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Short Circuit Analysis due to Reconfiguration of AC to DC Electric Power System on Tanker Ship with Hybrid Energy Source

Adi Kurniawan[a], Arialdi Almonda[a] and Sardono Sarwito[a*]

[a)] Institut Teknologi Sepuluh Nopember, Surabaya 60111 Indonesia
*Corresponding author: sardonosarwito@gmail.com

ABSTRACT

The conventional AC electric power distribution system on ships has a higher impedance than the DC system, thus providing more significant distribution losses. Due to the enormous losses in the distribution system, a larger power output is required to balance the power required by the loads, and the losses occur on the line between the sources and the loads. Therefore, reconfiguring the power distribution to the DC system is promising. However, analysis in other aspects needs to be performed, including for short circuit current. In this research, power system simulator software is used to analyze the amount of fault current that contributes to each type of distribution. The simulation is performed under four ship operation modes, including sailing, maneuvering, at port, and cargo loading-unloading. The results of the simulation show that the short-circuit current can be significantly decreased after the reconfiguration of the system. A similar phenomenon has occurred in other operation modes. The short circuit value decreases around ten times in the DC system compared to the AC system. Therefore, the DC system is safer than the AC system.

Keywords: *Clean Energy, Modern Electricity, Renewable Energy, System Safety.*

1. INTRODUCTION

Oil dependency as an energy source has remained the same. Since oil production is limited to some countries, oil transportation through the sea dominates the world's sea transportation. The data shows that oil tankers hold 25% of all merchant ships [1].

One of the primary needs of a ship, including a tanker ship, is electricity. Not only is electricity required for the crew's daily lives, but it is also required for the ship's operation. In the tanker ship, the large cargo pump, which is used to load and unload the bunker, requires large electric power.

Rapid technological advances have made quite a few vehicles that use environmentally friendly hybrid technology. The hybrid system is a combination of several different energy sources. For Indonesia itself, the use of a hybrid system by combining solar cells (Photovoltaic) and a diesel generator is one of the best options because Indonesia, which is located in the Tropics, more precisely on the Equator Line, is constantly exposed to 10-12 hours of sun a day. Indonesia has the potential for solar energy of 4.5 kWh per square meter per day. Indonesia can be said to be rich in solar energy sources because it has the potential for sunlight of 2000 hours per year [2].

While photovoltaic generates direct current (DC) electric voltage, the diesel generator, as the primary power source, generates alternating current (AC) electric voltage. On the other hand, most of the equipment on the ship also requires AC electric voltage. Therefore, on standard merchant ships, the electricity is transmitted between the generator and the equipment in the AC waveform. However, transmitting the electricity in the AC form, which either uses 50 or 60 Hz frequency, has a significant drawback. The presence of the frequency itself led to the appearance of an ohmic value called reactance when it flows through the coil. The total ohmic value between reactance and the natural resistance from the conductor material is called the impedance [3]–[5].

One effort to improve the efficiency of the electrical system on a ship is by reducing the total impedance on the transmission line. It can be done by either reducing the resistance or the reactance. Since the value of the resistance depends on the size, length, and material of the cable, which is already determined from the calculation, reducing the reactance value is easier. The easiest method to reduce the reactance value is by transmitting the electricity in the form of a DC wave, which does not have any frequency. Therefore, there is no value of frequency, resulting in zero reactance and more negligible impedance through the cable. However, to change the electrical transmission from AC to DC, an investigation in every aspect, especially in the safety of the system, is required. One of the common faults in electric systems is short-circuit occurrence, which generates high, abnormal, and dangerous current flows on the cable.

Moreover, the addition of photovoltaic as a power source will increase the value of the short circuit current in the existing system [6].

A short circuit is a common disturbance that often occurs in the ship's electricity, either due to internal or external factors. According to IEC 60909, a short circuit is a disturbance in the form of an excess current that occurs due to an accidental or intentional conductive path between two or more conductive parts, which forces the electric potential difference between these conductive parts to be equal or close to zero. The most significant value of the short circuit current occurs on the line between the power source and the main switchboard, as the power has not been spread to branch panels [7]. The conversion of electrical transmission to DC, as well as the addition of photovoltaic, may change the short circuit current value from the original system. Therefore, to ensure the safety of the system, the protection system needs to be evaluated and if necessary, needs to be rearranged. The protection system includes the setting of the circuit breaker as the executor of line disconnection when a short circuit occurs [8]. The protection coordination arrangement used is adjusted to the amount of possible current so that it can work to protect the equipment as well as the crew.

To consider the occurrence of short circuit currents on tankers due to the reconfiguration of the AC power distribution system to DC, as well as the penetration of the photovoltaic, a simulation-based analysis was carried out so that the magnitude of the short circuit as well as the protection configuration and setting that should be used could be determined. This numerical analysis is considered as an effort to decrease the risk on the proposed system.

2. METHODOLOGY

The analysis is based on numerical simulation, which is carried out based on the installation data from the sample ship, an oil tanker ship with a 17,500-tonnage. The circuit diagram and the technical specifications of the electric part are modeled in the power system simulation software.

The possible number of renewable energy sources, which are photovoltaic (PV) panels, is determined using 3D modeling. The model is in accordance with the general arrangement of the ship. The 435 Wp PV is chosen and placed in the empty space of the ship. The results show that 294 panels, totaling 298 kW, can be installed on the ship. The 3D modeling of the ship is shown in Fig. 1.

Figure 1. 3D modeling of the ship with photovoltaic panel

The obtained number of PV panels was then added to the power system simulation software as a parallel source to the installed diesel generator. Both sources generate electricity, which is collected in the ship's main switch board (MSB).

The simulation was then carried out to calculate the short circuit current for the original AC distribution system, which is injected with PV. The next step is to reconfigure the distribution system to DC. As the voltage from the generator is AC, it is converted to DC by using a rectifier. The voltage is then returned to the AC form before entering the busbar of the load panels by using inverters. The results of the short circuit current of both systems were then compared.

In the original AC distribution system, the electric power is distributed from the generator to the main switch board (MSB), then to the MSB to the other distribution panels, then to the load panels, which then distribute it to the electrical load. All of the electrical power is AC voltage. The generator produces 450 V, while some of the load requires 220 V, which is supplied through a step-down transformer.

The reconfiguration of the DC distribution system takes out the transformer while adding the additional equipment called rectifier and inverter. A rectifier is used to convert the AC voltage produced by the generator to the DC voltage before the MSB. The electricity is distributed in the form of DC voltage until before entering the load panels. The inverter is placed before the load panels to re-convert the power into AC voltage while also setting the voltage as required by the load, either 450 V or 220 V. Therefore, the long-distance cable between the generator and the load panels is distributing DC instead of AC voltage.

3. RESULTS AND DISCUSSION

The electric load profile of the ship can be varied depending on the necessary equipment. However, it can be concluded into four categories of operation. The first and the most common is the sailing mode, in which the main engine, as well as the supporting system, is assumed to work continuously. The next category is leaving/arriving port, which is mainly characterized by the intensive use of the steering gear. The other categories are when the ship is anchoring at the port, either for just rest or for doing the movement of the cargo which is called loading/unloading mode. In the tanker ship, the highest load occurs during loading/unloading due to the use of the large cargo pump.

The difference in the load profile in each operation mode results in a difference in the magnitude of the short circuit current. The magnitude of the short circuit current determines the specification of the circuit breaker.

The discussion focuses on the results of the short-circuit current measurement results from the simulation and the arrangement of the protection coordination. The first results show the AC transmission system, which already accommodates photovoltaics. The results indicate that the total short circuit current that flows to the main switch board is proportional to the electric load profile, as shown in Table I. The most significant load profile among the four conditions is during loading/unloading the cargo, while the lowest is during at port without doing cargo movement.

Table 1. Short circuit current with AC distribution system

Condition	Average of Short Circuit Current (kA)
Sailing	10,494
Loading/unloading	13,401
Leaving/arriving Port	12,897
At Port	6,090

After the simulation of the AC electrical system with the addition of photovoltaic, the following simulation is to observe the short circuit value of the DC electrical system combined with the photovoltaic. The parameters used in the simulation are the same as the first simulation, including the specification of the equipment.

The results of the simulation are summarized in Table II. Compared with the first simulation, the short circuit current in the DC system is about five times smaller in each condition. The decrease in the short circuit current is a good indicator of the proposed system, as a higher value increases the system's risk.

The photovoltaic itself does not contribute a large current during the fault. This is due to its size, which is significantly smaller than the capacity of the diesel generator.

The DC system with the photovoltaic can result in a smaller short circuit current due to the use of a rectifier and inverter as the voltage converters. Aside from their main purpose as converters, they can also isolate the current contribution from the other equipment.

Table 2. Short circuit current with DC distribution system

Condition	Average of Short Circuit Current (kA)
Sailing	1,844
Loading/unloading	1,686
Leaving/arriving Port	2,003
At Port	1,243

4. CONCLUSION

Observed from all operating conditions, the average value of short circuit current that occurs before reconfiguration is 10.72 kA, while after reconfiguration to the DC system is 1.694 kA. The addition of the photovoltaic does not affect the amount of the fault current. The simulation shows that the current of the AC/DC system with or without the photovoltaic is still the same. Therefore, it can be concluded that the DC system is safer than the AC system, even if renewable energy sources are involved. It may open the addition of the other clean energy source other than photovoltaic, as the number of panels has been maximized according to the space on the ship. The emerging technology such as fuel cells, which are also isolated by the converter, may be considered to get higher efficiency and a greener ship's electrical system.

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