area of the boat roof. In this case, based on the main dimension of the boat, the area of boat roof which is possible to install with solar panel is around 8 m x 5 m. By using specification of solar panel with size 1.6 m x 1 m and its each power is around 250 watt then the number of solar panel is obtained around 22 panels and the power is around 5.5 kW.

The energy harvested by solar panel is calculated by using Equation 2. By using productivity (effective sun irradiation) a day is around 4.6 hours (Rumbayan et.al., 2012) then the maximum energy can be harvested by solar panel is around 25.3 kWh per-day. This is equal to around 16% of total energy required by boat for propulsion system.

3.7 Lightweight and Deadweight Calculation

Lightweight of reference boat without existing motors, batteries, and solar panels is around 14 tons. The current power motor is around 2 x 22 kW. Based on reference (Aquawatt Catalogue) the weight of motor is 40 kg each, thus the total weight of motors is 80 kg. Meanwhile, the battery capacity of current design is 155 kW or around 16 batteries. Based on the reference (Aquawatt Catalogue, 2016) the weight of each battery is 125 kg, then total of battery system weight is 2 tons. The last is the weight of solar panels. With 22 panels, while the weight of each panel is around 20 kg (Neo Solar Power Catalogue) then the total weight of panels is 440 kg. Finally, the lightweight of current design is the total of lightweight of reference boat without existing systems plus the weight of new systems i.e. around 16.44 ton.

Meanwhile, the deadweight is the number of passenger, crew, and weight of freshwater. In this case, the number of passengers is 46 persons, two crews, and one cubic meter freshwater. So, the deadweight of current design is 4.6 ton.

3.8 Freeboard Evaluation

The required minimum freeboard of the boat is calculated by using Small Craft Code by MCA, UK (Marine and Coast Guard Agency). Based on the calculation is known that allowed minimum freeboard for this boat is around 60 cm while the actual freeboard is 80 cm. It means that, the freeboard of the boat is fulfilled the regulation.

3.9 Stability Evaluation

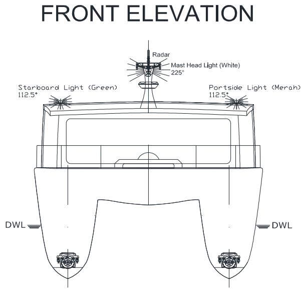
Boat stability is evaluated by using criteria of HSC 2000 Code (International Maritime Organisation, 2000). Stability of the boat is evaluated with 3 (three) loading conditions i.e. lightship condition, half-load condition, and full-load condition. Based on the calculations as summarised in Table 2 are known that the all loading condition of the boat are fulfilled the requirements.

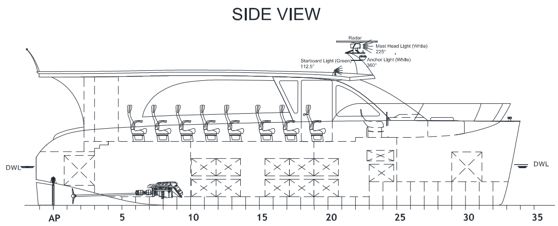
Table 2: Stability evaluation.

No.	Criteria	Req.	Loading Condition		
			Light	Half	Full
1	Area 0 to 30	≥ 3.5856 m.deg	22.58	24.52	24.35
2	Angle of max. GZ (intact)	$\geq 10^0$	26.40	29.10	30.00
3	Area between GZ and HTL	≥ 1.604 m.deg	7.79	7.010	6.43
4	Value of max GZ(damage)	≥ 0,05m	1.420	1.390	1.38
5	Angle of equilibrium with gust wind	$\leq 10^0$	0.6	0.5	0.5
6	Passenger Crowding Heeling arm	$\leq 10^0$	0	7.56	8.92
7	Range of positive stability(damage)	$\geq 15^0$	135.8	132.0	128.9
Status			Pass	Pass	Pass

3.10 General Arrangement and 3-D Image

Based on the dimension of the boat, lines plan, number of passengers, motor, battery, and solar panels and also with regard to the stability evaluation then the position of passenger seating, motor and battery placement are arranged. The General Arrangement of the boat is shown in Figure 6 and 3-D image can be seen in Figure 7.





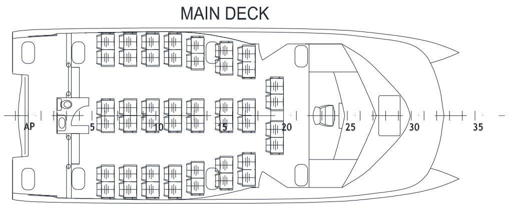
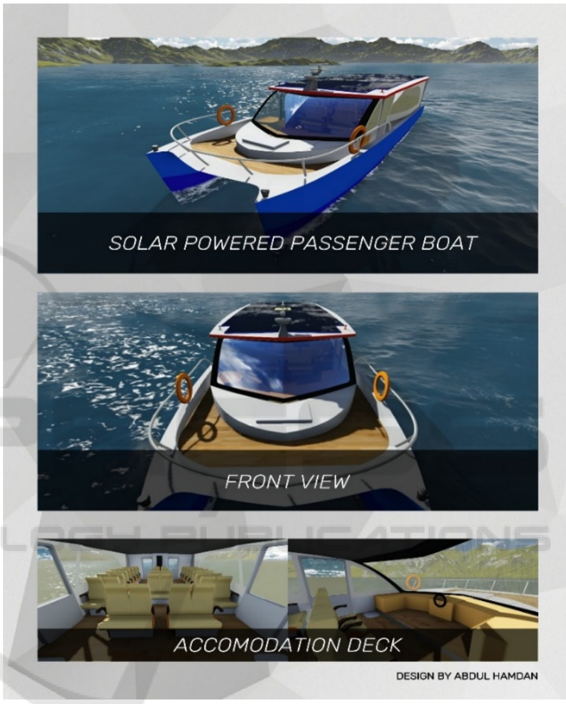


Figure 6: General Arrangement

Figure 7: 3-D Image



4 CONCLUSIONS

A concept of a catamaran passenger solar power boat for Gili Ketapang Island, Probolinggo, Indonesia has been designed. The capacity of the boat is 46 passengers. By using parent ship design approach, the main dimensions of the boat is 14.12 meters length, 5 meters maximum breadth, 1.48 meters breadth of demihull, 1.2 meters draught, 2 meters depth, and 21 tons displacement. By 8 knots service speed, the power required is around 31 kW (NCR condition) and 44 kW at MCR with maximum speed around 9 knots. The battery capacity of 155 kWh can cover around 6 trips or 4 hours endurance at 8 knots (service speed) or covers around 2.8 hours endurance at 9 knots (maximum speed). The 155 kWh battery capacity is equal to is equal to 16 batteries of 48 volt and 200 Ah. The solar power can be installed to the boat is around 5.5 kW which can produce energy around 25.3 kWh per-day or around 16% of total energy required. Freeboard and stability of the boat are fulfilled the requirement set by Small Craft Code, MCA, UK and HSC 2000 Code.

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