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The Design of 3 GT Fishing Vessels using DC Electric Power as Driving and Electricity

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Abstrak

Tujuan dari penelitian ini adalah untuk merancang kapal ikan 3 Gross Tonnage (GT) kecepatan 6 knot dengan bentuk dan ukuran kapal yang menggunakan sistem energi panel surya yang sesuai untuk wilayah perairan. Kapal tersebut rencananya menempuh jarak maksimal 18 Km dari titik keberangkatan. Langkah-langkah metode penelitian desain kapal penangkap ikan antara lain menentukan ukuran utama kapal, membuat gambar garis, menyusun rencana umum, desain konstruksi, kapasitas tonase kapal, kebutuhan listrik, dan kemudian merancang sistem energi panel surya. Penelitian ini menghasilkan desain kapal yang memiliki panjang 8 meter, lebar 1,75 meter, dan tinggi 1,3 meter. Spesifikasi tersebut digunakan sebagai batasan untuk menentukan jumlah panel surya dan baterai. Untuk memenuhi semua tujuan itu, panel surya dibatasi 0.9KWh untuk perjalanan 9,7 NM (18 KM) dengan kecepatan 6 knot. Keterbatasan itu memaksa nelayan yang bekerja setiap hari dan malam untuk menganggur selama sehari. Jumlah baterai untuk memancing dimalam hari 49% lebih banyak dari pada memancing siang hari yang menggunakan 25 pcs 3.2V 100Ah. Dengan penggunaan baterai 51 pcs, nelayan juga bisa bekerja di siang hari sehingga bisa memancing lebih sering dari hanya memancing malam hari.

Kata kunci: kapal; panel surya; elektrik

Abstract

The purpose of this study was to design a 3 Gross Tonnage (GT) fishing boat with a speed of 6 knots with such shape and size of the vessel that is suitable for the water area that using the solar panel energy system. The ship had the plan to travel about a maximum of 18 Km from the departure point. The steps of the research method for the design of fishing vessels include determining the principal size of the ship, making line drawings, drafting a general plan, construction design, ship tonnage capacity, electricity requirements, and then designing solar panel energy systems. This research resulted in a ship design have 8 meters long, 1.75 meters wide, and 1.3 meters high. Those specifications are used as constraints to determine the number of solar panels and batteries. In order to satisfy all of the goals, the 3 GT boat has limited 0.9KWh solar panels to travel for 9.7 NM (18 KM) at a speed of 6 knots, forcing daytime and night fishing to idle for a day. The difference is in the number of night fishing batteries that are 49% more than the daytime fishing that uses 25 pcs 3.2V 100Ah. With the use of 51 pcs of battery, night fishing can move into daytime fishing so that it can fish more frequently than night fishing mode only.

Keywords: *ship; solar; panels; electric;*

1. Introduction

According to [1] The potential for marine fisheries in Indonesia was ± 6.5 million tons / year, some of which taken by Indonesian fishermen, was about ± 5.81 million tons / year in 2012, and some of which were taken by fishermen from neighboring countries illegally. This is due to the limited number and size of fishing vessels operating. According to the Head of the Marine and Fisheries Human Resources Development Agency of the Indonesian Ministry of Marine Affairs and Fisheries [2], he estimates that the potential number of fish resource catches allowed in Indonesia's fisheries management areas reached 12.5 million tonnes in 2017. One area that has potential for capture fisheries is Bojonegara District, Serang Regency, Banten Province. The length of the Wadas Bojonegara pier is approximately 150 meters, with a pool depth of fewer than 70 centimeters. Can accommodate ± 20 fishing vessels with an average size of 3 to 5 GT.

Capture fish landing area is not more than 5 hectares. Even though with a vessel with a capacity of more than 5 GT, these fishermen can contribute more to state tax revenue. However, on the basis of equal distribution of jetty use and economic distribution of fishermen, fishermen are not allowed to own ships above 5 GT unless they have their jetty. Based on this capacity limitation, fishers are required to operate more often than if they own a 5 GT vessel. It is natural because the logical consequence is that the 3 GT boat will be filled with fish more quickly and will use fuel more often to go back and forth. The use of this fuel is reducing the welfare of fishermen because of the cost and causing an increase in fish prices.

In fishing operations at night, fishermen use electric lights to invite plankton to come closer as shown by Sari [3] and Zain and Patta [4]. That way the fish will chase plankton and also get closer to fishing boats. The power of this electric light often comes from a diesel engine, so it wastes fuel. Apart from using a diesel engine, many ships use flooded batteries. Upon returning from the sea, this fishermen removed the flooded battery to charge at the charging service. This operation requires a lot of money if it did every day. To overcome the problem of electrical energy, with the alternative use of solar panel installations as a provider of electrical energy as a substitute for fuel energy and the previous electrical energy system. In general, all-electric ship research uses the same technology, namely solar panels, batteries, solar charge controllers, and DC motor drives [5, 6]. Meanwhile, this study also considers the ship's operation as a constraint so that optimal electrical design will be created.

Dewantara [5] uses the assumption that sun has effective light for only 3 hours per day. The reality in the field depends on the season and where the ship users live. Then the use of VRLA battery was assumed to use a depth of discharge (DOD) of 100% [5]. It significantly reduce battery life as shown in Figure 1, which caused Dewantara's goal [5] to be not achievable due to frequent replacement of new batteries.

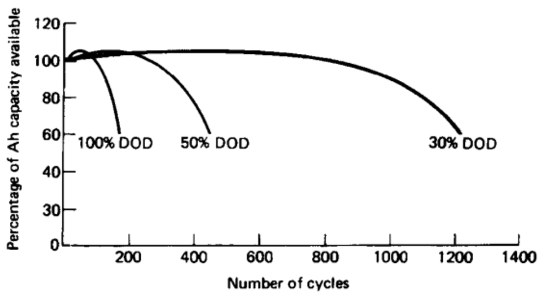

Figure 1. Cycle service life of prismatic lead-acid battery in relation to depth of discharge (DOD) at 20°C [11]

Endro [6] found that in full operation of a 15x5 meter passenger ship could use 64 solar panels, assuming 8 hours of sunshine. However, he also uses 15 pcs of $LiFePO_4$ 243Ah battery which can operate fully for 8 hours. So there is a waste of energy supply, plus this renewable energy has the goal of saving operational costs so that it may not need batteries at all. Therefore, in this study, it is necessary to have a win-win solution policy using optimization principle.

2. Material

Fishing Vessel is a type of fishing boat that is specifically used to catch fish including, storing, cooling or preserving it. This fishing vessel is equipped with fishing gear according to the provisions of the Ministry of Marine Affairs and Fisheries [7]. In 1975, solar powered boats were first built in England [8]. By 1995, passenger ships using solar panels began to appear, and are now widely used. In 1996, Kenichi Horie crossed the Pacific Ocean in a solar boat, and a double hulled solar powered ship (catamaran) named Sun21 passed through the Atlantic Ocean in the winter of 2006-2007. In May 2012, Turanor Planet Solar became the first solar electric vehicle to circle the world [9].

2.1 Construction And Propulsion

Fishing vessels must be able to operate in the Wadas port fishing ground, Tangerang Regency. The construction of this fishing boat is planned to be made of aluminum, fiberglass, or wood. The material is formed into a shell, frame, web, and stiffener. Material thickness and modulus of construction elements refer to the classification and construction regulations issued by the Classification Bureau or the Non Convention Vessel Standard (NCVS) regulations. Parts of the ship that are calculated for the thickness of the material and the modulus are: leather material, deck, base construction, ivory, bulkhead, bow and stern height and others.

The propulsion energy is influenced by the resistance and the desired speed of the ship. Ship resistance is influenced by many parameters such as density and viscosity of sea water, gravity, Wetted Surface Area, shape of the back of the ship, length of run, Hydrostatic Curve data and others. In short, the Effective Horse Power (EHP) formula is as Equation (1). There are 38 equations needed to get the *RtDinas* value. However, to save this article page, please contact the researcher for a detailed explanation.

$$\boldsymbol{EHP = \frac{RtDinas\ x\ Vs}{0.746}} \tag{1}$$

Where:

RtDinas = Total cruise line resistance

Vs = Speed required

2.2 Valve Regulated Lead Acid Battery (VRLA)

According to [10] and a summary of the handbook of batteries by Reddy [11], VRLA batteries have a larger weight and dimensions than Lithium iron phosphate. VRLA can have a lifecylce of more than 1000 cycles as long as the DOD is at 30%. The VRLA voltage needs to be maintained above 11.4v when it is not used for a long time because VRLA self-discharges which results in the VRLA's amperage capacity being reduced when it is recharged. However, this rarely happens even though it rains for 7 days, unless repairing the ship takes more than 1 month then VRLA needs to be maintained. This type of battery can not serve DOD more than 100%.

The best operating temperature for VRLA is 25°C. These temperatures can occur when fishermen operate at night. However, temperature is not the only factor affecting VRLA performance. In addition, is the amount of discharge. Based on Figure 2 [11], the greater the discharge, the smaller the capacity at the same temperature. The advantage of VRLA is cheap at the start of the investment, but it will be expensive if use it on a large scale and for a long period, considering that the normal life of VRLA is less than 2 years when using up to 50% DOD.

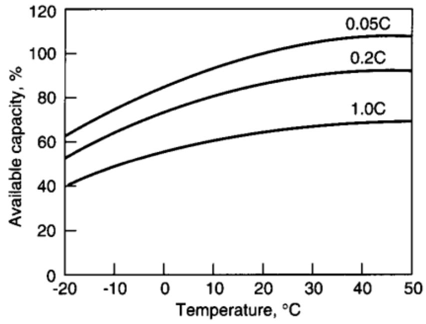

Figure 2. Effect of temperature on discharge performance of thin prismatic lead-acid batteries [11]

2.3 Lithium Iron Phosphate Battery ($LiFePO_4$)

Lithium-based batteries have the advantage of being very effective over VRLA in that they can maintain the voltage level when energy is running low as shown in Figure 3 below [11]. This battery has dimensions and weight that is lighter than VRLA and according to Rosenkranz in [12, Fig. 3] LiFePO4 has a very long life over 5000 cycles. This battery can still operate effectively up to a temperature of 60 ° C at daytime temperatures [11].

3. Methods

The research begins by identifying the problem of fish shipping in Wadas port. The problem found is about unsustainable operational costs. Further explanation of the problem can refer to the introduction chapter. The next step is to make a proposed solution to the problem. The solution offered is to design a fishing boat powered by electricity from solar cells. Obviously by collecting data to support this solution. The data taken are two existing 3 GT ship characteristic references. The following is a summary of the research methods.

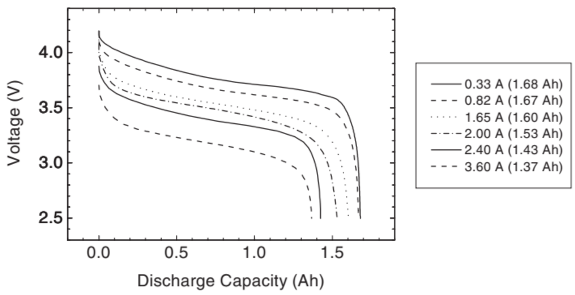

Figure 3. Discharge capability of 18650 type C/$LiCoO_2$ batteries at constant current at 21 C to 25°C [11]

Table 1. Research Step

No	Step	Methods	Output
1	Problem identification and Data collecting	Literature study, survey	Characteristic of a similar 3 GT fishing vessel
2	Pre- Design	The existing ship principal size ratio methods are: L/B, B/T, D/T as shown in Table 4	Ship Principal Size: Loa: the entire length Lpp: length of vertical line Lwl: the length of the water line.

No	Step	Methods	Output
			B: wide D: high T: laden with water
3	Estimated Ship Weight	Using reference vessel of comparison and general formula as shown in Table 3	Dead weight (Deadwieght), namely the weight of the catch fish, lubricating oil, cooling water, crew members and their luggage. Empty Ship Weight (Lightweight), namely construction, engineering, and equipment / tools.
4	General Arrangement	Uses general ship regulations and CAD software as shown in Figure 4	Draw the layout of all rooms, room access and equipment locations. Side, front, and top view images.
5	Determination of Ship Equipment and Making Specifications	Uses general ship regulations and equipment selection including the electrical system	Equipment for ship propulsion system, accommodation, mooring, safety; Equipment operating specifications and procedures.
6	Determination of Construction	Ship Classification Bureau Regulations	Determination of load, number of bulkheads, frames, hull plates, deck plates.
7	Tonnage calculation	GT = .25 * (L * B * D * T)	The volume of the entire room
8	Calculation of Drive Power	Using Hullspeed Equation (1)	Wet surface resistance value, Effective horsepower.
9	Calculation of electricity requirements	General or Basic math calculation	The amount of electric power required
10	Solar energy calculation and installation	Basic electronics math	The amount of power generated and the installation circuit
11	Stability Calculations	Ms =Δ * GM * Sin γ	curves of empty and full ship conditions, as well as the roll period

4. Results and Discussion

The following is the operational data summarized from interviews with Wadas fishermen

Table 2. General Data

No	Data	Spesification
1	Length of pier	+ 60 meter
2	Pier pond	tidal + 2,5 meter, recede + 1,5 meter
3	Ships visits	+ 30 ships / day
4	Fishing gear	trawl
5	Catch	Udang, bilis, petek, dan tembang
6	Catch Amount	+ 120 kg / ship / day
7	Fuel	7500 liter / day
8	Ice cube	+ 60 cube / day

4.1 Main Specification

The determination of the principal size of the vessel for the 3 GT is based on the existing comparison vessels, as follows:

Table 3. Comparison of Existing Fishing Boat

	Control Vessel 1	**Control Vessel 2**
	CV. Javanese boat	FiberBoat Factory ”Kurnia Marina”
Length overall	8 meter	8 meter
Width	1.71 meter	1.83 meter
Deck height	1 meter	1.3 meter
Draft	0.35 meter	0.5 meter

The principal sizes of the designed vessels are as follows:

Length Overall (Loa)

According to the comparison ship, the total length (Loa) is determined to be 8.00 meters

Length Between Perpendiculars (Lpp)

$$\boldsymbol{Lpp = k\sqrt[3]{GT}} \tag{2}$$

According to Fishing Boat of The World the price is k = 5.9, so the value of Lpp is 7.44 m. According to the Indonesian Classification Bureau (BKI) the value of Lpp is 7.50 m. The Lpp thes set at 7.50 m.

Waterline Length (Lwl)

$$\boldsymbol{L}wl = \frac{Lpp}{0.96} \tag{3}$$

According to Equation (3) the Lwl is set at 7.75 m.

Breadth (B)

Determined from the average width of the comparison vessel, namely:

$$B = \frac{1.71 + 1.83}{2} = 1.77\ m \tag{4}$$

Height (H)

To have more reserve for buoyancy, the height of the ship is determined according to one of the height of the comparison vessel. H is set at 1.30 meters

Draft (T)

From the comparison ship:

$$\left(\frac{B}{T}\right)_1 = \left(\frac{1.71}{0.35}\right) = 4.9 \tag{5}$$

$$\left(\frac{B}{T}\right)_2 = \left(\frac{1.83}{0.5}\right) = 3.7 \tag{6}$$

$$\left(\frac{B}{T}\right)_{average} = \left(\frac{4.9 + 3.7}{2}\right) = 4.25 \tag{7}$$

$$T = \frac{2.1}{4.25} = 0{,}51 \text{ m} \quad (8)$$

T is set = 0.5 meter

Table 4. Correction of Ship Principal Size Results

Compare of	Standard	Calculation
L/B	4.50 – 5.50	4.6
T/B	0.28 – 0.4	0.3
B/H	1.50 – 2.00	1.8
T/H	0.52 – 0.74	0.53
L/H	8.00 – 9.50	0.81

Ship form coefficient:

Block Coefficient (Cb):

$$Cb = \frac{\Delta}{L \times B \times T \times 1{,}025} \quad (9)$$

Cb is determined according to the standard, namely 0.55, so Midship Section Coefficient (Cm) is :

$$Cm = 0{,}9 + 0{,}1 \times Cb^{0,5} = 0{,}9 + 0{,}1 \times 0{,}55^{0,5} = 0{,}77 \quad (10)$$

According to the limit, Cm is set at 0.76, so the water line coefficient (Cw)

$$Cw = \frac{1 + (2 \times Cb)}{3} = \frac{1 + (2 \times 0{,}55)}{3} = 0{,}69 \quad (11)$$

In accordance with the Cw limit is set at 0.74 so the Prismatic coefficient (Cp) is :

$$Cp = \frac{Cb}{Cm} = \frac{0{,}55}{0{,}76} = 0.72 \quad (12)$$

The shape coefficient corrections for fishing boats are:

Cb = 0.45 to 0.55

Cm = 0,72 to 0,82

Cw = 0,72 to 0,78

4.2 General Plan

4.2.1 General

A general plan is presented to explain the design of a fishing boat with a capacity of 3 GT with 7 HP electric marine engine and can operate in coastal waters 10 miles from the coast of Bojonegara for 10 hours.

4.2.2 Main Specification

Length overall (LOA) :8.00 meter

Length deck (LDK) :7.50 meter

Waterline length (LWL) :7.75 meter

Breadth, moulded (B mld) :1.75 meter

Deck, moulded (Dmld) :1.30 meter

Drat (T) :0.50 meter

Speed	:5 - 6 knot
Operation endurance	:10 jam
Cruise range	:25 Nautical mile

4.2.3 Capacity

Fish Hatch (Fish + Ice)	: 1.5 tons
Fresh water	: 80 liters
Crew / complement	: 4 people
Gross Register Tonnage (GRT)	: 3 GT (*gross tonnage*)

4.2.4 Propulsion

Marine electric engine	: 1 unit
Engine output (BHP)	: 6-7 HP
Maximum speed	: 2,000 RPM
Fixed propeller	: 1 unit

4.2.5 Speed and Cruising Range

Based on formula (1), the power needed for the ship to maintain a speed of 6 knots in calm waters with a load of 3 GT is 6,627 HP or equivalent to 4.94 KWh of energy. This formula has included a variety of special factors such as shape of the back of the ship, to include the East Asian shipping lane stipulation of 15%. When operating at full speed 6 knots, the engine condition is loaded at 90% MCR and is able to sail a total cruising distance of 10 NM with 10 hours endurance.

4.2.6 Layout of a 3 GT Fishing Vessel

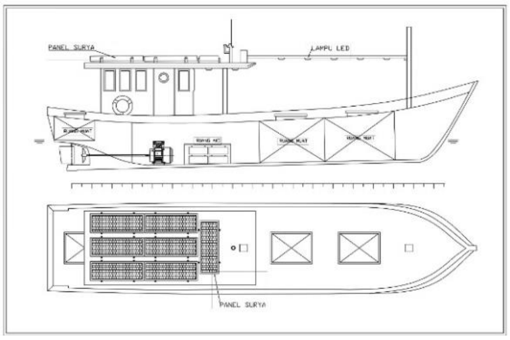

Figure 4 General Plan Layout of a 3 GT Fishing Vessel

4.3 Power From Solar Panels

The resulting solar cell voltage will be used by the charge controller to charge the batteries for supplying the current to the inverter to turn on the load of Alternating Current (AC) devices such as navigation lights, television, radio, communication equipment, etc. Installing a solar power plant requires planning regarding power requirements: (i) Number of usage, (ii) Number of solar panels / solar cells and (iii) Number of batteries. Calculation of power requirements, calculation of device electrical power can be seen on the label on the back of the device, or read from the manual:

4.3.1 Fishing Patterns

Batteries are the most expensive tools in cost compared to solar panels and propulsion engines. For that reason we need alternative scenarios in fishermen operations. According to Masyhuri in Sujarno (2008: 39) there are at least three fishing patterns that are commonly carried out by fishermen.

1. The catch pattern is more than one day

   This kind of fishing is offshore fishing. The catchment area is far away and the size of the boats used determine the length of time at sea.

2. One day fishing pattern

   Usually fishermen go to sea around 14.00 back around 09.00 the next day. Fishing like this is usually classified as offshore fishing.

3. Midday fishing patterns

   Fishing like this is fishing near the coast. Generally they leave around 03.00 in the morning or after Fajr, and return in the morning around 09.00.

Based on the above pattern, we can logically confirm that the first pattern requires a large investment because the distance is the most distant. Then the latter pattern requires a cheaper investment because it is short range. In the context of ships powered by solar panels, cruising distances can be increased if departure starts at 7am when the sun is bright enough and stays 1 day at sea. However, this is very rarely done as fish become scarce on sunny days. Based on interviews with fishermen, they left at 9pm and returned home at 4am. They work at night because they rely on the lights to attract the attention of the fish to come and gather. So, we will use 2 alternative scenarios, they are: the last fishing pattern (night fishing) and the alternative daytime fishing. In the night fishing we use the assumption that the fishermen will not shift to another location from the point they arrived and solar panels are not installed on the land.

4.3.2 Amount of Solar Panels and Batteries

Based on previous interviews, fishermen did not want to install panels all over the surface of the boat. The maximum allowed by fishermen is 7 panels. Therefore, the speed and cruising range of the ship will decrease unless the fishermen sails every 2 days, it can reach up to less than 18 km. The number of solar panels and batteries depends on the speed, distance traveled, weather requirements and the dimensional of the ship. The predefined factors are a minimum speed of 6 knots, a range of 18 km and 7 solar panels of 100 watt peak as shown in figure 4. In the first and second scenarios use these provisions.

In the night fishing, operations run for about 6 hours because fishermen leave for the sea at 3 am and then arrive at the port at 9 am. At a speed of 6 knots to depart and return for 36 km, it takes 3 hours 12 minutes. Then there is spare of time about 3 hours for fishing using LED lights. In the daytime fishing, fishermen go to sea at 7 am then return to the port arriving at 6 pm. So the operation runs 11 hours. Due to the daytime fishing, it does not require lights. However, as a consequence the ship can shift from the point of arrival at sea because it gets energy from the sun. The time given for fishing is:

$$11 \text{ hr} - 3.2 \text{ hr} = 7.8 \text{ hr} \quad (13)$$

Both scenarios have similarities in terms of activities to go and return. So that we can calculate the energy with simple mathematics, the ship requires energy to go and return by:

$$4.94 \text{ KWh} \times 3.24 \text{ hours} \approx 16 \text{ KWh} \quad (14)$$

Then the fishing activity using a dipped LED light requires 17.6 watts [13] for 3 hours. The use of this LED lamp only applies to the first scenario hence its energy requirements:

$$17.6 \text{ watt x } 3 \text{ hours} = .0528 \text{ KWh} \tag{15}$$

$$15 \text{ watt x } 3 \text{ hours} = .045 \text{ KWh} \tag{16}$$

Equation (16) means that when sailing at night, the ship needs lighting above the deck using 15 watt LEDs for 3 hours because at 6am it start looks bright. The fishing activity in the second scenario relies on a wider reach to install a maximum 300 meter long seine nets [14] so that the boat needs to move 600 meters to mount it and pull it back. This movement when using a speed of 6 knots requires energy of:

$$\text{Watt} = \left(\frac{600\,\text{meter}}{6\,\text{knots}}\right) \times 4.94\,KWh = 0.266\,KWh \tag{17}$$

So the total energy requirements for all activities in the night fishing and daytime fishing scenarios are respectively: (i) (14) + (15) + (16) = 16.097 ≈ 16.10 KWh and (ii) (14) + (17) = 16.266 ≈ 16.30 KWh. The energy requirements above do not appear to differ significantly. It has been determined that the ship only has 7 solar panels with a capacity of 100wp per panel, so the panels contribute as much as 0.7 KWh. In theory, the panel can produce 7 KWh in 10 hours with the assumption that the weather is conducive so that the time needed to charge the battery is around:

$$\text{Hours Charge} = \frac{16.1 \text{ KWh}}{0.7 \text{ KWh}} = 23\,hours \tag{18}$$

The hours charge value above cannot be completed in 1 day because the longest sunshine only occurs on December 21-22 for 12 hours which is called the December Soltice. After that moment the duration of the day is reduced so it takes 3 days for the batteries to be fully charged. This charging hour is detrimental to night fishing fishermen because they are unemployed for 2 nights. The solar panels are then added 2 more so that unemployment time can be reduced, then the charging hours are:

$$\text{Hours Charge} = \frac{16.1 \text{ KWh}}{0.9 \text{ KWh}} = 17.8\,hour \tag{19}$$

or approximately 9 hours per daytime

Thus, fishermen can work at night after the battery is charged during the day before. This means that fishermen are unemployed for only one night. Both scenarios can use 9 solar panels. It's just that the operational method is different and the number of batteries is different because in a daytime fishing scenario, the driving energy can be supplied from solar panels. While the nigth fishing scenario requires 100% energy from the battery. Referring to the explanation in the chapter of Materials, the recommended battery type in all scenarios is LiFePO4 because it is able to maintain a stable voltage requirement until the energy runs out. This stable voltage also keeps the ship's velocity from decreasing significantly. The following batteries as shown in Figure 5 are selected based on economic considerations in the Chinese market, taken from the alibaba.com website:

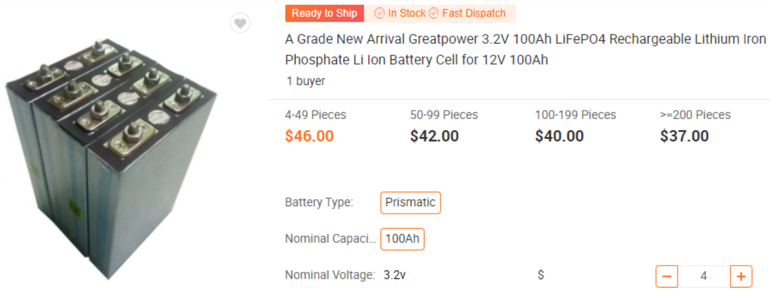

Figure 5 LiFePO4 3.2V 100Ah [20]

The number of batteries required in a night fishing scenario if the fishermen return before sunrise is defined in Equation (20) and the power need is defined in Equation (21). The result of Equation (21) is used in the Table 5 to be Reserve.

$$\frac{16.1\ \text{KWh}}{(3.2\text{V} \times 100\text{Ah})} = 50.3\,pcs \approx 51\,pcs \tag{20}$$

$$51\,pcs \times (3.2V \times 100\ Ah) = 16.32\ \ KWh \tag{21}$$

In the daytime fishing scenario, the battery does not need to be 51 pcs. Because when the ship is moving, some of the energy is supplied by solar panels. If we use the same working method as night fishing, the fishermen will be idle for 2 days so that the battery is full. Then the next morning they go to sea. This can be detrimental to fishermen although it can be compensated by 2 round trips after 2 days of idle. This compensation can occur because there is still 9.1 KWh left at 6pm. So that tomorrow morning the ship can go straight away without waiting in full charge. Figure 6 is a graph of energy usage history when using 51 pcs of battery:

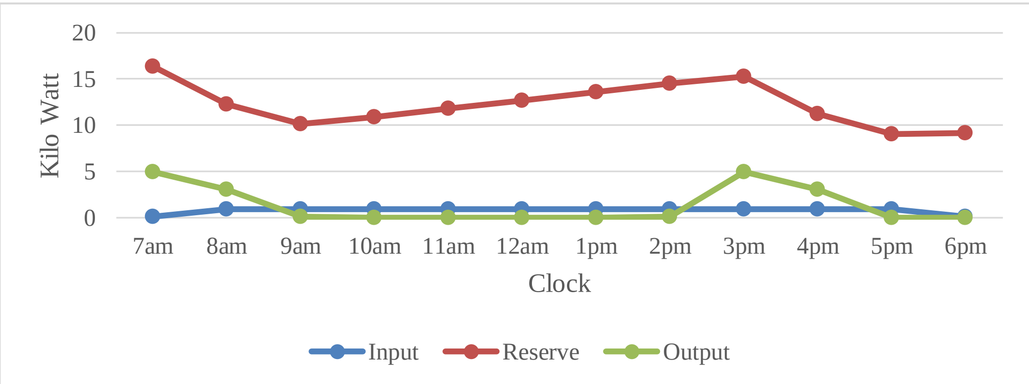

Figure 6 Energy Usage History for daytime fishing

The operation above uses the assumption that the battery energy is fully 100% as much as 16.32 KWh. Then the sunlight starts to be effective at 7 am, so the battery gets 0.9 KWh of energy at 8 am. Then the ship departs at 7 am using 4.94 KWh of energy for 1 hour 37 minutes so that the subtotal energy usage becomes 8 KWh. The following is a brief summary of energy input and output :

Table 5 Energy Usage History for daytime fishing with 51pcs battery (in KWh)

Clock	Input	Reserve	Output

7am	0.1	16.32(Cap)	4.94
8am	0.9	12.28	3.06
9am	0.9	10.12	0.133
10am	0.9	10.887	0
11am	0.9	11.787	0
12am	0.9	12.687	0
1pm	0.9	13.587	0
2pm	0.9	14.487	0.133
3pm	0.9	15.254	4.94
4pm	0.9	11.214	3.06
5pm	0.9	9.054	0
6pm	0.1	9.154 (salvage)	0
Total	**9.2**		**16.266**

With the remaining energy in the battery at 6 pm is 9.154 KWh, in next day the battery will reach 100% at 3 pm. There are 2 operational hours left. This means the excess number of batteries due to the remainder. To be more efficient, the number of batteries is defined in Equation (22). The term safety stock in (22) was taken from industrial terms which means of energy spare. It is for anticipating the condition of non-conducive environment such as non-linear wind direction.

$$\left(total\ output - total\ input\right) \times \left(1 + \%\ safety\ stock\right) = \text{The number of batteries power that can provide energy for daytime fishing optimally is :}$$
$$\left(16.266 - 9.2\right) \times \left(1 + 10\%\right) = 7772.6\ watt \tag{22}$$
$$\frac{7772.6}{320} = 24.28\,pcs \approx 25\,pcs$$

daytime fishing optimally is 25 pcs x 320 watt = 8 KWh, so in the first row Reserve column in table 5 should be changed to 8 KWh. Table 6 is showing a simulation of 43 pcs (25) battery usage with the remaining energy in the battery at 10 am is 202 Watts, in next day the battery will reach 100% at 3 pm. Then the fishermen can go work that night.

$$\frac{13500\,W}{320\,W} = 42.18\,pcs \approx 43\,pcs \tag{23}$$

the 13500 watts value obtained from a solar energy input simulation conduct in excel software. The value depends on the time when fishermen return home. The current simulation was using the assumption of following the last fishing pattern that returns home at 8 am. So the solar panel has a chance to be power up by sunlight in the morning.

Table 6 Energy Usage History for night fishing with 43 pcs battery (in KWh)

Clock	Input	Reserve	Output
2am	0	13.5(Cap)	4.94
3am	0	8.56	3.06
4am	0	5.5	0.0326
5am	0	5.467	0.0326

6am	0.	5.434	0.0326
7am	0.1	5.502	0
8am	0.9	6.402	4.94
9am	0.9	2.362	3.06
10am	0.9	0.202(salvage)	
	9.2(fullday)		**16.0978**

4.3.3 Selecting Solar Charge Controller

There are 2 types of solar charge controllers circulating in the market, namely Maximum Power Point Tracking (MPPT) and Pulse Width Modulation (PWM). PWM type is the cheapest but the feature is not suitable in weather conditions where the light intensity changes frequently due to clouds and the angle of the sun's tilt towards the panel. PWM type cannot maintain charge voltage when sunlight is reduced due to cloud cover. This weakness is corrected by the MPPT type solar charge which can maintain the voltage even though the consequence is that the charging current becomes small [14]. For that reason, this study recommends using the MPPT type. The MPPT specification uses the highest output voltage on the international market, which is 72V. This high voltage is to reduce heat in the cable due to the delivery of large currents to the electric propulsion. Based on the formula Electric Power equal Voltage times Current (I), the higher the voltage, the smaller the current delivered, the less heat it will be. The current available on the MPPT is a maximum of 40A. So according to the formula above, this MPPT can handle 2.88 KWh. Meanwhile, based on formula (1), this ship needs 4.94 KWh to maintain a velocity of 6 knots, so the number of MPPT is required 2 pcs in parallel connection system [16]. The total energy handled is 5.76 KWh. The following is table 7 regarding the MPPT specifications

Table 7 MPPT Specification

Brand	Asha
Max PV Array Open Circuit Voltge	230V
Max PV Array Watts Aplicable	3.1KW
Nominal Battery Voltage	72V
Maximum Charging Current	40 A
Efficiency	98.9%
Net Weight	3.9 Kg

4.3.4 Electric Propulsion Engine

Based on the consideration of temperature factors and specifications in table 7 above, the propulsion engine which called Brushless DC, must have a voltage of 72Volt and have a power of 5 KWh and have liquid cooling as shown in Figure 7. A BLDC cannot draw power directly from batteries or other power sources. BLDC requires a controller as shown in Figure 8, to adjust the current so that the propeller rotation changes according to the needs of the driver. Detailed designs of propulsion blades were carried out in next research. This study only discusses electric power, voltage current and assemblies.

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Figure 7 Brushless DC Motor (BLDC) [21]

Figure 8 BLDC Controller 5KW [21]

4.3.5 Wiring Diagram

Assembly is starts from the battery cells connected in series to a block of 23 pcs of 3.2V battery (26) then connected to 3 row paralel (28).

$$\frac{72\text{V}}{3.2\text{V}} = 22.5 \approx 23\, pcs \tag{24}$$

$$23\, pcs \times 3.2V = 73.6V \tag{25}$$

Unit rounding (26) causes the voltage to be 73.6V (27). MPPT can still tolerate this voltage because it has a rectifier diode inside, so that the current does not return to the MPPT when solar panel's voltage are drop. This battery will not reach 73.6V when charged because the MPPT can be set to only 72V, but it does not mean that its capacity does not meet the operational needs of the ship. According to Equation (20), if the boat return home before sunrise, then it requires 51 pcs of battery. If it is installed in series with (26) to reach operational voltage, there will be:

$$\frac{51\text{pcs}}{23\text{pcs}} = 2.21 \approx 3\, blocks \tag{26}$$

Except one of the blocks consists of 5 batteries in series, we can call it a small block. It has 1.6KWh in Equation (27), however, it cannot be directly connected parallel to a large block because it only has 16 Volts in Equation (28). Because of that we need to assemble the 18650 type of battery, which have 3.7 V and 2.1Ah [11], as much as 20 pcs in series in Equation (29) times 154 or 155 in parallel Equation (31) so we call it 20S154P.

$$320\text{watt} \times 5\, pcs = 1600 \text{ watt} \tag{27}$$

$$5\text{pcs} \times 3.2\text{V} = 16\text{V} \tag{28}$$

$$\frac{72\text{V}}{3.7\text{V}} = 19.45 \approx 20 \;\; pcs\, of \; 18650 \;\; type \tag{29}$$

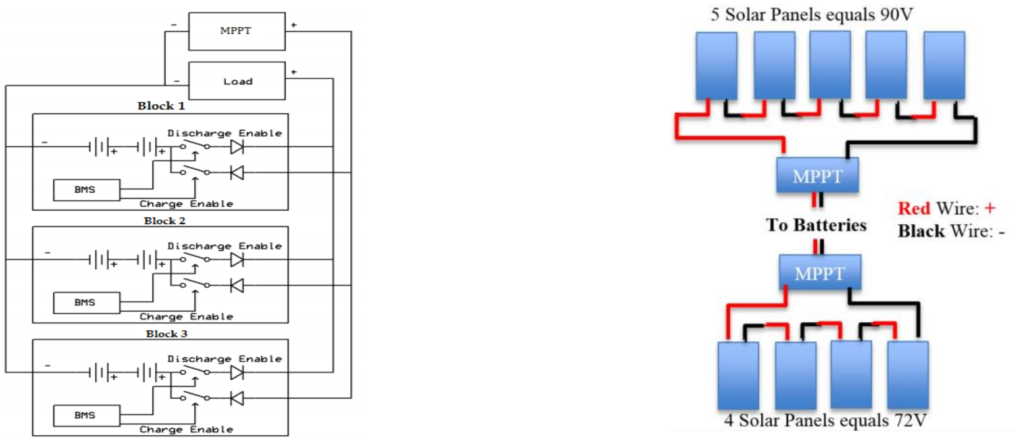
$$20\, pcs \times 3.7V = 74V \tag{30}$$

$$\frac{1600 \;\; watt}{20\, pcs \times 3.7V \times 2.1A} = 154.4 \approx 155 \;\; row \tag{31}$$

There is a slight voltage difference between large blocks (27) and small block (32). When we connecting these blocks in parallel wiring, that differences might produce an electrical arc and can result in a significant current flow from the large blocks into the small blocks even though very small differences in voltage, this is called inrush currents [17]. In addition, although LiFePO4 could maintain the voltage stability, the small block energy will run out faster when the ship is at full throttle. As a result, 2 large blocks will charge to a small block at the end of the small block's power. This will reduce the speed of the ship because the power is diverted to a small block. So it is necessary to add a large diode, contactor, and three battery management system so that the power does not enter to the small block [17] as shown in Figure 9a. This approach is uses two separate DC buses – one for charge and one for discharge. In this configuration, the charge and discharge contactors are directly controlled by the BMS in each block. Since current can only flow in one direction on each bus, eddy currents between blocks are completely prevented from occurring in the first place. According to formula (23), daytime fishing requires 25 pcs of battery. If it is installed in series according to formula (26) to maintain operational voltage, then there will be:

$$\frac{25\text{pcs}}{23\text{pcs}} = 1.08 \approx 1\,block$$

This one block will produce voltage as 25 pcs of battery times 3.2V equals 80V. The voltage of this block is above the needs of the BLDC controller electric propulsion motor. However, based on the Goldenmotor's BLDC controller guide book, it can handle overvoltage up to 90 volts.



(a) (b)

Figure 9 (a) Paralleled blocks with two separate DC busses [17]; (b) Five Series Plus Four Series

4.3.6 Solar Panel Wiring

In general or in the marketplace, the maximum voltage of a 100wp solar panel type while in closed circuits is 18V. The voltage uses in this system on the boat was 74V as shown in Equation (27) that has 23 batteries of 3.2V in series. Lithium-ion cannot accept overcharge, has tighter voltage tolerances, and can only accept a maximum of 4.2V [18]. If charged more than 4.2V it would cause plating. So 23 batteries in series could accept 96V maximum. The panels have to arrange until reach a minimum output of around 96V. So we divide 96V with 18V equals 5.3 panels in series and the MPPT's output could be set at 96V if want to quick charging. However, 5.3 solar panels were not satisfied the power system needs. As mentioned earlier that the electrical system needs 9 solar panels, so we divide it into 2 rows in parallel, each row has 5 panels in series which resulting in 90V. However, there was 1 panel that lacks that has voltage of 72V as shown in Figure 9b , however MPPT could raise voltage up to level [19] which could charging the lithium batteries safely. The MPPT could be set to parallel connection [16] and set to the same voltage, because according to basic physics principle, the electrons does flow to the lower voltage, so not to worry about wrong way flow. In addition, the MPPT has a rectifier diode which prohibit the voltages to comes in.

5. CONCLUSION

To satisfy all of the goals, the 3 GT boat has limited 0.9KWh solar panels to travel for 9.7 NM (18 KM) at a speed of 6 knots, forcing daytime and night fishing fishermen to idle for 1 day. The difference is in the number of night fishing's batteries that are 49% more than the daytime fishing which using 25 pcs 3.2V 100Ah. With uses 51 pcs of battery, night fishing fishermen can move into daytime fishing so that it can fish more frequently than night fishing mode only.

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