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Photovoltaic-Based Electric Tourist Boat Design to Support Island Tourism at the Labuan Bajo

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***Abstract*— Indonesia as an archipelagic country certainly has a great opportunity to develop the potential of the marine tourism sector. Maritime tourism in Indonesia has become a prima donna for foreign and foreign tourists, especially in Labuan Bajo. Task Island - Kelor Island - Karangan Island - Makasar Island is a new marine tourism destination that is currently being visited by many tourists. The design of electric ships based on renewable energy is expected to be able to answer the limited access between islands and the increasingly expensive depletion of fossil energy at this time. To get the size of the ship to be used, the linear programming method is used from several electric ship comparators that have been widely used. By utilizing batteries as energy storage for the propulsion of ship engines and using Photovoltaics as an energy source to operate navigation systems such as radar, radio, lights, and sonar. This ship can carry as many as 20 passengers with a route as far as 9,131.80 m. The operational time from 07.00 to 17.00 can be operated by as many as 5 ships with each ship taking 2 trips. The electric ship design principal dimension LOA = 14,00 m, LWL = 13,00 m, B = 6,00 m, H = 1,3 m, Cb = 0,236, Vops = 10 Knot, Vmax = 12 Knot, Electric Motor = 75 kW, Displacement 15,720 Ton**

Keywords— Linear Programming, Photovoltaic, Electric Ship Design

I. INTRODUCTION

In Indonesia, the opportunity for electric-powered ships is quite large because of the many crossing routes between islands. In Indonesia, the opportunity for electric-powered ships is quite large because of the many crossing routes between islands. Electric propulsion is suitable to be applied to inter-island crossing ships because it sails on short routes regularly, has short travel times, and so has sufficient time for recharging [1].

Ship Electric Motor Propulsion is a direct propulsion motorway to drive propellers. Propulsion equipment generally consists of propellers, motors, generators, prime movers and controls, and other components. Electric propulsion has low noise, good mobility, flexibility of delivery space, and other advantages [2]. The electric ship presents both opportunities and challenges for Naval Architecture according to [3].

Ship electric motor propulsion offers several advantages over traditional propulsion systems as follows:

- Electric propulsion significantly reduces greenhouse gas emissions and helps mitigate climate change. Electric motors produce zero direct emissions, eliminating air pollutants such as sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter. This makes electric propulsion an attractive option for addressing environmental concerns and complying with increasingly strict emission regulations.
- Electric motors are more energy-efficient compared to traditional internal combustion engines. They convert a higher percentage of the energy from the power source (such as batteries or fuel cells) into propulsion, resulting in lower energy wastage. This can lead to significant fuel savings and operational cost reductions for shipping companies.
- Electric motors operate more quietly and generate fewer vibrations compared to conventional engines. This is particularly advantageous for passenger ships, luxury yachts, and cruise liners, as it enhances onboard comfort and minimizes noise pollution in sensitive marine environments.
- Electric motors offer precise control and rapid response, making ships more maneuverable. They enable dynamic positioning, improved low-speed maneuvering, and precise station-keeping, which are crucial for activities like docking, berthing, and offshore operations.
- Electric propulsion systems can be configured with multiple motors and power sources, offering increased redundancy and reliability. If one motor or power source fails, the others can still provide propulsion, enhancing safety and reducing the risk of downtime or stranding.
- Electric motors have fewer moving parts compared to traditional engines, resulting in simplified maintenance and reduced operational costs. They require less frequent servicing, have longer lifespans, and can operate with lower noise and vibration levels, leading to improved crew comfort and reduced wear and tear on the ship's components.
- Electric propulsion systems can be integrated with various energy sources, such as batteries, fuel cells, or shore power. This allows for hybrid propulsion configurations, enabling optimal power management, better efficiency, and the use of renewable energy sources. It also offers the potential for future

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advancements in energy storage technology to be seamlessly integrated into the ship's power system.

It's worth noting that the suitability of electric propulsion depends on factors such as the ship's size, operational profile, and available infrastructure. However, as technology continues to advance and environmental regulations become more stringent, ship electric motor propulsion is increasingly being considered as a viable and sustainable alternative for the maritime industry.

In this study, the photovoltaic-based electric tourist boat design to support island tourism at Labuan Bajo is conducted. Solar energy is one of the energies that is currently being actively developed by the Indonesian government because as a tropical country, Indonesia has a large enough potential for solar energy according to [4].

The photovoltaic-based electric propulsion for boats is possible and has been implemented in various forms. Here are some important points to consider:

- Solar Panels: Photovoltaic (PV) panels convert sunlight into electricity. They can be installed on the boat's surface, such as the deck or roof, to capture solar energy. The electricity generated by the solar panels can be used to power the boat's electric propulsion system directly or stored in batteries for later use.
- Power Output: The power output of solar panels depends on factors like the panel's efficiency, surface area, and the amount of sunlight available. While the power generated may not be sufficient for high-speed or large vessels, it can provide a supplementary power source or be used for low-power propulsion on smaller boats, yachts, or leisure crafts.
- Hybrid Systems: To overcome the limitations of solar power alone, hybrid systems can be implemented. These systems combine solar power with other energy sources such as batteries, fuel cells, or generators. Solar energy can be used to charge the batteries, reducing reliance on external power sources and extending the vessel's range.
- Energy Management: Effective energy management is crucial in photovoltaic-based electric propulsion systems. It involves optimizing power generation, storage, and consumption. Advanced control systems and algorithms can help efficiently distribute the available power to the propulsion system, onboard equipment, and battery charging.
- Range and Efficiency: The range of a photovoltaic-powered boat depends on factors like solar panel capacity, battery storage, energy consumption, and the vessel's speed. Higher energy efficiency through lightweight materials, streamlined design, and optimized power management can maximize the boat's range and overall performance.
- Limitations: Despite the benefits, there are limitations to photovoltaic-based electric propulsion. Insufficient sunlight, such as during cloudy or low-light conditions, can impact the power output. The limited space available on smaller vessels may also restrict the installation of an adequate number of solar panels.
- Applications: Photovoltaic-based electric propulsion finds practical applications in smaller boats, sailboats, catamarans, and leisure crafts that operate at slower speeds. It is also commonly used in solar-powered boats for recreational activities or eco-tourism, where the focus is on sustainable and low-impact navigation.

As solar panel technology continues to improve, becoming more efficient and cost-effective, the viability and applicability of photovoltaic-based electric propulsion for boats are expected to increase. Additionally, advancements in energy storage technologies, such as high-capacity batteries, further enhance the potential for solar-powered electric boats.

Photovoltaic-based electric ship design will answer the problem of energy-efficient and environmentally friendly transportation because fossil fuels are getting less and less [5].

II. METHOD

In planning the size of the ship using the comparison ship method to find out the most appropriate and effective size for use in this study. In completing the ship design process, several methods used in designing this ship are as follows:

A. *Cycle Time Method*

The length of the cycle time of round-trip public transport routes in the city is one of the most important technical and operational indicators.

This value is used to determine the required number of route vehicles (RV), frequency and headway, distribution of transit vehicles between routes, scheduling and scheduling, and the organization of combined communication modes on the route [6]. Meanwhile, according to [7] the transportation time for all sub-routes (T) is determined by the following equation :

$$T = \sum_{1}^{n} \frac{d_{ab}}{V_k} + \alpha \qquad (1)$$

Where :

- d_{ab} defined as the distance from point A to point B
- V_k defined as ship speed
- α defined as the time required for the process of fastening/releasing the rope between the tug/barge.

The number of trips (N_1) with ships waiting at the port for loading and unloading, can be calculated using the following equation :

$$N_1 = \frac{T_o}{T} \qquad (2)$$

Where:
T_0 is defined as a total operational time
T is defined as the travel time of 1 ship

B. Linear Regression Methods

Linear regression is a statistical method used to form a model or relationship between one or more independent variables X and a response variable Y. Regression analysis with one independent variable X is referred to as simple linear regression, whereas if there is more than one independent variable X, it is referred to as multiple linear regression. In analyzing the functional relationship between the independent variables X and variables response Y, there is a possibility of a different linear relationship for each interval X. If the regression X to Y has a certain linear relationship at the X interval but also has a different linear relationship at other X intervals, then the use of a simple linear regression model is not appropriate in this case because the results of the analysis cannot provide comprehensive information about the data.

Piecewise linear regression is a form of regression that includes various regression models' linear fit that fits the data for every X interval [8]. In general, regression analysis is a study of the relationship of one variable which is referred to as the explained variable with one or two explaining variables. The variables that are explained hereinafter are referred to as response variables, while the variables that explain are usually called independent variables [9].

In operations research, linear programming is one of the models in mathematical programming, which is very broad and needs to be analyzed. Mathematical programming includes more optimization models known as Non-linear Programming, Stochastic Programming, Integer Programming, and Dynamic Programming - each of them is an efficient optimization technique for solving problems with a certain structure, which depends on the assumptions made in formulating the model [10].

C. Solar Panel Selection

The solar panels that are commonly used and available on the market are as follows:

- Monocrystalline Silicon

Monocrystalline silicon solar cells are made from a single crystal structure. The silicon material used in these cells is grown in a controlled environment, resulting in a uniform and continuous crystal lattice structure. This structure allows for the efficient movement of electrons, contributing to higher conversion efficiency. Monocrystalline silicon solar panels often have a sleek and uniform black appearance, which is considered more visually appealing to some homeowners and businesses compared to other solar panel types. This aesthetic feature makes them a popular choice for residential installations.

It is also known that monocrystalline silicon solar panels are known for their durability and long lifespan. They have a low rate of degradation over time, meaning they can maintain their performance levels for several decades. Many manufacturers provide warranties of 25 years or more for monocrystalline panels. It is the most efficient panel that is produced with the latest technology & produces the highest electrical power per unit area. The monocrystalline solar cells show the highest efficiency version of all silicon solar cells, but the production of monocrystalline silicon wafers requires the largest investment funds. The picture of monocrystalline solar panels shows in Figure 1(a).

The specification of monocrystallin*e* 100 wp is shown as follows:

- The voltage at Pmax (Vpm) = 18,0 V
- Current at Pmax (Imp) = 5,56 A
- Weight = 7,75 kg
- Dimension = 1.200x550 x35 mm
- Efficiency = 16% - 19%

- Polycrystalline Silicon

Polycrystalline silicon solar cells are made from multiple silicon crystals. During the manufacturing process, molten silicon is poured into a mold and then solidified, resulting in a material with multiple crystal structures. These crystals are not as uniform as those in monocrystalline silicon cells. Polycrystalline Silicon also known as a solar panel has a random crystal arrangement because it is manufactured by a casting process. This type requires a larger surface area compared to the monocrystal type to produce the same electrical power. This type of solar panel has lower efficiency than the monocrystalline type, so it has prices that tend to be lower according to [11] Polycrystalline is made of large rectangular bars of liquid silicon blocks cooled and solidified. The picture of the polycrystalline solar panel shows in Figure 1(b).

Polycrystalline silicon generally has a lower efficiency compared to monocrystalline panels. Due to the presence of multiple crystals and grain boundaries, the movement of electrons within the material is less efficient, resulting in slightly lower conversion efficiency. The efficiency of polycrystalline panels typically ranges from 13% to 16%.

The specification of polycrystalline 100 wp is described as follows:

- The voltage at Pmax (Vpm) = 17,5 V
- Current at Pmax (Imp) = 5,71 A
- Weight = 7,55 kg
- Dimension = 1.085x 675x25 mm
- Efficiency = 13% - 17%

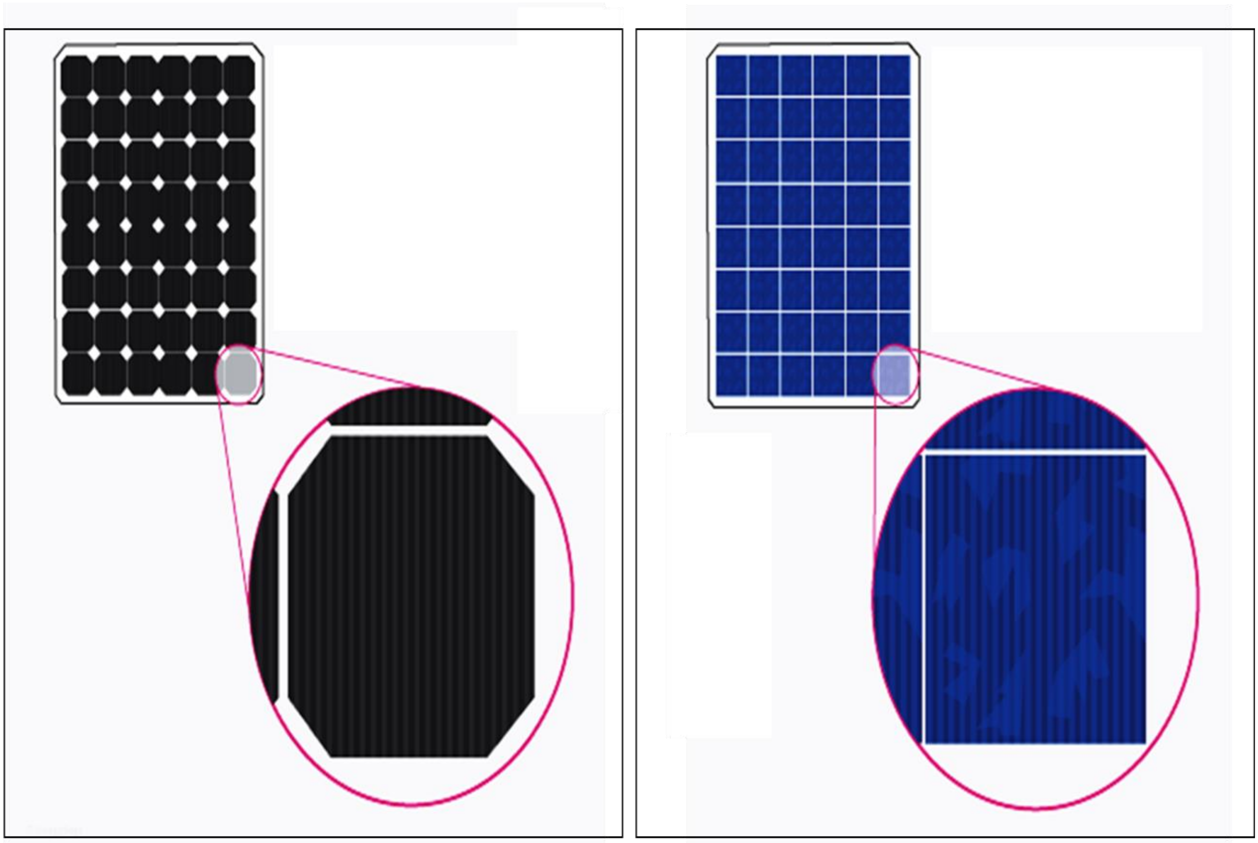
- Thin Film Solar Cells

Thin film solar cells (TFSC) shown in Figure 2 are a promising approach for terrestrial and space photovoltaics and offer a wide range of options in terms of device design and manufacture [12]. Thin film solar cells offer the most promising option to substantially reduce the cost of photovoltaic systems. Semiconductor thin film compounds such as CulnSe2-based alloys, and CdTe thin film solar cells. Tremendous advances in device performance have been made in most of these technologies, and much effort has gone into the commercialization of these technologies

The specification thin film solar cell 100 wp is described as follows:

- The voltage at Pmax (Vpm) = 18,0 V
- Current at Pmax (Imp) = 6,1 A
- Weight = 2,5 kg
- Dimension = 864 x 563 mm
- Cell Efficiency = 18,56 %

III. RESULTS AND DISCUSSION



(a) (b)

Figure. 1(a). Monocrystalline Silicon; **(b)** Polycrystalline Silicon

Figure. 2. Thin Film Solar Cells

A. Shipping Route

In this study, the shipping routes that will be carried out are shown in Table 1. From the total distance traveled by each island, the total distance traveled by ship is 9,131.80 meters or 9,131 kilometers.

B. Cruise Concept

The concept of shipping that is carried out needs to be planned so that shipping is more effective and efficient. The concept of the shipping line is illustrated in Table 2. Based on the data shown in Table 2, the initial estimation of voyage planning carried out for 10 hours can be seen in Figure 3.

Based on this figure we can define the time to get in and out of the ship as follows:

- Blue Line : Ship 1
- Red line : Ship 2
- Gray Line : Ship 3
- Yellow Line : Ship 4
- Light Blue Line : Ship 5

In the results of the data analysis that has been obtained using the cycle time concept, it can be seen from the graph above for 1 ship trip with a speed of 10 knots, which is the most optimal sailing service speed and can be traveled in 299,585 minutes. In the period from 07.00 – 17.00 which is for 10 hours, as many as 5 ships can be used with each ship can take 2 trips. So that the total number of ships produced using this system is 10 ships in 10 hours with a speed of 10 knots.

C. Determination of the Main Size of Ship Design

Ship data can be obtained from existing ships in production. The ship is also already operating in several countries. In this study, the ship's data will be used as a reference in data processing as shown in Table 3.

The selection of ship size is based on the results of the ship speed analysis has been obtained as shown in Table 3. In this research, the optimal ship speed is 10 knots. However, to be more optimal based on this research, the researchers took the assumption to increase the resulting speed at a range of 12 knots. So that the ship can operate with a maximum speed of 12 knots and a sailing service speed of 10 knots. The good speed ship on the criteria is shown in Table 4.

TABLE 1.
ROUTE DISTANCE

No	Route	Distance (m)	Distance (km)
1	Tugas Island – Kelor Island	692,99	0,693
2	Kelor Island – Karangan Island	2414,98	2,415
3	Karangan Island – Makasar Island	3084,81	3,085
4	Makasar Island – Tugas Island	2939,02	2,939

TABLE 2.
ROUTE DISTANCE

Condition	Step Stage
Start	1
Waitting Time	1
Pulau Tugas – Pulau Kelor	2
Waitting Time	2
Pulau Kelor – Pulau Karangan	3
Waitting Time	3
Pulau Karangan – Pulau Makasar	2
Waitting Time	2
Pulau Makasar – Pulau Tugas	1
Waitting Time	1

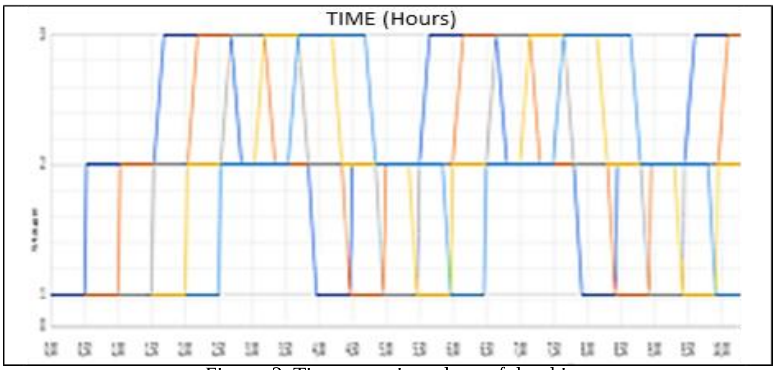


Figure. 3. Time to get in and out of the ship

The above data will be used as a comparison to get the main size estimate on the design of the ship design in Labuan Bajo. By referring to the ratio parameters and regional geographic data based on the Southampton catamaran series (Ship Resistance and Propulsion) Demihull model, namely Lwl/b = 10.4 and b/T = 1.5, we get:

- Lwl =13.03 m
- b = 13.03/10,4 = 1.25 m
- T = 1.25/1.5 = 0.83 m

To find the size of the width and height, a ratio comparison is made with the regression method as shown in Figure 4(a) and (b). The calculation of L/B ratio and L/H ratio are calculated as follows:

- L/B = 0,0441x + 1,5986
  With the above calculation formula with L= 13,03 m. Then calculated L/B = 0,0441 x 13,03 + 1,5986 = 2,173. B = L/(L/B) = 13,03 / 2,173. So the result is L= 13,03 m, B = 5,99 m, and L/B = 2,173.

- L/H = -0.2493x + 10.237
  With the above calculation formula with L = 13.03 m. Then calculated L/H = -0.2493 x 13.03+10.237= 1.9 m. So the results obtained for the height of the ship is H = 1.9 m.

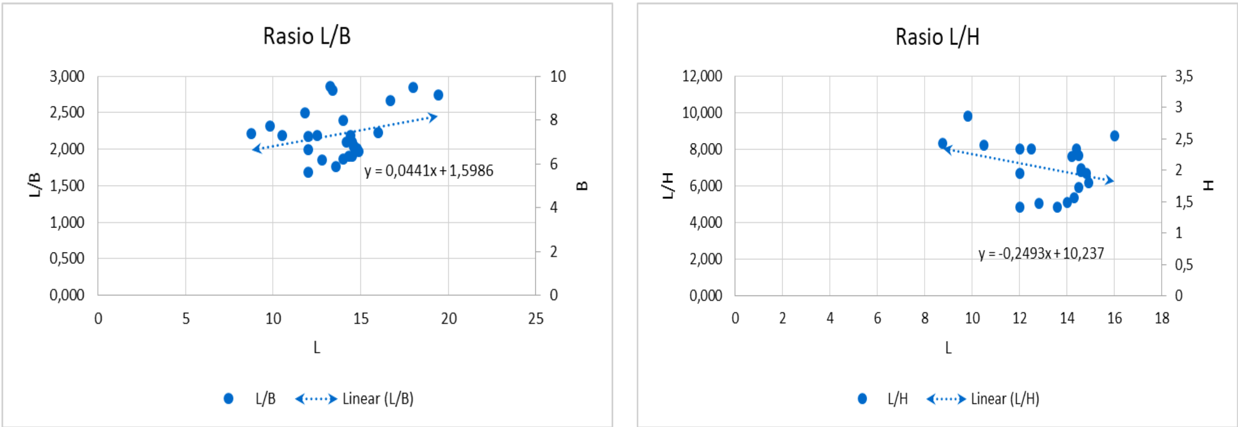
To design a ship with the size that has been obtained, we use Maxsurf software with the results shown in Table 5 and the general arrangement shown in Figure 5.

TABLE 3.
SHIP DATA COMPARISON

No	Name	LOA (m)	B (m)	T (m)	vs (max) Knot	vs ops Knot
1	Soel Shuttle 14	14	4,9	0,65	12	7
2	Soelcat 12	11,8	5,8	0,7	14	8
3	silent yacht 55	16,7	8,46	0,64	11	7
4	silent yacht 64	19,43	9,5	1,1	11	8
5	silent yacht 44	13,4	7,2	0,75	12	8
6	silent yacht 60	17,99	8,99	0,93	14	8
7	aquanima 40	13,25	6	0,65	9	6

TABLE 4.
SHIP DATA COMPARISON

No	Nama	LOA (m)	B (m)	T (m)	vs (max) Knot	vs ops Knot
1	Soel Shuttle 14	14	4,9	0,65	12	7
2	Silent Yacht 44	13,4	7,2	0,75	12	8



(a) (b)

Figure. 4(a). L/B Ratio; **(b)** L/H Ratio

TABLE 5.
PRINCIPAL DIMENSION OF SHIP DESIGN

Principal Dimension	Size	Unit
Loa	14,00	m
Lwl	13,00	m
B	6,00	m
H	1,30	m
T	0,83	m
Cb	0,236	
Vs	12	Knot
Electrik Motor	75	kW
Displacement	**15,720**	**Ton**

From Figure 5 we can see that the electric ship has a roof that can be opened for placing solar panels that can be utilized for navigation equipment, lighting, and radio. The use of solar panels can be utilized in the rooftop area obtained, it can contain a total of 182 solar panels with a capacity of 100 Wp to be used.

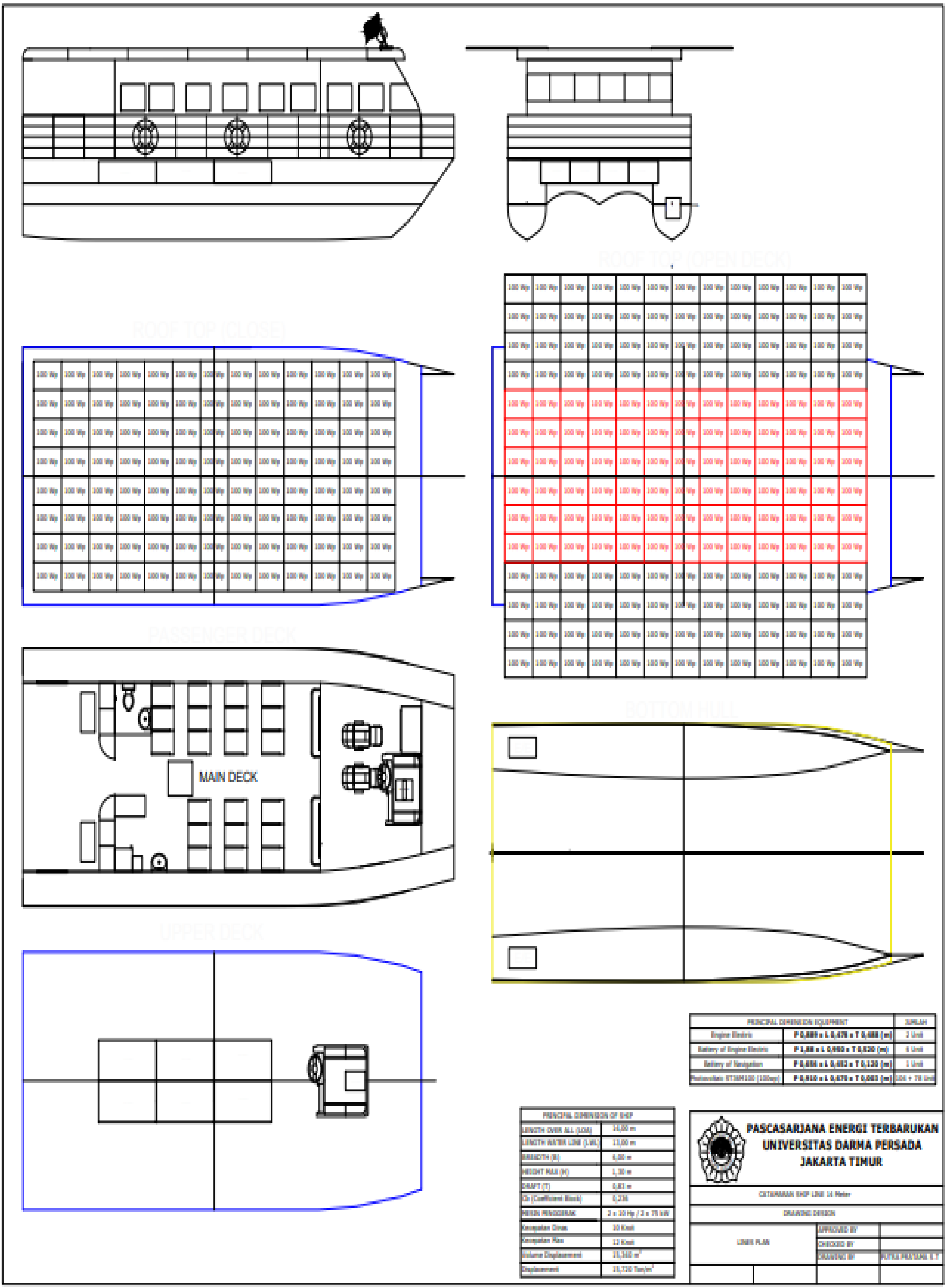


Figure. 5. Ship Electric Design

IV. CONCLUSION

From the results, it can be concluded that the maximum number of vessels that can be used within an operational time of 10 hours is 5 vessels. Each ship can take 2 trips with an operational speed of 10 knots. Where the principal dimension of the ship design with the most optimal size has characteristics: LOA=14 m, LWL=13 m, B=6 m, H=1.3 m, T= 0.83m, Cb=0.236 Vs_{ops}=10 knot, Vsmax=12 Knot, electric motor = 75 kW, and displacement =15.72 Ton.

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