Comparison of short-circuit current in AC and DC shipboard electrical power distribution systems: A case study of 17,500 DWT tanker vessel

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Abstract. The current ability of power electronic devices increases the possibility to change the shipboard electrical power distribution system from widely-used alternating current (AC) to direct current (DC) systems. DC distribution systems has been known to offer higher power efficiency compared with AC distribution systems. However, the decision to move the shipboard electrical power distribution systems to DC systems requires more information in technical aspects aside of power efficiency. In this study, the investigation to compare short-circuit current between AC and DC distribution systems in non-electric propulsion vessel is conducted. The investigation is performed for electrical power distribution system of 17,500 DWT tanker vessel. Short-circuit current profile for both systems are obtained from simulation in computer software. The results indicate that the DC shipboard electrical power distribution systems has lower short-circuit current than the AC system for the same vessel.

1. Introduction

The tanker vessel is a ship that serves to transport liquid cargo. Being one of the most widely used types of ships to meet human needs, it is increasing day by day. According to data in 2020, the number of commercial vessel fleets in the world opened 55.655 units with the first position being occupied by General Cargo 30.7%, followed by Oil Tanker 25.06% in the second position, and Bulk Carrier 21.82% in the third position [1]. Tankers are supported by systems that work in them, most of which require electricity to operate [2]. Electricity is one of the most important things in life. The need for electricity is quite large in supporting human activities, every activity can hardly be separated from the use of electricity as well as on ships.

In the operation of the electrical system on the ship is supplied by an electric generator. Electric Generators produce AC electricity which is used to power the equipment on board. The use of AC electricity on ships has positive and negative sides, the positive side can be channelled directly to equipment, most of which are AC loads, while the negative side is AC electricity has a higher impedance value (Z) compared to DC electricity. AC electricity has a high impedance value because there is not only a resistance value (R), but also a reactance value that depends on the amount of inductance (L), capacitance (C), and frequency (f) [3].

In order to reduce the existing impedance value, a reconfiguration of the electricity distribution system on tankers from AC DC is carried out using a Rectifier. A rectifier or what is often called a
wave rectifier is a device that has a function to convert alternating current into direct current [4]. By using a DC system, the impedance in electricity will decrease because there is only a resistance value (R), as a result the value of falling and power loss will be smaller. Changes made will affect the amount of short circuit current that may occur [5-8].

Short circuit is a common disturbance that often occurs in the ship's electricity due to both internal and external factors. According to IEC 60909, short circuit is a fault in the form of an overcurrent fault that occurs due to the presence of a non-forced conductive path makes the relationship between two or more conductive differences between these conductors equal or close to zero. The closer to the source of the generator or generator, the greater the short-circuit current, this is because near the generator it still has a little current branching [9]. Due to changes in the magnitude of the short circuit in the electrical system, it is necessary to rearrange the coordination of protection. The use of protection in the distribution of electricity on ships is intended to reduce the potential for damage due to short circuit disturbances. In order to operate quickly and have high sensitivity in sensing and isolating disturbances in the surrounding equipment, it is necessary to adjust the timing of a circuit breaker [10]. The protection coordination settings used are adjusted to the amount of current available so that they can be used when a short circuit occurs so as not to damage the equipment on board.

To consider the occurrence of short-circuit currents on tankers due to reconfiguration of the AC to DC power distribution system, it is necessary to have a simulation-based analysis so that the magnitude of the short-circuit current can be determined and the protection that must be used can be determined. With this simulation analysis, it is hoped that the electrical system on the tanker will remain safe even though the electrical distribution system is changed from AC to DC.

The rest of the paper consist of the explanation of the research method in the 2nd section, followed by the presentation of the results in the 3rd section. The summary of the results and the future tasks are provided in conclusion.

2. Method

2.1. Collecting Data
The data collection stage is the stage carried out to collect electrical data from the 17500 DWT tanker. The electrical data is in the form of technical specifications of existing equipment ranging from generators, electric motors, to cables and circuit breakers used in AC distribution.

2.2. Modelling single line diagram of AC distribution system
After getting the tanker electrical data, the next step is to model a single line AC distribution diagram as shown in Figure 1. The modeling is done using software and then when ready it will be used for the simulation process. In this modeling will be arranged based on the existing bus and the grouping of each load on each bus. Equipment specifications, be it electric motors, cables, and circuit breakers, will be set according to the data that has been collected. The process of compiling a single line distribution diagram is divided into several stages, including setting the main generator, setting the main bus consists of MSB, ESB, and generator panel, setting the load bus, setting the cables, and setting the equipment on each load bus.
2.3. Modelling single line diagram of DC distribution system
After previously modeling and simulating the AC distribution, the process of reconfiguring the AC to DC distribution will begin as shown in Figure 2. In this case, the electrical system on the tanker which was originally AC will be changed to DC. The process is almost the same, only this time the modeling is in the form of a one-way DC distribution diagram. The reconfiguration process from AC to DC distribution is divided into several stages, including setting the rectifiers after output of main generators, grouping the load buses in a group based on the location of the deck, and setting the inverters on each group buses.

3. Results and Discussion
Short circuit simulations are carried out on several main ship conditions, namely sailing, loading/unloading, departing/arriving at the port, and at the port. Through the simulation will be known the value of the short circuit that occurs in each equipment and bus. From the short circuit simulation that has been carried out, it is obtained that the condition with the largest average value of short circuit current occurs in the loading/unloading condition of 13.455 kA as shown in Table 1.
Table 1. Short-circuit current (Pre-reconfiguration)

| Condition                  | Average of short-circuit current (kA) |
|----------------------------|--------------------------------------|
| Sailing                    | 10.48                                |
| Loading/unloading          | 13.46                                |
| Leaving/arriving port      | 10.99                                |
| At port                    | 6.13                                 |

Then, as shown in Table 2, on one of the load buses there is one equipment that has a quite large short-circuit current value on loading/unloading conditions, namely No. 1 Cargo Pump and No. 3 Cargo Pump.

Table 2. Short-circuit current on bus floor no.1 (Pre-reconfiguration)

| Equipment contributor       | Short-circuit current (kA) |
|-----------------------------|----------------------------|
| MSB 450 V No. 1             | 25.09                      |
| No. 1 Water Ballast Pump    | 0.29                       |
| No. 1 Cargo Pump            | 2.36                       |
| No. 3 Cargo Pump            | 2.36                       |
| Sampling Pump ODM           | -                          |
| ST 1 Booster Alpha Lub      | 0.15                       |
| **Total**                   | **30.23**                  |

Just like before the reconfiguration, short circuit simulations were carried out on several main conditions of the ship, namely sailing, loading/unloading, exiting/incoming the port, and at the port. Through the simulation will be known the value of the short circuit current that occurs in each equipment and bus. In Table 3, the data obtained from the simulation results can be analyzed to compare with the short-circuit current values before reconfiguration. It can be seen that after reconfiguration there is a decrease in the average value of short circuit current in each condition.

When compared to the Bus Floor No. 1 during loading and unloading, the short-circuit currents before and after reconfiguration from the main bus direction have different short-circuit currents, namely 25.087 kA and 1.387 kA. Similarly, the total short-circuit current contributing to the bus is 30.228 kA and 6.366 kA, respectively. While the short circuit current of each equipment after reconfiguration has the exact same value before reconfiguration as shown in Table 4.

Table 3. Short-circuit current (Post-reconfiguration)

| Condition                    | Average of short-circuit current (kA) |
|------------------------------|--------------------------------------|
| Sailing                      | 1.18                                 |
| Loading/unloading            | 1.61                                 |
| Leaving/arriving port        | 1.95                                 |
| At port                      | 1.10                                 |

Then, as shown in Table 4, on one of the load buses there is one equipment that has a quite large short-circuit current value on loading/unloading conditions, namely No. 1 Cargo Pump and No. 3 Cargo Pump.

Table 4. Short-circuit current on bus floor no.1 (Post-reconfiguration)

| Equipment contributor       | Short-circuit current (kA) |
|-----------------------------|----------------------------|
| MSB 450 V No. 1             | 1.18                       |
| No. 1 Water Ballast Pump    | 1.61                       |
| No. 1 Cargo Pump            | 1.95                       |
| No. 3 Cargo Pump            | 1.10                       |
| Sampling Pump ODM           | -                          |
| ST 1 Booster Alpha Lub      | 0.15                       |
| **Total**                   | **30.23**                  |
Table 4 Short-circuit current on bus floor no.1 (Post-reconfiguration)

| Equipment contributor         | Short-circuit current (kA) |
|------------------------------|----------------------------|
| MSB 450 V No. 1              | 1.39                       |
| No. 1 Water Ballast Pump     | 0.29                       |
| No. 1 Cargo Pump             | 2.36                       |
| No. 3 Cargo Pump             | 2.36                       |
| Sampling Pump ODM            | -                          |
| ST 1 Booster Alpha Lub       | 0.15                       |
| **Total**                    | **6.37**                   |

4. Conclusion
In the AC power distribution system, prior to reconfiguration, the load bus that failed received a short-circuit current contribution from the equipment on the bus, especially electric motors, besides that, a short-circuit current from the MSB main bus was also obtained which was the cumulative contribution of the short-circuit current provided by another load branching bus. When viewed from each condition, the average value of short circuit current that occurs in the loading/unloading condition has decreased by 88.02%. Then when viewed from the load bus (Bus Floor No. 1) the short circuit current value from the main bus direction (MSB 450 V No. 1) has decreased by 94.47%. Based on the loading/unloading conditions that have been analyzed, it can be concluded that after the reconfiguration process there is a decrease in the average short-circuit current that occurs in each load bus or in each condition. Changes in the value of short circuits occur due to changes in the arrangement of the arrangement with the addition of a new bus for the installation of the inverter. Prior to reconfiguration, the short-circuit current received on the load bus is affected by the existing equipment and the short-circuit contribution from other load buses which are collected together on the 450V MSB bus until it finally enters the load bus. Meanwhile, after reconfiguration, the load buses are grouped according to the location of the deck for inverter installation. Therefore, the contribution of the incoming short-circuit current from other load buses is much smaller so that the average value of the short-circuit current received is much smaller.

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