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Optimization Analysis of Determining Generator Power Capacity in MV Sabuk Nusantara 71

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ABSTRACT: MV. Sabuk Nusantara 71 is a Indonesian passenger cargo ship with the Ambon – Tual route which has three generators. As is well known that the main generator of electrical power on a ship is a generator. The installed generator is expected to be able to supply the electric power needs of the ship optimally and efficiently. But in fact, the distribution of the load on the ship is still less than optimal and efficient. This results in excess fuel consumption. The purpose of this research is to find efficient load sharing so that the required fuel consumption is optimal. To achieve this, the research uses several stages. First, calculate the amount of electrical power needed on the ship. Second, look for the magnitude of the electric power load for each operating condition of the ship when leaning, sailing and maneuvering. Third, look for the fuel consumption of ship generators using the dynamic programming method which aims to get efficient generator fuel consumption. The results of this calculation simulation on MV. Nusantara Belt 71 operations with a voyage from Ambon – Tual (round trip) obtained an efficient fuel consumption of 20,724.77 liters by using generator 1 configuration for leaning, and generators 1 and 2 for maneuvering and sailing

KEYWORDS: Merchant Vessel, Optimization Analysis, Diesel Generators, Dynamic Programming, Fuel Efficiency

I. INTRODUCTION

A power plant is a collection of equipment and devices used to create electrical energy by converting energy from different sources. Ships, like cities, need all fundamental amenities to maintain life on board, one of which is electric current [1]. The advantages of using electric current aboard ships range from illumination to addressing the demands of the ship's operational tasks [2], [3]. Electric current also contributes to the comfort of passengers and ship personnel when sailing. The need for electric power grows with the passing of the years [4], [5]. All electrical loads are supplied or delivered by a generator as long as the ship is operational, hence generator capacity must be properly calculated while designing a ship. The major source of ship power, as is widely known, is a generator that transforms mechanical energy into electrical energy [6], [7]. Generators that are often used on ships nowadays still utilize fuel oil to function, therefore when a design flaw develops, it might result in wasteful fuel for the generator itself. The generator's output power must also be configured such that the ship's power needs are fulfilled even if the aggregate is damaged or halted [8]–[10]. If no special instructions are given about the reserve power, the output power must be 15% more than the specified need [11]. In reality, the workload allocation for ship generators is not totally optimum and efficient, resulting in higher fuel consumption [12].

Belt Nusantara is a cargo passenger ship that travels between Ambon and Tual. This ship has three generator units with a total output of 330 kW to meet the demands of electric power in each operation, and it is envisaged that by determining the present generator, it would be possible to minimize fuel consumption. Calculations are performed using known optimization techniques to get optimum fuel for the generator.

In his study, Saputro examined B100 and B20 fuels in long-term diesel engine operation systems. According to the research, B100 fuel used 14.61% higher than B20 fuel [13]. Tumilar used an electrolysis technique fed into the manifold to optimize generator set fuel, resulting in a 3.26% fuel savings [14]. Paridawati found a 12% savings at the position of the ignition timing forward 20% in her study to improve fuel consumption by altering the ignition timing using the Artificial Neural Network approach [15]. Purba produced more than 30% fuel savings in the optimization of generator power capacity harvesting analysis using the dynamic programming approach [12]. As a consequence, in this research, the optimum approach for calculating generator load using dynamic programming was chosen since the results achieved may be superior to other methods. This research also attempts to optimize load sharing by varying generator combinations with varied specs.

Dynamic programming is a kind of management science that is applied to issues by engaging connected sequential choices, particularly problems that are stated in a succession of phases (multistage) that impact one another [16]. Dynamic programming may also be used to solve optimum fuel control issues [17].

The Optimization Analysis of Determining Generator Power Capacity on KM Ships is a previous study that used the dynamic programming approach. Sinabung, where the total load for each operational situation is calculated to be 633.64 kW for berthing, 899.53 kW for maneuvering, and 678.72 kW for sailing. In addition, utilizing generators 1 and 3 on the Tanjung Perak-Tanjung Priok-Kijang cruise and returning to Tanjung Perak, the generator fuel usage was 7,349.41 liters [12].

The purpose of this research was to establish the amount of optimum and efficient generator fuel consumption based on the electric power needs of each ship operation using the dynamic programming approach on the 1,124 nautical mile Ambon - Tual - Ambon route.

II. METHODS

II.1. *Object of research*

This investigation has many steps to achieve its goals. The ship's load and uniformity factors were determined first. Second, the power balance of MV. Sabuk Nusantara 71 was examined while docking, anchoring, and maneuvering. Third, using dynamic programming and calculating software, each generator's attributes were studied to calculate fuel consumption equal to power released. To ensure generator efficiency, load sharing criteria were created. Next, specified loads and situations were used to calculate generator fuel usage. All generator fuel consumption was included to compute total fuel usage. Finally, the research team determined the best loading conditions for fuel efficiency.

The pioneer passenger-goods ship or Sea Toll Ship MV. Sabuk Nusantara 71 promotes rural, frontier, backward, and border areas. Eastern Indonesia's 1,124-nautical-mile Ambon–Tual–Ambon route. The Directorate General of Sea Transportation awarded this ship to PT. Pelni in 2019. Principal dimension and voyages of MV. Nusantara Belt 71 can be seen below.

Table I. Principal Dimension MV. Sabuk Nusantara 71

Item	Value
Length Overall (LOA)	68.50 m
Length Perpendicular (LPP)	63.00 m
Breadth (B)	14.00 m
Height (H)	6.20 m
Depth (T)	2.90 m
Service Speed	12.00 Knots
Engine Power	2 x 1400 HP
Length Overall (LOA)	68.50 m
Length Perpendicular (LPP)	63.00 m
Breadth (B)	14.00 m

Figure 1. MV. Sabuk Nusantara 71 Operational Route Ambon – Tual – Ambon with a length of 1124 nautical miles

Table 3 presents the original generator specification data on MV. Sabuk Nusantara 71, which is utilized as a research object, as well as a new generator that will be evaluated and simulated alongside the original generator. The information in table 3 is derived from freely available accessible sources. This study also needs data on the power requirements of motor equipment that runs on electricity and is considered to be at full operational load at night.

Table II. Diesel Generator Specifications MV. Sabuk Nusantara 71

Item	Former Generator	New Generator	
Manufacture	Societe Des Moteurs Baudoin	Caterpillar	Caterpillar
Power	330 kW	480 kW	572 kW
Frequency	50 Hz	50 Hz	50 Hz

II.2. *Generator Set Power Capacity Planning*

When building a ship's generator set, consider the present electrical equipment's power needs and its maximum and minimum requirements [18]. The trigonometric sum of active and reactive power determines an electrical device's maximal power requirement, which happens at short periods during its operation [19]. Designing a ship's generator requires knowing all present equipment's load factor. Electrically powered ship motors operate only when needed. The method below allows us to calculate the ship's optimal generator capacity based on the variable load factor

$$Load\ Factor = \frac{\Sigma\ Operating\ Time}{\Sigma\ Conditioning\ Time} \qquad (1)$$

Due to working hours, ships have constant and intermittent power loads. Intermittent load is electric motor equipment that operates intermittently, whereas continuous load is equipment that works continuously. BKI Vol. IV requires a minimum equality factor of 0.5 [20]. The ship's operating conditions—berthing, maneuvering, and sailing—determine the generator's power capacity. If the ship has specialized functions, add more conditions. Calculation requires motor equipment and power data. Power balance tables are derived using motor equipment data, load factor, uniformity factor, and ship state.

II.3.*Fuel Optimization Using Dynamic Programing*

The relationship between fuel and the power generated by the generator in dynamic programming can be formulated. To find the i-th unit fuel consumptionCi, a quadratic polynomial regression equation is used to determine the performance of a motor, where a_i, β_i, y_i are the relationship constants of fuel and power generated by the i-th unit, and Pgi is the power generator unit i-th is generated

$$Ci = \alpha i + \beta iPgi + \gamma iPgi^2 \tag{2}$$

The constants αi, βi, γi are obtained by determining the three intersection points between fuel consumption (yi) and generated power (xi) generating units [21]. The three intersection points are x_1y_1 (high load), x_2y_2 (medium load), and x_3y_3 (low load). So to determine the value of a_i, β_i, y_i write the equation:

$$\begin{aligned} y_1 &= a_1 + \beta_1 x_1 + y_1 x_1^2 \\ y_2 &= a_2 + \beta_2 x_2 + y_2 x_2^2 \\ y_3 &= a_3 + \beta_3 x_3 + y_3 x_3^2 \end{aligned} \tag{3}$$

In calculating the total fuel consumption using a number of n generators (Ct), the total fuel consumption can be formulated by finding the sum of the i-th unit fuel consumption (Ci) to the number of generating units (n) [20]:

$$Ct = \sum_{i=1}^{n} Ci \tag{4}$$

The distribution of the ship's electric power load (Pd) must meet the limitations of the generator capacity to supply as in formula (x), if the power load is carried by several n generators then approach (x). Requirements for the number of ship generators n [20]:

$$P_d = P_1 + P_2 + \cdots + P_n \tag{5}$$

$$P_1 = P_2 = \cdots = P_n = \frac{P_d}{n} \tag{6}$$

After determining the total demand for electric power and the number of generators in operation, the calculation of load between generator units and fuel consumption to generate power is:

1) If the power load is supplied by one generator unit and meets the requirements $P_{1min} \le P_d \le P_{1max}$, then the fuel consumption can be written as:

$$C_t(P_d) = C_1(P_d) \tag{7}$$

2) If the power load is supplied by two generator units or n = 2, then the fuel consumption can be obtained by adding or subtracting with δ, where δ is a certain value provided that it still meets the generating capacity, $P_{nmin} \le P_n \pm \delta \le P_{nmax}$, can be written as:

$$\begin{aligned} C_t(P_d) = \Bigg[\left\{C_1\left(\left(\frac{P_d}{2}\right) \pm \delta\right)\right\} \\ + \left\{C_2\left(\left(\frac{P_d}{2}\right) \pm \delta\right)\right\}\Bigg] \end{aligned} \tag{8}$$

Then the distribution of the burden can be divided into two ways, namely:

a) The power load is divided equally:

$$C_t(P_d) = \left[\left\{C_1\left(\frac{P_d}{2}\right)\right\} + \left\{C_2\left(\frac{P_d}{2}\right)\right\}\right] \tag{9}$$

b) The power load is shared unequally:

$$\begin{aligned} C_t(P_d) &= \left[\left\{C_1\left(\frac{P_d}{2} + \delta\right)\right\} + \left\{C_2\left(\frac{P_d}{2} - \delta\right)\right\}\right] \\ C_t(P_d) &= \left[\left\{C_1\left(\frac{P_d}{2} - \delta\right)\right\} + \left\{C_2\left(\frac{P_d}{2} + \delta\right)\right\}\right] \end{aligned} \tag{10}$$

However, when calculating δ, it must satisfy the generator's capacity. Then, iterate as desired and compare the fuel consumption results of the most efficient loading variation.

In general, if the specifications of the generators used are identical, the burden distribution on ship generators is equalized between generators. For the use of generators with differing specifications, the effect of speed decline on load distribution will be accounted for. This application is performed to prolong the life of each generator and reduce generator failures. After determining the number of generator units, the next step is to create a table containing the operating conditions, the required power, the distribution of the generator's burden, the duration of operation, and the quantity of fuel consumed. The table is customized for the intended simulation, such as generator or power combinations.

III. RESULTS AND DISCUSSION

III.1. *Ship Power Balance Calculation*

Taking into consideration the load factor and the uniformity factor that the designer has decided for each motor equipment that needs electrical power as its source, the motor equipment is separated into two categories of loading, namely continuous load (CL) and intermittent load (IL). The power balance calculation must take into account the ship's operating situations, hence the power balance table is divided into three sections: berthing, sailing, and maneuvering. Table 4 describes the power needs while the ship is in berth. The overall peak load reached during maneuvering operation is 412.28 kW, with two active generators. 62.47% of diesel generator requirements are met. While the total under load attained in lean operation is 238.38 kW with one active generator and a generator demand percentage of 72.24%.

Table III. Total load during normal ship operations

No.	**Item**		**Harbour**	**Maneuver**	**Cruising**
1	Total Power Requirement (kW)	CL	215,51	266,15	267,95
		IL	55,52	215,93	95,70
2	DF = 0.9 (LC) + 0.8 (IC)		238,38	412,28	317,72
3	Active Diesel Generators		330	2 x 330	2 x 330
4	Diesel Generator Power Requirement Percentage (%)		72,24%	62,47%	48,14%

III.2. *Calculation of Generator Characteristics*

The values for the amount of fuel used by each generator are shown in Table 5. The actual Class records are used to compile the generator load data for numbers 1, 2, and 3. The value of the Load% variable indicates the maximum load that can be supported by each generator.

To determine the fuel consumption equation for each generator (Cn) the calculation is carried out in the same way as generator 1, then the equation is obtained

$$CDG_2 = 9.8659 + 0.1206P_1 + 0.0002P_1^2 \quad (12)$$

$$CDG_3 = 2.7299 + 0.1939P_1 + 0.0001P_1^2 \quad (13)$$

$$CDG_{B1} = 12.5666 + 0.1983P_1 + 0.00001P_1^2 \quad (14)$$

$$CDG_{B2} = 17.7357 + 0.1770P_1 + 0.00001P_1^2 \quad (15)$$

III.3. *Load Sharing Between Generators*

The load is distributed on generators of various specifications by calculating the speed drop using equation 2 and assuming the decrease occurs at 49 Hz in accordance with the lossless reference standard used by ENTSO-E (Europe) [22]. Table 6 shows the load on each generator during operation. MV. Sabuk Nusantara 71 operates with one generator unit for leaning and two generator units for maneuvering and sailing. The complete load is carried by one generator unit during automated berthing, and the load sharing computation in table 6 is utilized for maneuvering or sailing.

Table IV. Diesel Generator Load

Scenario	Generator Amount (Unit)					Note	Speed Drop load	
	DG_1	DG_2	DG_3	DG_{New1}	DG_{New2}		Cruising (kW)	Maneuver (kW)
1	1	1	1			$DG_{1/2/3}$	158.86	206.14
						$DG_{1/2/3}$	158,86	206,14
2	1	1		1		$DG_{1/2}$	129.44	169.97
						DG_{New1}	188.28	244.31
3	1			2		DG_1	129.44	169.97
						DG_{New1}	188.28	244.31
4	1				2	DG_1	116.24	150.83
						DG_{New2}	201.48	261.45

III.4. *Generator Load Distribution Simulation Using Dynamic Programming Method*

To simulate the original conditions when the ship is working, the generator power load is distributed into 4 scenarios and each scenario is repeated 6 times in this study which can be seen in detail in the following table.

Table V. Diesel generator load distribution simulation scenario

Scenario	DG_1 (kW)	DG_2 (kW)	DG_3 (kW)
1	330	330	330
2	330	330	480
3	330	480	480
4	330	572	-

Table 7 explains the differences in fuel use after performing calculations using the dynamic programming method, it was found that efficient and optimal fuel consumption of 20,724.77 liters was found in the first scenarios with the use of diesel generator 1 (DG_1) 330 kW for berthing, and diesel generator 1 (DG_1) 330 kW and diesel generator 2 (DG_2) 330 kW for maneuvering and cruising.

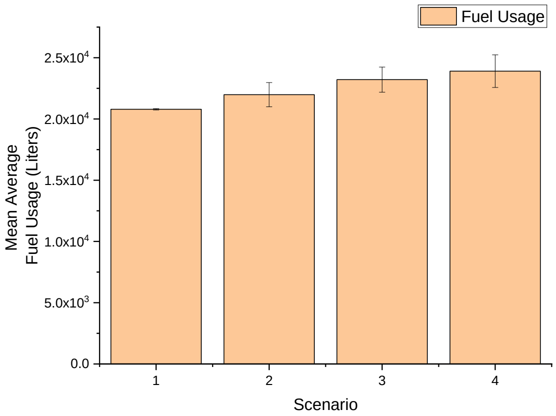

Figure 2. Diesel generator fuel donsumption for each scenario

CONCLUSIONS

According to the study findings, the peak load point of the MV. Sabuk Nusantara 71 was discovered during maneuvering ship operations with a load of 412.28 kW and the bottom load point was discovered during berthing operations with a load of 238.38 kW. The results of a fuel consumption simulation performed on ships sailing from Ambon to Tual (round trip) yielded the most efficient and optimum usage of 20,724.77 liters. There is a savings of 2,944.23 liters, or 12.44%, as compared to the reported fuel usage. These savings are calculated utilizing a 330 kW first diesel generator for leaning and 330 kW second and third diesel generators for maneuvering and cruising. The reported findings do not account for the condition of the generator components or the usage of generator oil. Meanwhile, according to real documents, the ship has been working for around three years and utilizes the third generator for leaning and the second and third generators for navigating and sailing.

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