Numerical Simulation of Harmonic Distortion on DC Power Distribution System on Trailing Suction Hopper Dredger Vessel

Bagas Raihan Akbar, Adi Kurniawan and Indra Ranu Kusuma
Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

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Abstract: The distribution system on ships usually uses an AC system, while in this study, the reconfiguration of the AC distribution system into DC will be carried out, this is a way to increase the efficiency of fuel use in ship diesel generators. By reconfiguring the distribution system, the influence of impedance on the AC current can be eliminated. But reconfiguring the distribution system has an additional component, namely the converter, so that it can increase harmonic distortion and total harmonic distortion (THD) in the ship's electrical system. This harmonic improvement can affect the quality of the power flowed in the system because it changes the waveform to not perfectly sinusoidal, so that the ship's electrical equipment can experience overheating which can reduce the performance of the ship's electrical equipment. In this study, an analysis was carried out to determine the number of harmonics that occur when the ship uses a DC electricity distribution system. Harmonic disturbance analysis is simulated using computer software, considering the operational conditions of the ship. From the results of the DC distribution simulation, total harmonic distortion (THD) was obtained on the generator bus and got the average of each condition are at 7.30% on the generator bus. Based on IEEE 519-2014 standard, the limit of total harmonic distortion is 8%, so that the result of total harmonic distortion is less than to the specified limit standard, but the results of Individual Harmonic Distortions (IHDs) are still exceeding the limit of IEEE 519-2014, which still above 5%. So, it is still necessary to find solution to reduce harmonic distortion that occurs.

1 INTRODUCTION

Dredger ship is a specially designed ship that has function to perform dredging such as in seas, rivers, lakes, and so on. Dredger ships are designed for dredging of siltation waters. There are various types of dredger ship, one of which is Trailing Suction Hopper Dredger (TSHD). TSHD ships have some special equipment used in dredging. Equipment used includes drag head gantry, trunnion gantry, intermediate gantry, etc. Most of these components require a large supply of electricity. The electricity in ship is supplied by generator which produces AC electricity. The use of AC electricity on the ship itself has advantages and disadvantages, which one of the disadvantages is to have frequency value where in the DC Current distribution it will eliminate the frequency value, so that losses that occur due to impedance in the cable can be eliminated (Budianto et al., 2022; Tessarolo et al., 2013).

The DC power distribution system works by using rectifier to convert AC voltage from the generators to DC voltage, distribute it through 0 frequency DC line, and restore it to AC before the load panels (Kurniawan et al., 3 02), (Kusuma et al., 2022). However, the conversion from AC-DC-AC leads to harmonic distortion which may causing several consequences such as overheating to communication interference in communication lines, which can result in the equipment not being able to operate optimally or causing damage (Tariq and Iqbal, 2014; Naji and Hussein, 2021; Benaboud and Rufer, 2019). International of Electrical and Electronics Engineer (IEEE) contained in IEEE 519-2014 regulates the occurrence of harmonics with Individual Harmonic Distortion (IHD) less than 5% and Total Harmonic Distortion (THD) less than 8% in electrical components.

This research focus on harmonic analysis due to the application of the DC distribution system in a TSHD ship with the comparison of the harmonic on the original AC distribution system. If the results of THDs are more than the standards set by the IEEE, the passive filter will be calculated to reduce it

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2 METHOD

2.1 AC Distribution Single Line Diagram Modeling

The electrical system used in this research is from the data of the King Arthur III TSHD ship. The original single line diagram of the AC distribution system from the King Arthur III is modeled in power system simulation software. Figure 1 shows the modeling of the AC distribution system in power simulation software. The process of preparing a single line distribution diagram is divided into the following stages. First, setup the main and standby generator. Then, setup the buses such as MSB, ESB, Panel 220V, Panel 380V Pump Room, AC Panel, and generator Panel. Arrangement of the load buses, the cables and the equipment on the load buses are the last step to be done.

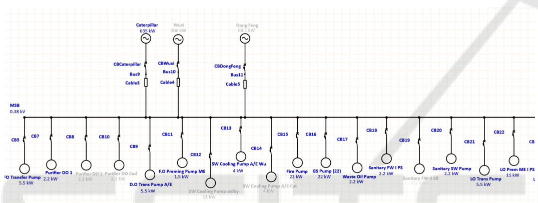

Figure 1: Original AC distribution system of King Arthur III ship.

When the modeling on single line diagram AC Distribution system process has been completed, the next step is to run a simulation with the software. The data that wants to be obtained from this simulation is the amount of harmonic in the power system

2.2 DC Distribution Single Line Diagram Modeling Using Software

After modeling and simulation on the AC distribution, the next process is reconfiguring the original AC distribution system to the DC distribution system. The modified system is shown in Figure 2. The process of reconfiguration from ac to DC distribution is divided into the following stages. First, calculate the rectifier to convert the AC power from the generator into DC before the main bus. Then, make the group of load buses based on their location on the ship, as each group will be connected to a 3-phase inverter. The other necessary equipment such as cables, circuit breakers and buses also need to be re-selected.

Similar to the original AC distribution system, in the DC distribution system, the amount of harmonic in the power system needs to be obtained. The data is obtained from run the simulation in power system simulation software.

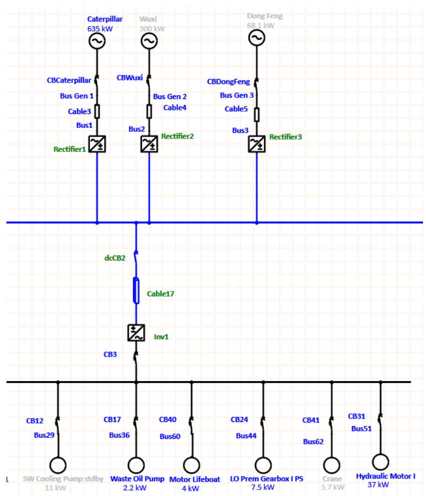

Figure 2: Modified DC distribution system of King Arthur III ship.

3 RESULTS AND DISCUSSION

3.1 Harmonic Analysis of AC Distribution System

Harmonic simulations were carried out on four main conditions of the ship, namely seagoing, manoeuvring, dredging, and at port. Through the carried-out simulation, the value of the harmonic that occurs in each equipment and bus are obtained. In this system, the 3 available generators are work not in sync, or works only one depending on the operating conditions. Caterpillar generators are used during seagoing, manoeuvring, dredging, and at port conditions, while Wuxi generators are used during seagoing, manoeuvring, and at port conditions. For seagoing and manoeuvring conditions, Wuxi generator is turned on alternately with Caterpillar generator. Meanwhile, the last generator, the Dongfeng generator is only used during at port for lighting, and communication navigation.

Based on the harmonic simulations that have been carried out, some of the largest harmonic value occurs in dredging conditions is shown in Table 1

3.2 Harmonic Analysis of DC Distribution System

In this section, harmonic simulations are also carried out on several main conditions of the ship,

Table 1: Voltage THD results of AC distribution system.

Bus Name	V (%)	THD(%)
FO Transfer Pump (Bus 1)	99.92	1.69
D.O Trans Pump A/E (Bus 10))	99.92	1.69
LO Trans Pump (Bus 35	99.92	1.69
GS Pump (Bus 57)	99.18	1.67
Bus Generator 1	100	1.68
Bus Panel 220V	97.97	6.12

namely seagoing, maneuvering, dredging, and at port. Through the simulation, the value of the harmonic that occurs in each equipment and bus is obtained. As shown in Table 2, the value of the harmonic in dredging condition after reconfiguration (DC) has increased compared to before the reconfiguration (AC).

Table 2: Voltage THD results of DC distribution system.

Bus Name	V(%)	THD(%)
FO Trans Pump (Bus 10)	100.00%	9.91%
DO Trans A/E (Bus 27)	100.00%	12.92%
LO Transfer Pump (Bus 41)	100.00%	12.05%
Bus 69 (GS Pump)	100.00%	14.51%
Bus Panel 220 V	100.00%	8.77%
Bus Generator 1	100.00%	7.30%

3.3 Harmonic Filter Installation

Based on the result of the simulation carried out on the DC Distribution system, the harmonics that occurs exceed the limits of the IEEE standard. Therefore, improvements are needed to reduce the harmonics that occur on each bus. In this study, passive filters are used as the tool to reduce the harmonics. The installation of a passive filter in the DC distribution electrical system aims to limit the harmonic current flowing on the bus used to supply electrical loads.

Passive filter is a circuit consisting of capacitor and inductive components, where these components can reduce harmonics that occur at a certain frequency. There are several kinds of passive filters, and in this study the passive filter used is a single-tuned passive filter, which can reduce harmonics at one frequency. The single-tuned filter also produces reactive power compensation so that this filter can also improve the power factor of the bus to which the filter is attached. There are several stages of design so that the installation of the filter can be effective and efficient. First, the harmonics source should be identified. After that, identify the largest harmonics in four conditions when the ship operates. Then, the highest Individual Harmonic Distortion (IHD) on the bus that would be filtered also need to be identified. Lastly, setup the harmonic passive filter at the bus which had the largest harmonic.

After analyzing each of the stages, a single-tuned passive filter design is obtained to reduce harmonics in the DC distribution system. Table III is the design of a single-tuned passive filter resulting from calculations with software about the size of the capacitor, inductor, and quality factor (Q factor) for each filter and the location of the filter installation

Table 3: Design of single-tuned passive filter for DC distribution system.

Bus	Filter	O	C µF	L mH	(Q)
Bus Generator	Single Tuned	47	167.3	0.0086	40
Bus 380V No.1	Single Tuned	47	441.3	0.0033	40
Bus 380V No.2	Single Tuned	47	166.9	0.0086	40
Bus 380V No.3	Single Tuned	47	169.7	0.0085	40
Bus 380V No.4	Single Tuned	47	153.8	0.0094	40
Bus 380V No.5	Single Tuned	47	131.9	0.0109	40
Bus 380V Pump Room	Single Tuned	47	455.1	0.0032	40
Bus Panel 220V	Single Tuned	5	664.8	0.1915	40

3.4 Harmonic Filter Installation Effect

The addition of a single-tuned passive filter affects the harmonic disturbance that occurs in the DC distribution system. With the harmonic filter there is a decrease in THD that occurs on each bus. Table IV shows the result of the simulation on the DC distribution system after the filter is installed. From the simulation results, the addition of a single-tuned passive filter may significantly reduce the harmonics that occur in the DC distribution system. It is to be noted that the installation of this filter does not fully eliminate the harmonics because only one harmonic frequency is muted so that there are still harmonics injected into the DC distribution system.

Table 4: Voltage THD results of DC distribution system with installed filter.

Bus Name	V (%)	THD(%)
Bus FO Trans (Bus 10)	100.00%	0.00%
Bus DO Trans A/E (Bus 27)	100.00%	0.00%
LO Transfer Pump (Bus 41)	100.00%	0.00%
Bus 69 (GS Pump)	100.00%	0.00%
Bus Panel 220 V	100.00%	2.36%
Bus Generator 1	100.00%	0.00%

4 CONCLUSION

Reconfiguration of the AC distribution system to DC on Dredger ship raises several technical challenges that need to be overcome, one of which is harmonic distortion. The addition of converters in the DC distribution system results in an increase in harmonic distortion that occurs. This is evidenced from the simulation results with THD on AC conditions on the bus generator panel of 1.67% THD on dredging conditions and 7.30% THD on DC distribution system and the Individual Harmonic Distortion at DC distribution system is 5.4% at 47th ordo. However, this level of THD and IHD are still solvable with installing a single-tuned passive filter on the DC distribution system. After installing the filter on the DC distribution system, the THD that occurs has decreased to 0.00% which is acceptable according to the IEEE 519-2014 standard. With a normal size, simple passive filter, the problem of THD on the DC distribution system can be ignored and the promising DC distribution system may be installed in conventional propelled ship such as TSHD vessel.

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