Load Flow Simulation of Radial Shipboard Network Structure with Direct Current Distribution Systems

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Abstract. The aim of this research is to investigate load flow of direct current distribution system on trimaran ferry ship. Radial Shipboard Network Structure with Direct Current Distribution Systems has been proposed in this research. Load flow simulation has been done by calculating electrical load calculation based on ship operation. Then, the one-line diagram of direct current distribution system is developed on electric power software. Simulation results show that direct current distribution system has been successfully implemented on hybrid powered trimaran Ship. In sailing conditions, the overall real power requirement is 20,201 MW and the reactive power is 7,757 Mvar. While the power distributed is 20,493 MW of real power and 7,816 Mvar of reactive power. In manoeuvring conditions, the actual power requirements are 21,251 MW and the reactive power is 8,16 Mvar and for power distributed is 21,573 MW of real power and 8,224 Mvar of reactive power. In loading and unloading conditions, the actual power requirements in this operating condition are 0.616 MW and the reactive power is 0.292 Mvar and for power distributed is 0.635 MW of real power and 0.296 Mvar of reactive power. In the condition of entering the port, the required power is 12.906 MW for real power and 4.969 MW for reactive power and for power distributed is 13,027 MW of real power and 4,994 Mvar of reactive power. The result showed that the concept direct current distribution system has been successfully developed in this research to combine diesel generators with marine renewable energy to make sure that the distributed power stay adequate all through operation.

Keywords: DC Distribution, Power Flow Simulation, Hybrid-powered Ship

1. Introduction

These Recently, the application of hybrid power systems on (HPS) ships have an important role in dealing with environmental problems at sea [1]. However, the use of renewable energy such as solar cells and wind turbines as a source of electrical energy on ships has more complexity and creates instability in power system [2].

Wind turbines depend on the speed and power of the wind to turn the turbine generator blades. Since, the wind speed is not constant all the time. It causes the rotation of turbine generator fluctuates so that the frequency produced by the generator turbine will not be constant at the desired frequency. Then, the impact of it caused the synchronisation process cannot be achieved. Whereas solar cells depend on sunlight, so the quantity and quality of the electric power produced varies throughout the day. In addition, the different power source platforms also contribute to HPS failure [3].

The concept of DC distribution system is believed to minimise the failure of HPS [4]. In terms of equipment, DC distribution systems have advantages over AC distribution systems [5]. In DC network, switchgears and large transformers are not used, so it provides benefits such as space and weight savings,
and flexible equipment management especially on ships that have limited space. In addition, DC power
distribution does not require synchronization of generating units, dc power systems allow prime movers
to operate at their optimal speed, and lead to significant fuel savings [6] [7].

DC distribution system concept offered is AC voltage from the diesel generator will be converted
into DC voltage by the rectifier. then, the electric power is controlled through the DC-DC Converter to
maintain voltage stability [8]. Then the electric power is transmitted to each electricity load using DC
current. Before entering each load, the DC current will be converted into AC current by the inverter, see
figure 1. In this research, it concerned about investigating of power flow analysis on DC distribution
system. Trimaran ferry ship use a combined source of electricity in the form of diesel generators and
batteries. Both of main electrical source are used together to meet the electricity needs of the trimaran
ship according to the operating conditions of the ship.

The flow analysis is carried out with several scenarios combining diesel generators and batteries
based on ship operations namely sailing, manoeuvring, loading, and unloading and at the port. the
procedure for carrying out power flow simulations begins with calculating the electrical load in each
operating condition of the ship, then determining the power capacity by selecting an electric power
source. After that, modelling the DC distribution system in electric power software.

2. Proposed Dc Power Distribution System Framework
The principle of a DC power distribution system on board in figure 4 shows that the ship has a main
power plant supplied by diesel generator sets, the electric power generated by the diesel generator is fed
into the DC bus.

The change from AC power distribution system to DC is done by rectifier and converter dc to dc.
The configuration used from the onboard DC grid uses a fully distributed system. In a fully distributed
system, each converter is near an electric generator [9] [10].

In this case, each electricity generator is equipped with a rectifier that is mounted directly on the
generator as shown in Figs. 4. The panel bus system is grouped into 3, as follows: Buses with a voltage
of 1100 AC volts, buses with a voltage of 690 AC volts, and buses with a voltage of 220 AC volts. For
panel bus with a voltage of 11000 AC volts used for electrical equipment supporting the ship's main
propulsion. For panel bus with a voltage of 690 AC volts used for electrical equipment supporting the
system and deck machinery bus panel and the HVAC and electric bus panel. For panel bus with a voltage
of 220 AC volts used for electrical equipment supporting the Navigation communication bus panel and
the lighting bus panel.
Figure 2. Radial DC Distribution for Shipboard Network
2.1. 11000 Volt Bus Panel

A voltage of 11000 AC volts used for electrical equipment supporting the ship’s main propulsion as seen in figure 5. Figure 5 shows that the three-phase ac power generated by the generator must be converted to dc power through a three-phase rectifier. Bidirectional power flow is not needed, so a three-phase diode current rectifier is an attractive choice because of its structural simplicity, high energy efficiency, and low cost. Another advantage is that the three-phase diode current rectifier can be easily used with a synchronous generator. The three-phase rectifier is already used in conventional electric propulsion systems to supply the dc connection of the propulsion electric drive [11][12].

![Diagram: 11000 Volt Panel Bus](image)

Figure 3. 11000 Volt Panel Bus

2.2. 690 Volt Bus Panels

The 690-volt AC load panel bus system will be supplied by diesel generators and supplied by batteries. It will support to system and deck machinery bus panel and HVAC and electric bus panel. From Diesel generator, 1100 AC voltage will be converted down to DC voltage by a rectifier of 690 AC Volts. After that, the DC voltage is controlled through the DC-DC Converter to maintain the voltage stability. Then the voltage is transmitted to each electrical load and before the power is supplied to the equipment load, the dc current will be converted to AC current.

From Battery, 690 DC Volt will be transmitted to each electrical load and before the power is supplied to the equipment load, the dc current will be inverted to AC current. Detail illustration can be seen in figure 4.

2.3. 220 Volt Bus Panel

The 220 AC Volt Bus panel is taken from 690 AC Volt Bus panel by using transformator. It is for supporting one phase electric equipment such as navigation and communication equipment and lighting equipment.
3. Methods
The capacity electric power on board must meet the required electricity needs and the maximum load that occurs in a short period. Based on the regulations of the Indonesian Classification Bureau, it is stipulated that the power generated from the power generating unit required for service as well as the operation of ships at sea is approximately 15% higher than the electrical power requirements of ships that have been calculated [13].

3.1. Electric Load Calculation
The selection of generators is determined based on the results of the calculation of the electrical load on the ship’s operational conditions [14]. The calculation of electrical equipment. The electrical equipment of the Trimaran Passenger Ship is grouped into 3 main categories, namely machinery parts, Hull parts, and electrical parts. Where the machinery part is divided into 5 parts consisting of electrical propulsion, water jet system, auxiliary engine service, general service, cargo service. Then the hull part is divided into 2 parts consisting of refrigerating & ventilation and deck machinery. Furthermore, electrical parts are divided into 2 parts consisting of navigation equipment and radio communications and lighting lamps. The grouping of electrical equipment based on vessel activities above aims to facilitate the determination of the load factor of each equipment, because not all electrical equipment on the ship is operated continuously. So, in the calculation of determining the power plant has several views to determine the operational conditions of the ship such as sailing, maneuvering, loading and unloading, and at the port.

Table 2 show that the result of the calculation of the electrical load which shows the total amount of power needed and the load factor on the main generator. In table 2 shows that the electric power needed in some operating conditions of the ship. In sailing conditions, the total power needed is 20518.69 kW, maneuvering conditions require electricity of 28500 kW. And when the ship enters the port and in the process of loading and unloading, each requires electrical energy of 13,112.96 kW and 542.17 kW.
Table 1. Total Electric Load

| No. | ITEM                  | Sailing (kW) | Maneuver (kW) | Cargo (kW) | At Port (kW) |
|-----|-----------------------|--------------|---------------|------------|--------------|
| 1   | MACHINERY PART        | 20,225.9     | 21,296.2      | 253.2      | 12865.7      |
|     | : CL                  |              |               |            |              |
|     | : IT                  | 244.0        | 257.4         | 202.2      | 132.4        |
| 2   | HULL PART             | 66.73        | 66.7          | 120.4      | 120.4        |
|     | : CL                  | 53.68        | 53.7          | 0.0        | 0.0          |
| 3   | ELECTRICAL PART       | 47.4         | 47.4          | 47.4       | 47.4         |
|     | : IT                  | 0.0          | 0.0           | 0.0        | 0.0          |
| 4   | SUB TOTAL LOAD        | 20,340.07    | 21,410.38     | 420.99     | 13033.49     |
| POWER (D) | : CL                | 298          | 311.05        | 201.97     | 132.45       |
| 5   | DIVERSITY FACTOR      | 178.63       | 186.63        | 121.18     | 79.47        |
| 6   | TOTAL ELECTRIC LOAD   | 20,518.69    | 21,597.02     | 542.17     | 13,112.96    |

3.2. Main Generator Capacity
The selection of the main generator is done by selecting 4 (four) types of generators with a capacity of 5000 kW, 7500 kW, 7030 kW and 8200 kW. Sailing conditions are used as a reference for selecting generators because in these conditions the ship operates for a long time compared to other operational conditions. In this condition, a generator that has a capacity of 5000 kW has a load factor of 1.05 with 4 generators available. And furthermore, generators that have a power capacity of 5700 kW have a load factor of 0.9 with the number of available generators there are also 4 pieces. Meanwhile, generators that have a power capacity of 7030 kW have a load factor of 0.73 with 4 generators available. Finally, a generator with a capacity of 8200 kW has a load factor of 0.63 with 4 generators available.

Table 2. Capacity of Generator

| No. | Power (kW) | Set | Load Factor Generator | Sailing | Manoeuvre | At Port |
|-----|------------|-----|-----------------------|---------|-----------|---------|
| 1   | 5000       | 5   |                       | 20518.69| 5000 x 4  | 1.03    |
|     |            |     |                       |         | 5000 x 1  | 0.11    |
|     | Cargo Handling | Set | At Port       |         | 542.17    | 1   |
| 2   | 5700       | 5   |                       | 20518.69| 5700 x 4  | 0.90    |
|     |            |     |                       |         | 5700 x 1  | 0.1    |
|     | Cargo Handling | Set | At Port       |         | 542.17    | 1   |
| 3   | 7030       | 4   |                       | 20518.69| 7030 x 4  | 0.73    |
|     |            |     |                       |         | 7030 x 1  | 0.07    |
|     | Cargo Handling | Set | At Port       |         | 542.17    | 1   |
| 4   | 8200       | 4   |                       | 20518.69| 8200 x 4  | 0.63    |
|     |            |     |                       |         | 8200 x 1  | 0.07    |
|     | Cargo Handling | Set | At Port       |         | 542.17    | 1   |
From the list of generators in table 2 shows that the generator load factor with the number 0.86 is not found. With the same number of generators, 4 (four) generators are obtained for a load factor above 0.86, i.e. generators with a capacity of 5700 kW have a load factor of 0.90 and generators with a capacity of 5,000 kW have a load factor of 1.03. While load actors are below 0.86, they are generators with a capacity of 7030 kW having a load factor of 0.73 and generators with a capacity of 8200 kW have a load factor of 0.63. In the operation of ships to maneuver, the generator load is obtained higher with the operating conditions while sailing that is the difference in load factors of 0.03 to 0.05 with a total of four generators.

In the port entry condition, the minimum electricity demand that must be available is 13,112.96 kW. To meet the class requirements, in this operating condition the generators available are generators with 5000 kW of power, 3 generators with a load factor of 0.87 must be provided. For generators with power of 5700 kW, 7030 kW and 8200 kW, there must be 3 generators with load factors of 0.77, 0.62 and 0.53, respectively. For ship operations in loading and unloading conditions, the total power needed is 542.17 kW. If minimum power is supplied by 1 generator at each capacity. Generator load factor between 0.07 to 0.11. By looking at the facts above, the generator was chosen with a power capacity of 5,700 kW. The basis for selecting a generator is under sail conditions, a generator with a capacity of 5700 kW has a load factor of 0.90 even though class requirements require a maximum load factor of 0.86. To meet class requirements the power shortage will be fulfilled by adding 1,500 kW of battery.

### 3.3. Hybrid Power Generator

The use of four generators with 5700 kW power does not meet the class requirements that the power that must be available on the ship is 15% more than the total power requirements under operating conditions. Therefore, trimaran passenger ships are planned to use hybrid electricity by combining the power generated by the generator with the battery. The use of four generators with 5700 kW power does not meet the class requirements that the power that must be available on the ship is 15% more than the total power requirements under operating conditions. To meet the classification requirements an additional power of 1000 kW is required. Therefore, trimaran passenger ships are planned to use hybrid electricity by combining the power generated by the generator with the battery.

The procedure in calculating Ampere Hour of batteries needed is by determining the amount of energy (Watt hours) then determining the ampere hour. The amount of energy needed is calculated from the power requirement of 1500 kW multiplied by the time of battery usage, as shown in equation 1.

\[
AH_{\text{required}} = \frac{\text{Watt-hour}}{\text{Voltage}}
\]  

The amount of battery is determined by dividing the Ampere Hour needed by the Ampere Hour of the battery, as shown in equation 2.

\[
\text{Total Battery} = \frac{AH_{\text{required}}}{AH_{\text{Battery}}}
\]

The application of hybrid electric power between diesel generators and batteries in sailing conditions meets class requirements where there is 15 percent more power when compared to the total power requirements during sailing conditions, as shown in table 4. In sailing conditions, 4 sets of diesel generators are used with each power capacity of 5700 kW and as many as 3 sets of batteries with a voltage of 690 VDC with an Ampere hour of 3550 AH. This hybrid electric power is used only during sailing conditions while in maneuvering conditions and the condition at the power plant port is fully diesel generator. For maneuvering, 5 sets of generators are used with a load factor of 0.76, while in the harbor, 3 sets of generators are used with a load factor of 0.77. And in the loading and unloading operating conditions, the electricity supply is carried out entirely by a two battery with a voltage of 690 VDC with an ampere hour of 3550 AH.
Table 3. Hybrid Power Generator

| Ship Operation | Hybrid Power Generation |
|----------------|-------------------------|
| **Sailing**    |                         |
| RPM            | Generator kW | Set | Load Factor Generator | Load Required 1.500 kW |
| 1500           | 5700         | 4   | 19518.69              | 5700 x 4              |
| Battery Voltage| AH | Set | Time | W h | Volt | Ah |
| 690            | 3550 | 3   | 8   | 8,000,000 | 690 | 11,5955 |
| **Maneuvering**| Load Factor Generator |           |
| RPM            | Generator kW | Set | Load Factor Generator | Load Required 542.2 kW |
| 1500           | 5700         | 5   | 21597.02              | 5700 x 5              |
| Battery Voltage| AH | Set | Time | W h | Volt | Ah |
| 690            | 3550 | 2   | 8   | 4,337,396.7 | 690 | 6,286 |
| **Cargo Handling** | Load Factor Generator |           |
| RPM            | Generator kW | Set | Load Factor Generator | Load Required 542.2 kW |
| 1500           | 5700         | 3   | 13112.96              | 5700,00 x 3           |

4. Result and Discussion

Power flow simulation is carried out to analyze the ability of the DC distribution system to supply electricity to the connected load. The purpose of conducting power flow studies on DC distribution systems is to provide insight and recommendations regarding distribution system operations and optimize control settings to obtain maximum capacity to minimize operating costs. In this power simulation, sailing conditions were chosen because these conditions are the longest running ships. While the study for other conditions will be discussed in the next paper. Analysis performed on the power generated, the power at each bus panel and the power at each load. It also is used to determine the power loss in each bus and each electrical equipment.

4.1. Load Power Flow

Power from the load panel will be distributed to the load / electrical equipment. The power transmitted in accordance with the electrical energy requirements of each piece of equipment. Table 4 shows the load flow of electrical equipment on trimaran ship based on DC Distribution.

Table 4. Load Flow

| List of Electrical Equipment | Loading Unloading | At Port |
|-----------------------------|-------------------|--------|
|                             | Sailing | Manoeuvring | kW | kvar | kW | kvar | kW | kvar |
| Electric Propulsion          |         |             |     |      |     |      |     |      |
| Motor Propulsion 1           | 9829.3  | 3747.3      | 10346.6 | 3944.5 | 0   | 0   | 6208 | 2366.7 |
| Motor Propulsion 2           | 9829.3  | 3747.3      | 10346.6 | 3944.5 | 0   | 0   | 6208 | 2366.7 |
| System Waterjet              |         |             | 11.58 | 6.42  | 0   | 0   | 4.05 | 2.25  |
| Main Motor Hydrualic         | 9.84    | 5.45        | 11.58 | 6.42  | 0   | 0   | 4.05 | 2.25  |
| Main cooling capacity hydraulic | 26.84 | 13.1        | 31.58 | 15.41 | 0   | 0   | 11.05 | 5.39  |
| Main cooling capacity lubricating | 13.42 | 7.17      | 15.79 | 8.43  | 0   | 0   | 5.53 | 2.95  |
| Auxiliary cooling capacity hydraulic | 19.68 | 10.01      | 23.16 | 11.78 | 0   | 0   | 8.11 | 4.12  |
| Auxiliary cooling capacity lubricating | 9.84  | 5.45      | 11.58 | 6.42  | 0   | 0   | 4.05 | 2.25  |
| Auxiliary Motor hydraulic    | 8.28    | 4.68        | 9.74  | 5.5   | 0   | 0   | 3.41 | 1.93  |
| Auxiliary Engine Service     |         |             |       |       |     |      |     |      |
| Motor for engine starting device | 33.55  | 19.41      | 33.55 | 19.41 | 33.55 | 19.41 | 33.55 | 19.41 |
| Motor for pre-lubricating pump | 67.11  | 35.84      | 67.11 | 35.84 | 67.11 | 35.84 | 67.11 | 35.84 |
| General Service              |         |             |       |       |     |      |     |      |
| Transfer Pump FW             | 9.84    | 5.45        | 9.84  | 5.45  | 9.84 | 5.45 | 9.84 | 5.45  |

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| List of Electrical Equipment       | Sailing kW | Sailing kvar | Maneuvering kW | Maneuvering kvar | Loading Unloading kW | Loading Unloading kvar | At Port kW | At Port kvar |
|-----------------------------------|------------|--------------|----------------|-----------------|----------------------|-----------------------|------------|-------------|
| FW Hydrophore Set                 | 2.68       | 1.71         | 2.68           | 1.71            | 2.68                 | 1.71                  | 2.68       | 1.71        |
| Transfer Pump SW                  | 9.84       | 5.45         | 9.84           | 5.45            | 9.84                 | 5.45                  | 9.84       | 5.45        |
| SW Hydrophore Set                 | 2.68       | 1.71         | 2.68           | 1.71            | 2.68                 | 1.71                  | 2.68       | 1.71        |
| Oily Water Separator              | 8.95       | 5.01         | 8.95           | 5.01            | 8.95                 | 5.01                  | 8.95       | 5.01        |
| Oily Bilge Pump                   | 4.92       | 2.94         | 4.92           | 2.94            | 4.92                 | 2.94                  | 4.92       | 2.94        |
| Main Fire Pump                    | 78.95      | 35           | 78.95          | 35              | 78.95                | 35                    | 78.95      | 35          |
| GS BG/BL                          | 67.11      | 29.75        | 67.11          | 29.75           | 67.11                | 29.75                 | 67.11      | 29.75       |
| Ramp Service                      |            |              |                |                 |                      |                       |            |             |
| Motor Ramp Door                   | 0          | 0            | 0              | 0               | 161.1                | 74.17                 | 0          | 0           |
| Deck Machinery                    |            |              |                |                 |                      |                       |            |             |
| Capstan                           | 13.42      | 7.17         | 13.42          | 7.17            | 13.42                | 7.17                  | 13.42      | 7.17        |
| Windlass                          | 6.71       | 3.88         | 6.71           | 3.88            | 6.71                 | 3.88                  | 6.71       | 3.88        |
| Pov. Crane                        | 6.71       | 3.88         | 6.71           | 3.88            | 6.71                 | 3.88                  | 6.71       | 3.88        |
| Refrigerating and Ventilation     |            |              |                |                 |                      |                       |            |             |
| Accommodation Supply Fan          |            |              |                |                 |                      |                       |            |             |
| Bridge Deck                       | 1.58       | 1.28         | 1.58           | 1.28            | 1.58                 | 1.28                  | 1.58       | 1.28        |
| Car Deck                          | 3.16       | 2.56         | 3.16           | 2.56            | 3.16                 | 2.56                  | 3.16       | 2.56        |
| Crew Deck                         | 17.88      | 14.51        | 17.88          | 14.51           | 17.88                | 14.51                 | 17.88      | 14.51       |
| E/R Deck                          | 0.526      | 0.427        | 0.526          | 0.427           | 0.526                | 0.427                 | 0.526      | 0.427       |
| Passanger Deck                    | 7.36       | 5.98         | 7.36           | 5.98            | 7.36                 | 5.98                  | 7.36       | 5.98        |
| Accommodation Exhaust Fan         |            |              |                |                 |                      |                       |            |             |
| Bridge Deck                       | 1.05       | 0.854        | 1.05           | 0.854           | 1.05                 | 0.854                 | 1.05       | 0.854       |
| Car Deck                          | 2.1        | 1.71         | 2.1            | 1.71            | 2.1                  | 1.71                  | 2.1        | 1.71        |
| Crew Deck                         | 6.31       | 5.12         | 6.31           | 5.12            | 6.31                 | 5.12                  | 6.31       | 5.12        |
| E/R Deck                          | 0.526      | 0.427        | 0.526          | 0.427           | 0.526                | 0.427                 | 0.526      | 0.427       |
| Passanger Deck                    | 2.1        | 1.71         | 2.1            | 1.71            | 2.1                  | 1.71                  | 2.1        | 1.71        |
| AHU                               | 13.42      | 7.17         | 13.42          | 7.17            | 13.42                | 7.17                  | 13.42      | 7.17        |
| ECR Ventilation                   | 40.26      | 18.54        | 40.26          | 18.54           | 40.26                | 18.54                 | 40.26      | 18.54       |
| Electrical Part                   |            |              |                |                 |                      |                       |            |             |
| Junction Communication & Navigation | 11.09     | 11.09        | 11.09          | 11.09           | 11.09                | 11.09                 | 11.09      | 11.09       |
| Junction Navigation Lighting      | 0.239      | 0.239        | 0.239          | 0.239           | 0.239                | 0.239                 | 0.239      | 0.239       |
| Junction Bridge Deck              | 0.757      | 0.757        | 0.757          | 0.757           | 0.757                | 0.757                 | 0.757      | 0.757       |
| Junction Lighting Car Deck        | 2.33       | 2.33         | 2.33           | 2.33            | 2.33                 | 2.33                  | 2.33       | 2.33        |
| Junction Lighting Crew Deck       | 15.26      | 15.26        | 15.26          | 15.26           | 15.26                | 15.26                 | 15.26      | 15.26       |
| Junction Lighting E/R             | 5.2        | 5.2          | 5.2            | 5.2             | 5.2                  | 5.2                   | 5.2        | 5.2         |
| Junction Lighting Pass Deck       | 10.79      | 10.79        | 10.79          | 10.79           | 10.79                | 10.79                 | 10.79      | 10.79       |
| Required Electrical Power         | 20201      | 77579        | 21251          | 81604           | 615508               | 291658                | 12906608   | 4969X       |

In the table 4, Load of main propulsion system 1 and load of main propulsion system 2 distribute real power to 9829.3 kW propulsion on sailing conditions, 10346.6 kW on maneuver conditions and 6208 kW on the condition of entering the port. As for the reactive power generated for propulsion 1 and propulsion 2 amounted to 3747.3 kVar for sailing conditions, 3944.5 kVar for maneuver conditions and 2366.7 kVar for conditions entering the port. And at loading and unloading conditions, propulsion 1 and 2 are not powered as shown in Figure 5.
In figure 6 shows that the load profile of machinery system. For Aux Cool Hydraulic equipment, the power distributed is 39.37 kW of real power and 20.03 kVar of reactive power during sailing conditions, 46.32 kW of real power and 23.56 kVar of reactive power during maneuver conditions and 16.21 kW real power and 8.25 kVar reactive power when conditions enter the port. Meanwhile, when loading and unloading, Aux Cool Hydraulic equipment is not powered. Then, Aux Motor Hydraulic equipment, the power distributed is 19.68 kW of real power and 9.35 kV reactive power during sailing conditions, 19.47 kW of real power and 11 kVar of reactive power during maneuvering conditions and 6.82 kW of power real and 3.85 kVar reactive power when conditions enter the port. Whereas when loading and unloading, Aux Motor Hydraulic equipment is not powered. For FW Hydrophore equipment, the actual power distributed under sailing, maneuvering, loading and unloading and port entry conditions is 2.68 kW. And the reactive power distributed in sailing, maneuvering, loading and unloading conditions and entering the port is 1.71 kVar.

For FW Pump equipment, the actual power distributed under sailing, maneuvering and unloading conditions is 19.68 kW. And the reactive power distributed in the conditions of sailing, maneuvering, loading and unloading and entering ports is 10.91 kVar. While entering the port, the power received by the equipment / load is 9.84 kW of real power and 5.45 kVar of reactive power.
Furthermore, GS BG / BL equipment, the power distributed was 134.2 kW of real power and 59.5 kVar of reactive power during sailing conditions, 157.9 kW of real power and 69.99 kVar of reactive power during maneuver conditions, amounting to 67.11 kW of real power and 29.75 kV reactive power during loading and unloading conditions and when entering ports.

For Main Cool Hydraulic and Main Cool Lubrication equipment, the power distributed is 53.68 kW and 26.84 kW real power during sailing conditions, for reactive power of 26.2 kVar and 14.33 kVar when sailing conditions. At the time of the maneuver, the distributed power is 63.16 kW and 31.58 kW real power, for reactive power is 30.82 kVar and 16.86 kVar. While entering the port, the distributed power is 22.11 kW and 11.05 kW real power, for reactive power is 10.79 kVar and 5.9 kVar. Meanwhile, when loading and unloading, Main Cool Hydraulic and Main Cool Lubrication equipment are not powered.

Next, Main Fire Pump equipment, the power distributed is 157.9 kW of real power and 69.99 kVar of reactive power during sailing conditions, of 157.9 kW of real power and 69.99 kVar of reactive power when maneuvering conditions, amounting to 78.95 kW of real power and 35 kVar of reactive power during loading and unloading conditions and when entering port conditions. For Main Motor Hydraulic equipment, the power distributed is 19.68 kW of real power during sailing and maneuvering conditions, for reactive power of 10.91 kVar when sailing and maneuvering conditions. While entering the port, the distributed power is 8.11 kW of real power, for reactive power is 4.49 kVar. Whereas when loading and unloading, Main Motor Hydraulic equipment is not powered.

For Motor Pre-Lubricating equipment. Pump and Motor Start, the power distributed is 67.11 kW and 33.55 kW real power, for reactive power is 35.84 kVar and 19.41 kVar in all ship operating conditions. As for the OWS, SW Hydrophore and SW Pump equipment, the power distributed is 8.95 kW, 2.68 kW and 19.68 kW real power, for reactive power is 5.01 kVar, 1.71 kVar and 10.91 kVar at all ship operating conditions.

For Oily Bilge Pump equipment, real power is distributed under sailing conditions, and maneuvering conditions of 9.84 kW of real power and 5.89 reactive power. And the condition of loading and unloading and entering the port, the power transmitted is 4.92 kW of real power and 2.94 kVar of reactive power. The graph of the machinery system load panel to the machining system equipment is shown in Figure 6 for real power.

In figure 7 shows that the load profile of deck machinery such as AHU equipment, Capstan, E / R Vent, Motor Ramp Door, Prov. Crane and Windlass. For AHU equipment, the received power is 13.42 kW of real power and 7.17 kVar of reactive power under sail and maneuver conditions. While in loading and unloading conditions, the received power is 12.63 kW of real power and 6.75 kVar of reactive power. And on the condition of entering the port, the received power is 25.26 kW of real power and 13.49 kVar of reactive power. For Capstan equipment, the received power is 26.84 kW of real power and 14.33 kVar of reactive power in sailing and maneuvering conditions. While at loading and unloading conditions and entering the port, the received power is 37.89 kW of real power and 17.45 kVar of reactive power.
For E / R Vent equipment, the received power is 40.26 kW of real power and 18.54 kVar of reactive power in sailing conditions. Whereas in the condition of maneuvering, loading and unloading and entering the port, the received power is 12.63 kW of real power and 6.75 kVar of reactive power. For Motor Ramp Door equipment, the received power is 161.1 kW of real power and 74.17 kVar of reactive power in sailing and maneuvering conditions. While in loading and unloading conditions and entering the port, the received power is 151.6 kW of real power and 69.81 kVar of reactive power.

For Prov. Crane and Windlass, received power is 13.42 kW real power and 7.17 kVar reactive power in sailing and maneuvering conditions. While in loading and unloading conditions and when entering port, the received power is 12.63 kW of real power and 7.31 kVar of reactive power. Power flow graphs on deck machinery equipment are shown in Figure 7.

For Refrigeration and Ventilation equipment, the received power is 20.1 kW of real power and 9.18 kVar of reactive power in sailing conditions. Whereas in the condition of maneuvering, loading and unloading and entering the port, the received power is 12.63 kW of real power and 6.31 kVar of reactive power. For Bridge Deck Supply Fan equipment, the received power is 12.63 kW of real power and 6.31 kVar of reactive power in sailing and maneuvering conditions. While in loading and unloading conditions and entering the port, the received power is 12.63 kW of real power and 7.31 kVar of reactive power. Power flow graphs on deck machinery equipment are shown in Figure 8.
The load profile of Refrigeration and Ventilation is shown in figure 8. Bridge Deck Exhaust Fan and Bridge Deck Sup Fan equipment, the received power is 1.05 kW and 1.58 kW for real power. As for the reactive power of 0.854 kVar and 1.28 kVar in sailing, maneuvering and loading and unloading conditions. And on the condition of entering the port, the received power is 0.99 kW and 1.49 kW real power and 0.803 kVar and 1.21 kVar reactive power.

For Car Deck Exhaust Fan and Car Deck Supply Fan equipment, the received power is 2.1 kW and 3.16 kW for real power. As for the reactive power of 1.71 kVar and 2.56 kVar in sailing, maneuvering and loading and unloading conditions. And on the condition of entering the port, the received power is 2.97 kW and 5.94 kW real power and 1.61 kVar and 2.41 kVar reactive power.

For Crew Deck Exhaust Fan and Crew Deck Supply Fan equipment, the received power is 6.31 kW and 17.88 kW for real power. As for the reactive power of 5.12 kVar and 14.51 kVar in sailing, maneuvering and loading and unloading conditions. And at the condition of entering the port, the received power is 5.94 kW and 16.83 kW of real power and 4.82 kVar and 13.66 kVar reactive power.

For E / R Deck Exhaust Fan and E / R Deck Supply Fan equipment, the received power is 0.526 kW and 0.526 kW for real power. As for the reactive power of 0.427 kVar and 0.427 kVar in sailing, maneuvering, loading and unloading conditions and entering the port.

For Pass Deck Exhaust Fan and Pass Deck Supply Fan equipment, the received power is 2.1 kW and 7.36 kW for real power. As for the reactive power of 1.71 kVar and 5.98 kVar in sailing, maneuvering and loading and unloading conditions. And on the condition of entering the port, the received power is 1.98 kW and 6.93 kW of real power and 1.61 kVar and 5.62 kVar reactive power. The power flow graph on the refrigeration and ventilation equipment is shown in Figures 8.

The load profile of lighting and HVAC equipment is shown in figure 9. The power distributed from the load panel to the lighting equipment under each operating condition is the same. For J. Com equipment at 9.04 kW real power, J. Mont equipment at 0.182 kW real power, JL Bridge Deck equipment at 0.578 kW real power, JL Car Deck equipment of 1.8 kW of real power, JL Crew Deck equipment of 12.8 kW of real power, JL E / R equipment of 4.08 kW of real power and JL Pass Deck equipment of 8.77 kW of real power. Power flow graphs for lighting and NavCom equipment are shown in Figure 9.

![Figure 9. Profile Load Flow on Real Power of NavCom and Lighting](image-url)
4.2. Distributed Power

Under sailing conditions, the overall real power requirement is 20.201 MW and reactive power is 7.757 Mvar. The availability of electric power is adequate and meets the class requirements in sailing conditions, i.e., power is supplied by 4 (four) diesel generators and 17750 AH diesel batteries as shown in table 4. The total available power is 24.3 MW consisting of 22.8 MW which produced by 4 (four) diesel generators and 1.5 MW of batteries, see table 4. Table 4 shows that the power distributed to each generator is 4.845 MW for real power (P) and 3.634 Mvar (Q) for reactive power. With the current and load factors in each generator are 317.9 and 85 percent, while the batteries are distributed at 1.5 MW every one hour.

In maneuvering conditions, the actual power requirements are 21.251 MW and the reactive power is 8.16 Mvar. The availability of electric power is supplied by 5 (five) diesel generators which are shown in table 4. The total available power is 28.5 MW. Table 4 shows that the total distributed power was 4.845 MW for real power (P) and 3.634 Mvar (Q) for reactive power. With the current and load factors in each generator are 317.9 and 85 percent.

Furthermore, for loading and unloading conditions, the actual power requirements in this operating condition are 0.616 MW and the reactive power is 0.292 Mvar. The electricity demand in this loading and unloading condition will be supplied by a 1.5 MW battery capacity. With a battery capacity as shown in table 4, a battery can last 2 hours. For the condition of entering the port (at port), the required power is 12.906 MW for real power and 4.969 MW for reactive power. Power requirements will be fulfilled by supplying electrical energy from 3 (three) diesel generators as shown in table 5.

| Table 5. Distributed Power |
|---------------------------|
|                           | Sailing       | Maneuvering  | Cargo Handling | At Port |
| Power Generation          | P (MW)        | Q Mvar       | P (MW)         | Q Mvar  | P (MW) | Q Mvar |
| Diesel Generator 1        | 4.845         | 3.634        | 4.845          | 3.634   | NA     | NA     |
| Diesel Generator 2        | 4.845         | 3.634        | 4.845          | 3.634   | NA     | NA     |
| Diesel Generator 3        | 4.845         | 3.634        | 4.845          | 3.634   | NA     | NA     |
| Diesel Generator 4        | 4.845         | 3.634        | 4.845          | 3.634   | NA     | NA     |
| Diesel Generator 5        | NA            | NA           | 4.845          | 3.634   | NA     | NA     |
| Battery                   | 1.5           | NA           | 1.5            | NA      | NA     | NA     |
| Total Distributed Power   | 20.9          | 19.8         | 24.23          | 18.17   | 1.5    | 0      |
|                           |              |              | 14.54          | 10.9    |         |         |

4.3. Sufficient electricity

Simulation results for power distribution under ship operating conditions are shown in Figure 10. The available power for each condition meets class requirements. In each operating condition, the load factor of each generator is 85%, with a generator capacity of 5700 kW or 7125 kVA distributing real power of 4845 kW and reactive power of 3634 kVAR. Figure 5 shows that the available power capacity is greater than the power needed in each operating condition.

The power distributed and transmitted to the direct current electricity network is 85% (eighty-five percent) of the available power at sailing conditions, maneuvering conditions and port entry conditions. Whereas in loading and unloading conditions, battery life in distributing electrical energy only lasts for 2 hours. And the amount of power distributed is greater than the power needed to operate in each condition.
5. Conclusion

The application of the DC distribution system for hybrid power trimaran ship has been successfully implemented. The use of hybrid electric energy sources namely diesel generators and batteries has been well simulated. Power simulations show that batteries make an important power contribution in sailing conditions. This additional power has increased the diesel generator load factor performance from 90% without batteries to 86% with batteries. In the power flow simulation, it is known that in sailing conditions, the overall real power requirement is 20,638 MW and the reactive power is 7,971 Mvar. The availability of electric power is adequate and meets the class requirements in sailing conditions that is power supplied by 4 (four) diesel generators and 17750 AH diesel batteries. In maneuvering conditions, the actual power requirements are 21,722 MW and the reactive power is 8,389 Mvar. The availability of electric power is supplied by 5 (five) diesel generators. And in loading and unloading conditions, the actual power requirements in this operating condition are 0.638 MW and the reactive power is 0.31 Mvar. The electricity demand in this loading and unloading condition will be supplied by a 1.5 MW power capacity battery.

The characteristics of equipment power flow on the ship’s main drive bus panel indicate that the greatest power is in maneuvering conditions. After that, followed by sailing conditions, conditions of entering the port and loading and unloading conditions.

In the machining system panel, the power flow characteristics are almost the same as the main driving bus panel of the ship where the greatest power is in a maneuver condition. After that, followed by sailing conditions, conditions of entering the port and loading and unloading conditions.

Whereas on the deck machined bus panels, the characteristics of the power flow are in sailing and maneuvering conditions, the flow of power to the equipment is almost the same. Similarly, the loading and unloading conditions and entering the port. Furthermore, for the refrigeration and ventilation bus panels, the characteristics of the power flow are in the sailing, maneuvering and loading and unloading conditions of the power flow to the equipment is almost the same. While in the condition of entering the port, the power flow is lower.

Finally, on Nav Com panels and lighting, the power flow characteristics are the same for all ship operating conditions.
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