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IMPROVING THE ENERGY EFFICIENCY OF A PASSENGER SHIP WITH A HYBRID ELECTRIC POWER SYSTEM THROUGH ROUTE OPTIMIZATION

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Key words: *Hybrid ship power system, route planning, energy efficiency.*
Abstract: *In route planning to increase the energy efficiency of passenger ships by determining the cruise speed and propulsion load, we can achieve the goal of saving energy and reducing emissions with high accuracy. Processing the large database on board passenger ships from past cruises can provide new opportunities and ideas for route analysis and optimization of the ship's energy efficiency. Segmentation and analysis of the navigation route according to environmental factors and optimization of speed in different route segments of a passenger ship with a hybrid electric power system can be improved by analyzing data from previous cruises In route splitting, the engine speed can be optimized, which can improve the ship's energy efficiency and therefore reduce* CO_2 *emissions.*

INTRODUCTION

This report analyzes data from the monthly ship report derived from the SCADA energy efficiency management system on board a passenger ship with a hybrid marine energy system. A detailed analysis of the optimization of the travel planning of a passenger ship between multiple ports, as well as the energy management during each cruise under different operatingmodes, has been carried out.

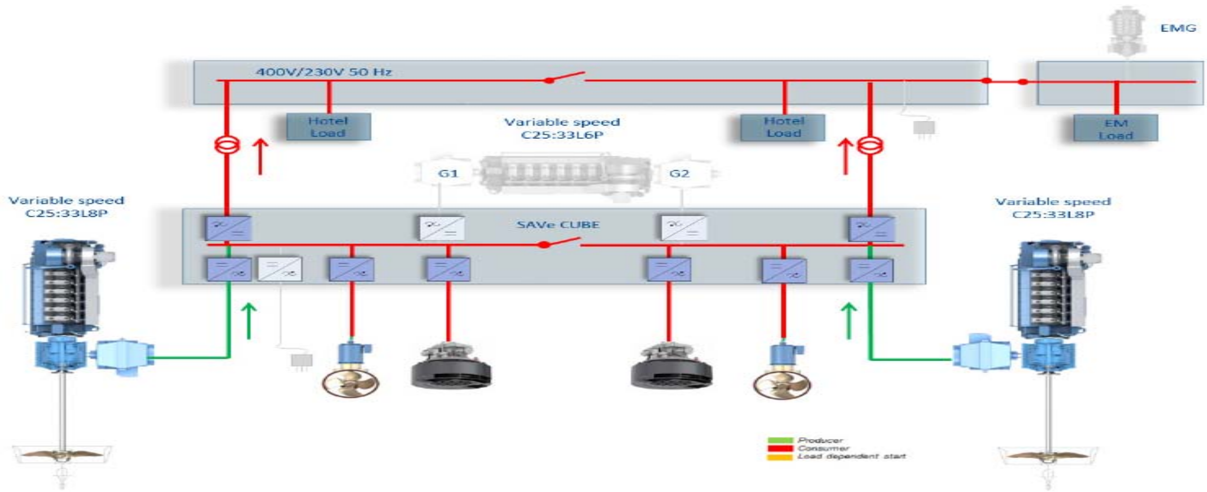

Fig. 1. Illustrate the operational of the SAVe CUBE marine hybrid power system

Like the traditional power system, SAVe CUBE is also divided into two independent power systems as shown in Figure 1.With the introduction of new technologies and an increase in the number and size of newbuilding ships, carbon emission requirements have increased. In the new constructions of the passenger ships, an increasing number of them are electrically powered. In this ship's hybrid power system, there are four diesel generators with internal common DC distribution. As well as the use of AC/DC and DC/AC converters between the DC switchboard and generators, large electric motors and the low-power AC network on board the ship. Compared to conventional marine power systems, the SAVe CUBE hybrid power system has become a preferred technology with great potential for fuel reduction. SAVe CUBE is an integration of switchboard and large frequency converters. Its advantages when compared to traditional power systems are compact size, capability for variable and fixed speed generator applications as well as fewer power conversion stages. The reports used for the voyage of the passenger ship are from its regular operation in different sea and climatic conditions. The reviewed period of the year, ship reports report a period during which the ship underwent annual scheduled hull maintenance, which positively affects the energy efficiency indicators calculated in this report.Figure 2 shows the monthly route analysis report for the month of October, and various levels of the actual rating achieved are obtained, which is calculated based on fuel consumed and nautical miles traveled by the passenger vessel.

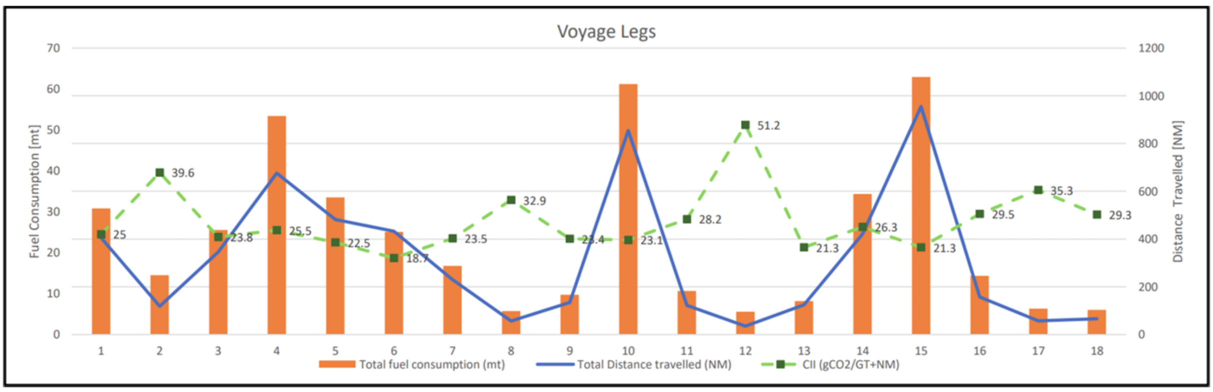

Fig. 2.The monthly route analysis

Calculating the change in real rating of the ship for 11 consecutive days from the month of October, it can be seen that when there is no interruption of the operational activity it leads to a stable trend towards higher values of the rating.

2. NAVIGATION MODE AND ENERGY EFFICIENCY OPTIMIZATION

Currently, new passenger ships are equipped with various advanced technologies that enable the ships to have good performance in different water areas and operating modes. When idle or at anchor, fuel consumption must be reduced as this affects energy efficiency. It is envisaged that in the future shore powering will be mandatory when a ship docks in a port in order to reduce carbon emissions. The report analyzes three operational modes of the passenger ship, in which different operating modes of the generators are used. During the three operating modes of passenger ships with a hybrid electric power system, various factors are taken into account - navigation speed, distance between ports, number of passengers, time to reach the next port, price of heavy fuel, price of light fuel and meteorological conditions. Figure 2 shows the three analyzed vessel operating modes and the hourly fuel consumption [1].

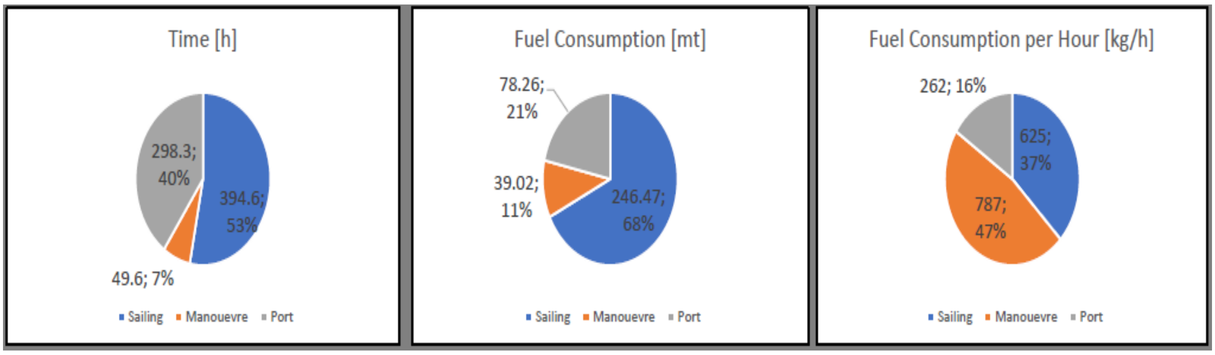

Fig. 3. Operating modes of a passenger ship

Optimizing the travel route leads to a reduction in fuel consumption. In the case of large cruise ships, the power depends mainly on the drive and electricity consumption in the hotel part. When considering the hotel's propulsion and load requirements, the overall power generation may be performed in a sub-optimal manner in terms of Main Engine efficiency. One of the main methods of reducing fuel consumption is to follow a trip plan optimized to minimize the required propulsion power. The main objective of this report is to investigate the potential for fuel savings under various different operating modes.

The SAVe CUBE system makes it possible to include the Power Management System, which is responsible for planning the operating mode of electrical consumers on board the ship, together with the ship's routing system. Optimal operation of a power system by managing the load on generators can affect the ship's energy efficiency.

By taking into account the efficiency of the ship's engine on various routes in relation to weather conditions, the fuel consumption can be determined. Here the main thing is to find an optimal route with respect to some cost function. The given trip plan is defined as a route and the corresponding speed profile. Route optimization is actually an optimal control problem, which is given in formula 1[2] [3] .

$$(1) \quad min_u J = \phi(x(t_f), t_f) + \int_{t0}^{t1} L\,(x(t), u, t), dt$$

$$(2) \quad \frac{dx}{dt} = f(x(t), u, t$$

where ϕ is a penalty put on the arrival and L varies depending on the type of the optimization problem. L is the fuel consumption rate if the minimization is done with respect to fuel. In time minimization, L is simply the constant 1, this called Euler-Lagrange equations, are satisfied[5]:

$$\frac{dx}{dt} = f(x(t), u, t \quad (3)$$

$$\frac{d\lambda}{dt} = -\left(\frac{\delta f}{\delta x}\right)^T - \left(\frac{\delta L}{\delta x}\right)^T \quad (4)$$

The Bleick and Faulkner [11] and Haltiner [12] numerical methods are for solving the problem directly, assuming that the state derivative function f is known [4].

$$\left(\frac{\delta f}{\delta u}\right)^T \lambda + \left(\frac{\delta L}{\delta u}\right)^T = 0 \quad (5)$$

$$x(t_0) = x_0 \quad (6)$$

$$\lambda(t_f) = \left(\frac{\delta \phi}{\delta x(t_f)}\right) \quad (7)$$

The purpose of improving energy efficiency through route optimization is not only to determine the energy consumption of the ship, but also to present energy efficiency improvement measures that can reduce fuel consumption and therefore reduce greenhouse gas emissions for the distance traveled from the ship. This section presents several of these measures with the corresponding reduction/savings in fuel consumption and emissions. To determine these measures to reduce fuel consumption and the corresponding emissions, they are calculated according to the values in the ship's report for the relevant period in Table1.

Table 1– Values for payback period and annual savings calculations

SFOC [g/kWh]		Fuel Price [€/ton]	Hours - WVO Data (01/2021 - 11/2022			WVO Data (01/2021 - 11/2022		Expected Carbon Price for 2023 [€]	Carbon Factor
Main Engines	Genset	MDO	Sailing	Manouevre	Port	MDO [ton]	Distance Travelled [nm]	ton-CO2	CO2 per ton MDO [tons]
190	190	1012,5	4 536	614	2 843	4 187	58 258	85	3,206

3. CONCLUSION

Following a set route is a difficult task in bad weather conditions, so it is necessary to optimize the route management in real sea conditions. When optimizing the route in order to increase the energy efficiency of passenger vessels, the safety and comfort of the passengers and the crew must be ensured.

REFERENCES

[1] Resolution MEPC.213(63): 2012 Guidelines for the Development of A Ship Energy Eciency Management Plan (SEEMP), 2012.

[2] Willard Evan Bleick and Frank David Faulkner. Minimal-time ship routing. Technical report, Monterey, California. Naval Postgraduate School, 1964.

[3] Cruise market watch, 2015. URL http://www.cruisemarketwatch.com/growth/. Last visited 2015-04-28.

[4] Joanna Szlapczynska and Roman Smierzchalski. Adopted isochrone method improving ship safety in weather routing with evolutionary approach. International Journal of Reliability, Quality and Safety Engineering, 14(06):635–645, 2007.

[5] Igor Griva, Stephen G Nash, and Ariela Sofer. Linear and nonlinear optimization.Siam, 2009.

ПОДОБРЯВАНЕ НА ЕНЕРГИЙНАТА ЕФЕКТИВНОСТ НА ПЪТНИЧЕСКИ КОРАБ С ХИБРИДНА ЕЛЕКТРОЕНЕРГИЙНА СИСТЕМА ЧРЕЗ ОПТИМИЗАЦИЯ НА МАРШРУТА

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Ключови думи: *Хибридна корабна енергийна система, планиране на маршрута, енергийна ефективност.*

Резюме: *При планирането на маршрута с цел повишаване на енергийната ефективност на пътническите кораби чрез определяне на крейсерската скорост и натоварването на задвижването, можем да постигнем спестяване на енергия и намаляване на емисиите с висока точност. Обработката на голямата база данни на борда на пътнически кораби от минали круизи, може да предостави нови възможности и идеи за анализ на маршрута и оптимизиране на енергийната ефективност на кораба. Сегментирането и анализът на навигационния маршрут според факторите на околната среда и оптимизирането на скоростта в различни части от маршрута на пътнически кораб с хибридна електрическа система, могат да бъдат подобрени чрез подробно анализиране на данни от предходни круизи. При разделянето на маршрута, скоростта на двигателя може да бъде оптимизирана, което може да подобри енергийната ефективност на кораба и следователно да намали емисиите на* CO_2.