Diesel electric propulsion on ∑IGMA class corvettes

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Abstract **— Nowadays, diesel electric-propulsion plays an increasingly important role in the naval shipbuilding industry. It is considered a design with great future potential due to its lower inboard and underwater noise, presumed lower fuel consumption and lower maintenance. Additionally, vulnerability can be decreased and reliability can be increased with a diesel-electric propulsion system. The system is less vulnerable in respect to failure as the redundancy is increased in comparison with a common diesel-mechanical propulsion system. In this context, this paper demonstrates the advantages and disadvantages of such a propulsion system, pointing out today's and future challenges.**

I. Introduction

The common need for nations to maintain a modern and well-equipped Navy is significant and diesel-electric propulsion plays an important role in this matter. Growing interest in electric propulsion is noticeable and can be explained by two factors: environmental considerations and specific requirements for naval operations.

Diesel-electric propulsion offers the possibility to operate the generator sets at their optimum operational point, resulting in lower emissions and lower fuel consumption.

In addition, diesel-electric propulsion has the capability to reduce noise and vibration. The system offers the possibility of acoustic isolation of the components and therefore noise insulation. Furthermore, the magnetic and infrared signatures can be minimized.

Diesel-electric propulsion is considered a design of great potential due to the high flexibility of the arrangement in the ship. Shorter shaft lines can be implemented and the vulnerability of the ship can be decreased. Reliability, Availability, Maintainability and Safety aspects (RAMS) play an important role, especially in the naval industry [1].

Despite the above, diesel-electric propulsion systems are still missing wide confidence from decision-makers in the naval sector.In this paper, a feasibility study is performed to evaluate the implementation of a diesel-electric propulsion system in a corvette of the ∑IGMA class (s. Fig. 1).

Fig. 1: A ∑IGMA 9113 corvette

The vessels of the ∑IGMA class, the new corvette class of the Dutch yard DAMEN Schelde Naval Shipbuilding (DSNS), are characterized by their modular design. Offering these ships with a (modular) diesel-electric propulsion system would consolidate the market position of the vessel class itself.

A weight estimation of the whole propulsion system, the arrangement in the vessel and calculations of the fuel oil consumption underline the difficulties with implementing today's diesel-electric propulsion systems.

In conclusion a perspective of future developments is given.

II. Diesel Electric propulsion

The implementation of a diesel electric propulsion system, instead of a direct diesel mechanical drive, has a number of advantages. The main advantage of a diesel electric propulsion system is the high flexibility in respect of the arrangement of the single systems in the vessel (s. Fig. 2).

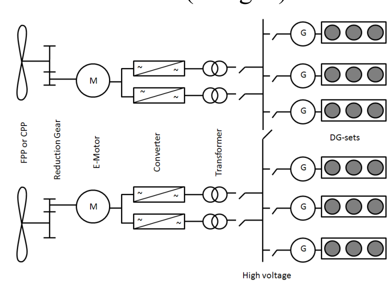

Fig. 2: Example for a propulsion line diagram of a diesel electric propulsion system

In contrast to a diesel direct system, the prime movers do not have to be connected directly with the propulsion shaft and the propeller. The generator sets can be placed where it is convenient for the general arrangement. This has got a positive effect in matters of: damage stability, vulnerability requirements and noise or infrared detect ability requirements. Furthermore, the reliability in respect to failure is higher as it is easier to implement higher redundancy, especially in comparison to a diesel direct propulsion system.

Another advantage of a diesel-electric propulsion system is the high potential for fuel saving and therefore a more environmentally-friendly operation. Additionally, fuel savings lead to savings of operational costs as well, especially as fuel costs take the largest part in Life Cycle Costs.

For vessels with large variations in operating conditions, such as transit, manoeuvring, dynamic positioning, etc, the propulsion load varies from very small values to nearly full installed power. By running a specified number of diesel generators at the optimum operation point for every loading condition, the overall fuel consumption is reduced, compared with conventional diesel direct propulsion [2].

Noise and vibration emissions can be reduced significantly by implementing a diesel electric propulsion system. However, some negative effects cannot be neglected either.

Higher acquisition costs, higher efficiency losses and an increased weight and volume of the whole propulsion system have to be taken into account.

III. Evaluation of the Systems

Costs, weight and customer preferences are the driving factors for the decision for one propulsion system or another, as the differences between the singular solutions are not great. Today’s options to choose from, the common versions as well as the less common ones are illustrated in Fig. 3.

It has to be decided on the following systems and subsystems:

- Type of the propeller, Controllable Pitch Propeller (CPP) or Fixed Pitch Propeller (FPP),
- Type, rotational speed and current of the electric motor,
- Voltage and frequency of the supply grid,
- Type of the frequency converter
- Type of the transformer (if applicable),
- Type and size of the generators, for the power generation.

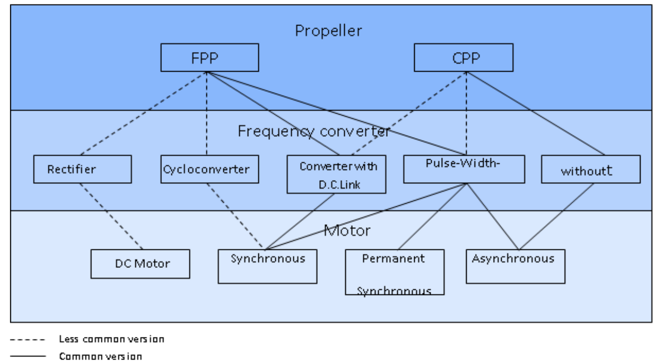

Fig. 3: Different solutions for diesel electric propulsion systems

The choice of the electric motor is related to a number of decisions. The speed range has to be determined, the type of cooling and the current (AC or DC). The implementation of a gearbox is related to the choice of the rotational speed of the motor as well. Due to its more compact design an asynchronous motor with a relatively high rotational speed has be chosen. The obvious disadvantage of this choice is that a gearbox needs to be implemented. This results in higher efficiency losses and in a higher noise radiation, the result being a particular disadvantage for naval applications.

Moreover, the voltage of the whole system has to be determined, choosing either a low voltage system (Unet < 1000V) or a medium voltage system (1000V < Unet < 52kV). Contingent on the different voltages, transformers and special circuit breakers have to be implemented. It has been chosen for a medium voltage (3.3kV) distribution grid in order to keep the cable diameters relatively small.

Concerning the electric drive, a decision has to be made in respect to the converter type, choosing a transformerless solution or not. Today, a typical installation is a Pulse-Width-Modulated (PWM) converter with a transformer. In this configuration it has been chosen for a configuration without a transformer for an Active-Front-End (AFE) converter. The main reasons for this decision are related to the available space on board and the restricted weight budget of the installation. A comparison of the dimensions and the weight of the different systems is given in TABLE I. to support this decision.

Additionally, the power generation has to be sufficient for the requested maximum speed of the ship. This requires a number of diesel generator sets have to be implemented into the ship. The options vary between a certain number of smaller generator sets, to a minimum number of generator sets with a high power to a combination of different sizes and power outputs.

TABLE I. Dimensions for Converters and Transformer

	Voltage	Power	L x B x H	Quantity	Overall area (m²)
AFE[6]	3,3 kV	6280 kW	8400x1200x2310	2	20,16
AFE[7]	3,3 kV	3140 kW	5800x1200x2310	4	27,84
DFE[8]	6,6 kV	4300 kVA	5422x1265x2380	4	27,44
Transformer[9]	6,6 kV		3300x1675x2400	4	22,11
					∑ = 49,55

The latter has been eliminated in order to keep the spare parts to a minimum. It has been chosen to implement four generator sets with a maximum power of 3MW each. That configuration allows for the highest power density in comparison with an installation with a number of smaller generator sets. All of these choices and decisions are related to the systems currently available on the market as well as the possibilities to implement them into the existing design of the ΣIGMA vessels.

IV. Conclusion

To achieve a sufficient ship speed, four diesel generators (s.Fig. 4) have to be integrated in a ∑IGMA corvette. The maximum ship speed is then about 22 knots. Therefore, a diesel-electric driven ∑IGMA class corvette would be operating in the medium speed range of today's corvettes operating worldwide. It is not possible to integrate more propulsion power due to the restricted available space on board of a corvette and due to the low power density of the diesel generators being currently available on the market. An overview of the chosen diesel electric propulsion system is given in TABLE II. .

Furthermore, the acquisition costs for a diesel-electric propulsion system are about 62% higher in comparison with a common diesel-mechanical propulsion system. These higher acquisition costs cannot be balanced out by lower life-cycle-costs, as the fuel consumption is higher during nearly the whole speed profile of the vessel. Fig. 5 indicates the fuel oil consumption in tones per hour over the whole speed curve, compared to a diesel-mechanical and a diesel-electric propulsion system. One of the reasons for the lower fuel consumption is that the specific fuel oil consumption of a diesel-generator is worse in comparison with a diesel-engine. Additionally, a diesel-electric system is more complex, heavier, and it requires more space in comparison with a diesel-mechanical system.

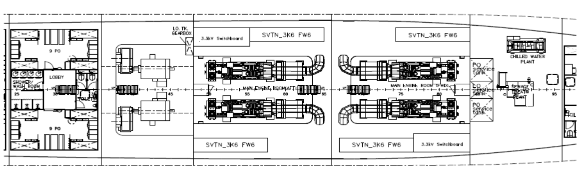

Fig. 4: Section of the General Arrangement Plan of the main engine room configuration

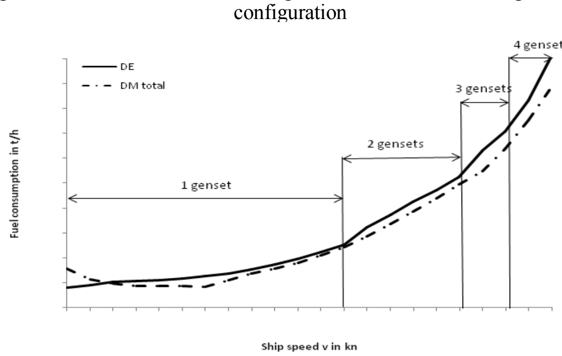

Fig. 5: Fuel oil consumption over the whole power curve for a diesel electric and a diesel mechanical system

TABLE II. CHOSEN DIESEL ELECTRIC PROPULSION SYSTEM

System	Main technical data	Quantity per ship
Propeller	FPP, D = 2700 mm, 5 blades, high skew, ISO 484 class I, NiAl-Bronze	2
Reduction Gear	Single stage, vertical offset = 880 mm, no horizontal offset, i = 5,22 , L x B x H = 1700 x 2035 x 1825 (mm), W ≈ 9500 kg	2
E-Motor	Asynchronous, 5 MW, 1200 rpm, L x B x H = 2950 x 2807 x 2645 (mm), W = 17000 kg	2
Converter/Transformer	AFE converter, P_M=3140 kW, 3,3kV, L x B x H = 5200 x 1200 x 2310 (mm), W ≈ 9000 kg water cooled, transformerless solution	4
Electric Distribution System	3,3 kV switchboards, L x B x H = 4400 x 1939 x 2250 (mm), W_{total}= 6300 kg	2
Generator Sets	20V4000N43S, P_m = 3015 kW L x B x H = 6900 x 2200 x 2800 (mm), W = 33 t, medium voltage generatorset	4
Distribution Transformer	3,3 kV/440 V, 2000 kVA, L x B x H ≈ 2200 x 2000 x 2500 (mm), W ≈ 4500 kg, [11]	2

However, the diesel-electric configuration allows for more flexibility in the arrangement. The generator sets have been split in two groups of two generators each (s. Fig. 4) Therefore, the vulnerability can be decreased significantly by increasing the redundancy. This is a very important aspect in naval shipbuilding. Nonetheless, these positive aspects cannot outweigh the negative aspects of higher acquisition and life-cycle costs.

Therefore, until diesel-electric configurations become the propulsion systems of choice, a lot of research has to be done in respect to light, compact and economical ways of power generation as well as power distribution.

V. Perspective

Current research projects are dealing with the improvement and development of propulsion systems in general and electric systems in particular.

Generally speaking, all the systems need to be more compact and lighter in weight. This includes the systems of the power generation, the power distribution and the direct propulsion part. Furthermore, the acceptance of diesel-electric systems and pure electric systems has to increase, especially in the naval sector. A higher acceptance would lead to a bigger focus in the research sector to continue and accelerate the developments. Furthermore, a higher acceptance would definitely lead to decreasing acquisition costs.

A high potential is adjudged to alternative solutions, such as the following: the pseudo direct drive technology (PDD) [3] and High Temperature Superconductive (HTS) motors and generators. Additionally, the capability to store energy in accumulator arrays or batteries has to be viewed in a positive context of efficient propulsion systems of the future.

Furthermore, the focus should shift from the all electric solution to hybrid configurations.

Acknowledgment

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