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"SHORE TO SHIP" SYSTEM – AN ALTERNATIVE ELECTRIC POWER SUPPLY IN PORT

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Abstract

Greater interdependence and integration among the countries worldwide have resulted in the growth of the world trade and, what follows, marine transportation. In the last few years, despite the world economic stagnation, the number of ships has increased. An increase in the marine transportation means greater air pollution caused by ships, what is of paramount importance for the port cities. One of the efficient ways of limiting the negative impact of ships lying in ports on the environment is the power supply from the local electricity stations. This will allow for turning marine power generating systems off, what will result in the emission elimination in the ship's mooring time along with the decrease of noise and vibrations. The infrastructure of the port electric installation necessary for the ships' supply has to be designed so as to make the operating of different ship types possible. It is complicated as all over the world ships are equipped with different electric systems. The paper deals with general issues related to common nominal voltages and frequencies for vessels which call in European harbours and their estimated power demands. Additionally, a case study of a ferry vessel, currently undergoing retrofitting for shore connections, is presented and some particulars concerning technical solutions and environmental profits are described.

***Keywords**: alternative marine power, electric shore-side supply, auxiliary diesel engine, exhaust emission*

1. Introduction

Marine transportation plays a significant role in the world transport. The 90 per cent of goods traded between the countries of the European Union and the rest of the world is transported by sea. A permanent increase of the number of transport ships has been noticed together with their frequent mooring. It results in a negative influence of ships on the natural environment on the shore and in the port, including air pollution. Ships are important sources of the exhaust gas emission in the form of: NO_x, SO_2, Particulate Matter, CO and CO_2 which cause serious danger, especially in ports located in the vicinity of inhabited urban agglomerations. It has been predicted that in the European Union the emission of NO_x and SO_x by ships will have exceeded the land based source emission by 2020 [1]. The prediction intensified the process of finding ways to limit the negative influence of ships in ports on the natural environment.

Acting within the International Maritime Organization, a set of regulations was completed on how to prevent air pollution by ships and it referred to two main harmful exhaust gas components, i.e. NO_x and SO_x for which the limits were introduced. The specific limits for NO_x emission were divided into several stages (presented in Fig. 1) and were started as stage 1 (Tier 1) in 2000. Stage 2 (Tier II) became effective on 1 January 2011, whereas stage 3 (Tier III), an unusual solution, will be effective only in Emission Control Areas from 2016 onwards. Following, from 2016 onwards, the ships built before 2000 and currently not restricted by the regulations limiting NO_x emission, will be subject to stage I – Tier I. Control areas (SECA - Sulphur Emission Control Areas already designated and NECA – Nitrogen Emission Control Area under development) have been formed as a result of legislative initiatives of the countries of a given open sea. The Baltic and the North Sea constitute SECA and it is planned to develop NECA [2].

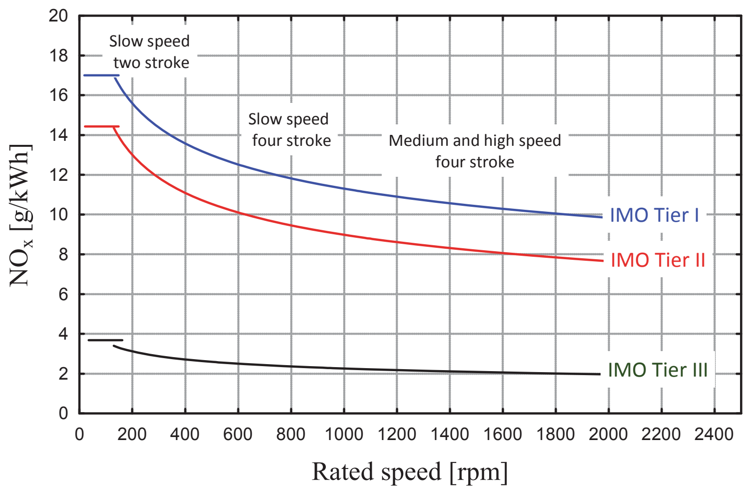

Fig. 1. Nitrogen oxides emission limits for marine engines

In the case of SO_x emission, a strategy has been adopted which is based on the reduction of elementary sulphur content in engine and boiler fuels. The introduced limits are global in character and the first were effective in 2010 [3, 4]. A schedule of reductions, shown in Tab. 1, presents the assumed permitted sulphur content in fuel oils.

Tab. 1. Permitted sulphur content in fuels according to annex VI of MARPOL Convention

<table>
<tr><th>Date of introduction</th><th>Global requirements</th><th>Requirements in SECA areas*</th></tr>
<tr><td>Existing</td><td rowspan="2">4.5% m/m</td><td>1.5% m/m</td></tr>
<tr><td>1 July 2010</td><td rowspan="2">1.0% m/m</td></tr>
<tr><td>1 January 2012</td><td rowspan="2">3.5% m/m</td></tr>
<tr><td>1 January 2015</td><td rowspan="2">0.1% m/m</td></tr>
<tr><td>1 January 2020**</td><td>0.5% m/m</td></tr>
</table>

**- apart from present control areas SOx (SECA) IMO will designate other areas*
***- in the case of negative evaluation by IMO, the standard will become effective on 1 January 2025*

Adequate requirements in SECA areas have been formulated separately and presented also in Tab. 1. The commonly accepted environmental policy comprises internal purposes increasing requirements and insisting on their introduction. Such attitude exists in the EU countries and resulted in the introduction of a requirement of low-sulphur fuel engine supply (0.1% m/m) for ships calling at ports in the EU countries. It took effect on the 1st of January 2011. The responsibility for prevention of air pollution by ships mooring in the port and for enforcing the adoption of introduced solutions rests with port authorities and sea administration offices. They may be subject to national policies on environmental protection which may largely differ from the assumptions accepted by the EU.

Currently, autonomous diesel generators supplying energy to ships, mooring in ports and heating and steam boilers are the main source of the exhaust gas emission in ports. Apart from the exhaust gas emission, diesel generators are also the noise source, at normal acoustic level exceeding 100dB. For generators with the power exceeding 1 MVA, the noise level reaches even 140 dB [4]. Diesel generators also emit vibration exceeding human sensitivity threshold, especially for the frequency range up to 30 Hz.

Turning off autonomous diesel generators and connecting the vessel electric supply system to a land electric grid is en effective method to reduce the emission of harmful substances as well as noise and vibration in ports.

Shore power supply, apart from minimizing the negative impact over the environment, also produces economic effects. It is connected with the different costs of power generation by diesel generators in relation to electric energy price on the land.

2. Power supply in ports – the system concept

The main problem faced, to connect the vessel electric supply system to a land electric grid, while mooring in the port is the electric grid with different ratings and the lack of standardization of the land electric grid performance. Nominal ratings of the low voltage land grid differ between ports, and more precisely between countries. Rated voltage of the grid is not as important as its frequency. Basically, in Europe, Asia and Africa there is electric grid voltage frequency of 50 Hz and in North America of 60 Hz. Considering this aspect in relation to the ship electric system, both voltage and frequency levels are essential. The ship electric system rated voltage differs depending on a vessel class, its size and vessel regional operating conditions [6]. The ship electric system voltage frequency of 60 Hz (about 70 per cent) prevails in the world merchant navy, whereas there are at least five voltage levels below 1 kV and three exceeding 1 kV. The majority of currently going ships has a separated field in its main switch board enabling the connection of the vessel electric supply system to a land electric grid. The panel of "shore connection" is equipped only with the connecting installation and alternatively phase sequence control.

The ship might be alternatively shore connected only if a shore voltage source is available with ship electric system voltage ratings. At present, electric incompatibility is the main obstacle, therefore supplying the vessel electric system by means of a land electric grid is relatively rare. The method of switching from own – ship's autonomous electric system to a shore connection and the other way round is an important aspect as short black-out appears. In a modern automated engine room automation and vessel control systems it is unacceptable. In current economic and organizational conditions as well as technical infrastructure of sea transportation with an emphasis on safety, the way of changing the electric power source, when there is black-out cannot be considered. As mentioned above, the main problem while designing the connection of the vessel electric supply system to a land electric grid is "adapting" the land electric grid to various, autonomous vessel systems.

The concept of a universal - Shore to Ship electric system, recommended in the EU directives [7] might be one of the solutions. As shown in Fig. 2, the main system elements are the following:

– transformer in the main switch board, matching land distributive grid voltage to the system installation (shore to ship),
– frequency converter matching land grid frequency to the vessel system,
– cable reel system enabling the supply of low voltage to the ship,
– transformer (on the ship) matching low voltage to ship voltage.

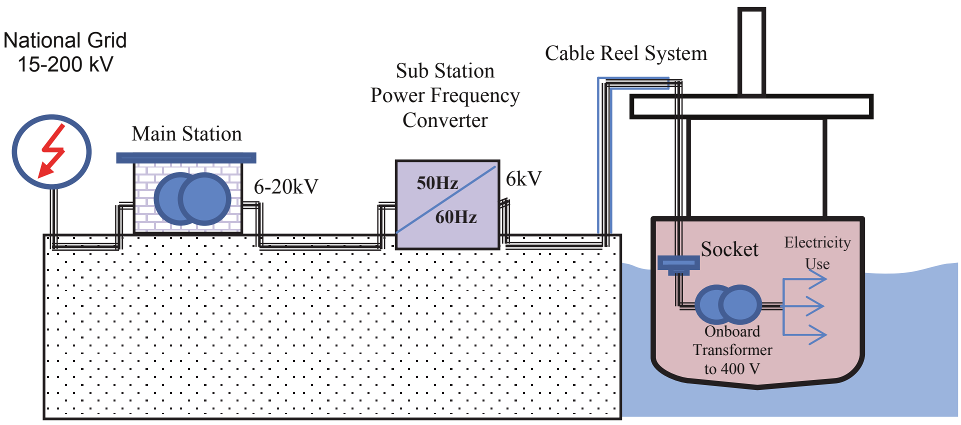

Fig. 2. The scheme of vessel electric supply system configuration in the port according to EU regulations

The cost of the whole system is determined by a frequency converter which is the only technologically complicated device in the Shore to Ship system. Owing to systematic development of electric technologies of high power in the range of up to 20 MVA, a possibility arose to build an

AC current frequency converter. Currently, high power frequency converters have been dominated by two types of fully-controlled valves: Insulated Gate Bipolar Transistor and Insulated Gate-Commutated Thyristor which are a connection between the Gate Turn Of and the Gate Control System. Alternative configurations of the vessel electric supply system may differ depending on local conditions [5, 7] and each of them has distinctive characteristics. The following configurations are distinguished:

– one central frequency converter located in the main switch board, whereas at the quay there are only matching transformers,
– in the main station there is only a land grid voltage descended transformer, whereas the converter with matching transformer are located at given quays,
– in the main station there is a transformer and rectifier; the energy supply in the port goes through a direct current transfer system, and at quays, there are inverters and matching transformers.

3. The power supply system at ferry terminals, line Poland-Sweden

The power supply system for ferry terminals, the line Poland-Sweden, at present has been at different stages of development. In Sweden (Ystad) the project is being implemented, while in Poland (Świnoujście) at the planning stage. Due to administrative causes, the system will at first start functioning at the ferry terminal in Ystad where it will have been built by the end of 2012. The ferry line Sweden-Poland (western part) is operated by Polish ship owners or operators.

3.1. The shore power supply system – a general concept

The system configuration must reduce the number of system elements located directly at quays because of intensified port operations: cars, tractors, cranes and others. The configuration of Ship to Shore system presented in Fig. 3 ensures the reduction of system elements at quays to a minimum. Matching transformers and frequency converters are located in the main station. The section independence of frequency converters (for every quay) increases the independence of the whole system. In the case of failure of one section, it is still possible for other converters to operate. Only low voltage flexible cable cranes (6.6 kV) are located directly at the quay. The crane may be operated remotely onboard.

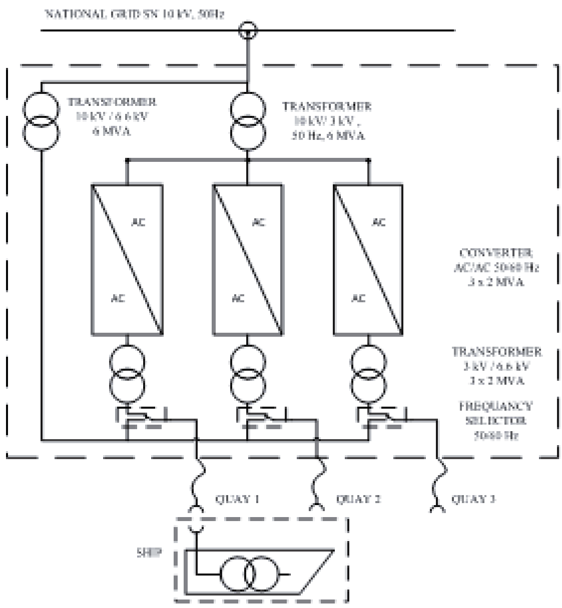

Fig. 3. The "Shore To Ship" concept for ferry terminals

Safe quick-connectors will be used for the onboard cable connection. A matched transformer converting low land voltage (6.6 kV) into low voltage (LV) of the ship electric system (440VAC) will be installed on ferries. Switching from an autonomous power supply to a land electric grid must happen without breaks. This fact imposes the requirement of synchronization of autonomous diesel generators with a land electric grid. A synchronizing panel with breakers will be installed on the ferry. The LV for the transformer secondary winding, will be connected to the main switchboard. The land electric grid must satisfy the port power demand to such an extent that the operation of autonomous auxiliary diesel generators is not required.

3.2. The ship electric system and electric supply system for Ro-Pax vessels

The first vessel adapted to a land electric grid operation is ferry - m/f Skania. The m/f Skania is a fast ship, Ro-Pax class, built in 1995 in Schichau Seebeckwerft Shipyard in Bremerhaven. The Unity Line ship and owner (Polsteam Szczecin), purchased the ship in 2008 and hosted the Świnoujście – Ystad connection. Tab. 2 shows the technical description of the ship.

Tab. 2. The main details of m/f Skania

1	IMO number	9086588
2	Tonnage	23663 GT
3	DWT (deadweight)	5717 metric tons
4	Length	173.50 m
5	Beam	24.00 m
6	Draught	6.41 m
7	Speed (maximum)	27.9 knots
8	Capacity	1400 passengers, 686 berths, 830 cars, 1850 lane meters

The ship electric system is determined by the size of its main propulsion. In the case of ships adjusted to transport RO-RO cargo, the main propulsion must additionally fulfil the requirements of space optimization, which excludes the possibility of using the large bore, slow speed two-stroke engine. Independence and high maneuverability are extremely significant. The conditional propulsion unit formed in this way caused the application of a specific configuration for the main and auxiliary ship propulsion, which is shown in Fig. 4.

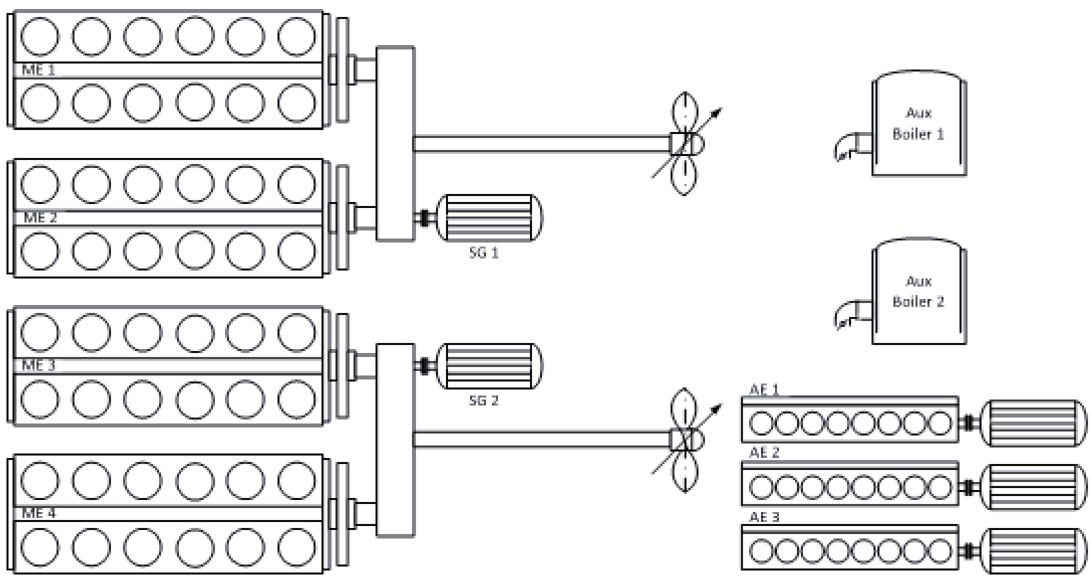

Fig. 4. The scheme of configuration for the main and auxiliary propulsion of m/f Skania

The ship main propulsion consists a twin shaft and propellers – CPP (Controllable Pitch Propeller). Each propeller, in turn, is driven by a pair of large bore, medium speed, four stroke diesel engines, coupled by means of a clutch and common gearbox.

The gearbox is additionally combined with shaft generator, whose main function is to electric supply thrusters, while maneuvering. Basic characteristics of the main and auxiliary engines as well as heating boilers are presented in Tab. 3.

Tab. 3. The specification of the main propulsion of m/f Skania

No.	Designation	Engine		Number	Power	Speed
		Maker	Type		P_e [kW]	n_n [rpm]
1	Main propulsion	ZGODA-SULZER	12ZAV40S	4	7920	510
2	Auxiliary generator	MAN B&W	8L28/32H	3	1260	720
		Boiler				Pressure [bar]
3	Auxiliary boiler	HTI Hamburg	HE12V30	2	1455	10

The construction of the main propulsion and electric supply system ensures the possibility to achieve high propulsion efficiency. Whereas the electric supply system is typical for this type of ships, as shown in Fig. 5. The scheme contains the information on an additionally planned (under construction) shore connection.

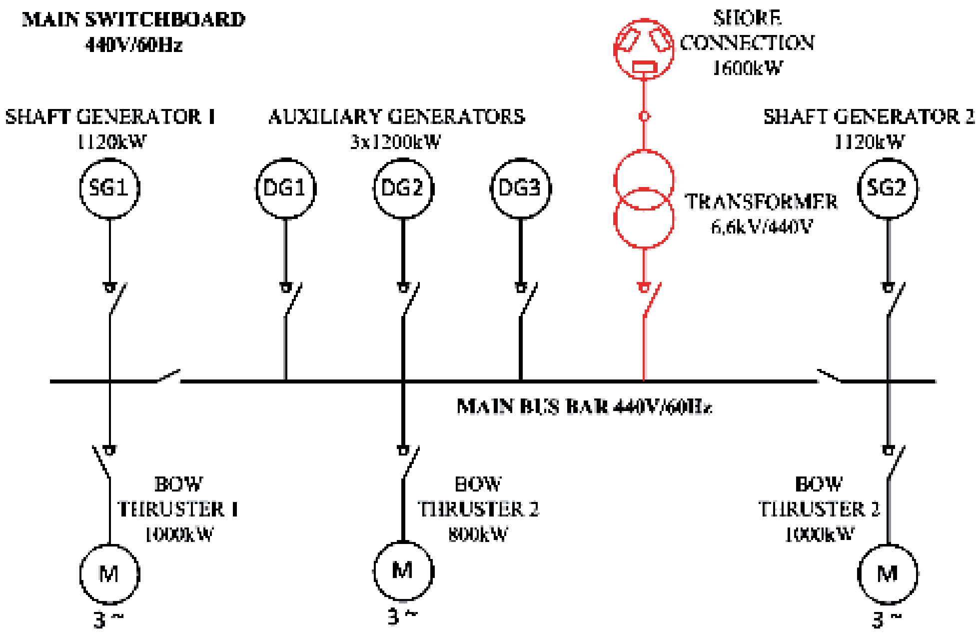

Fig. 5. The configuration of the electric supply system with the planned shore connection (in red)

4. The ship's impact on the natural environment while mooring

Generally, ships in their operating condition and lying in ports fulfil their functions associated with the character and purpose of operational service. Depending on the ship class, it is mainly unloading or loading cargo and the essentials of the process will depend on using own means such as cranes or port equipment. It will affect electric, mechanical and heat energy capacity generated in the ship's engine room and it will also cause different influence on the natural environment. The influence in question in the form of exhaust gas, noise and vibration low frequency emission, will always be negative and will be dependent on the ship's size and what follows on realistic levels of

To evaluate the level of the negative impact, a measurement cycle was completed to assess the realistic electric appliances performance – the propulsion units of m/f Skania. The measurement methodology is based on ISO [8] standards and technical guidelines, an annex VI to Marpol [3] convention. The measurement was made in all operating conditions relating to Świnoujście – Ystad connection which consisted of:

– mooring (unloading, loading),
– maneuvering in the port area,
– roadstead,
– service speed.

Next, to appraise the influence on the natural environment in the port, in the context of a land electric grid, the key state of the ship, further considered is its mooring – at the quay. The analysis contains the operation of autonomous diesel generators and heating boilers. According to present EU, [7], requirements, when lying in the port, the vessel engines are supplied with low-sulphur fuel (below 0.1% m/m of sulphur content) and this grade of fuel was used during the testing. To fulfil the requirements, the engine tests were conducted in the standard load power range. The exemplary results of the exhaust gas emission measurement, made for the auxiliary engine and auxiliary heating boiler, are presented in Fig. 6.

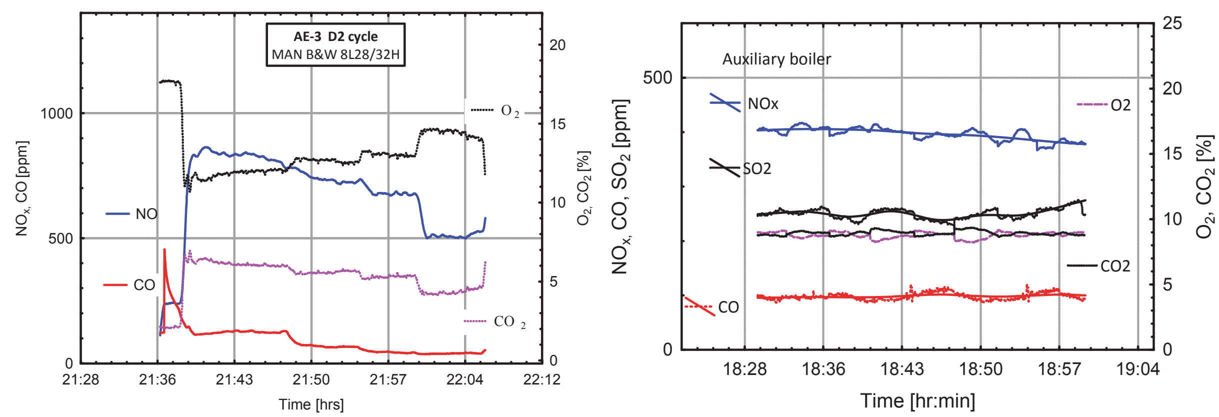

Fig. 6. The exemplary, registered exhaust gas composition for engine AE 3 and heating boiler

The results of the exhaust gas emission measurement, expressed as exhaust, specific weighted emission (compatible with IMO requirements) for auxiliary engines are contained in Tab. 4. Nitrogen oxides emission factors refer to this engine type, built in the time before introducing the requirement of reducing this exhaust gas component emission. Therefore, the nitrogen oxides emission factor for all the engines is over the Tier 1 limit, as shown in Fig. 7.

Tab. 4. Exhaust gas emission factors for diesel engine generators

No:	Gas component	Unit	AE-1	AE-2	AE-3
1	NO_x	g/kWh	12.29	12.33	13.49
2	CO	g/kWh	1.05	1.09	1.19
3	HC	g/kWh	0.81	0.83	0.90
4	SO_x	g/kWh	6.31	6.34	6.34

The measurement of the realistic diesel engine generators performance allowed estimating the gas component flow rate, while berthing in the port. The figures for one diesel generator within the load range and adequate to operating state, while berthing is contained in Tab. 5.

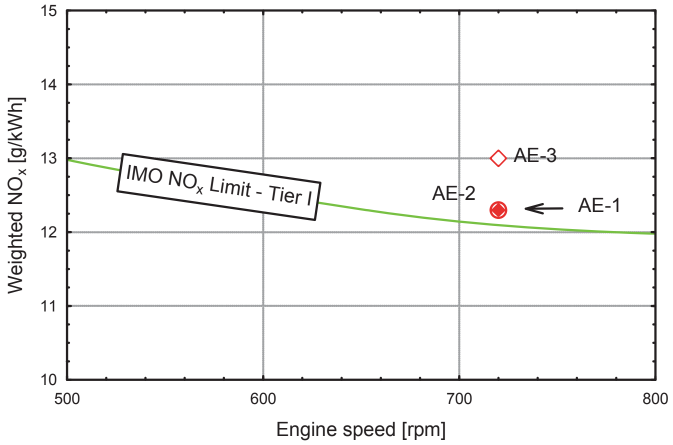

Fig. 7. NOx emission factors for ship diesel engine generators in Tier 1 limit

Tab. 5. Exhaust gas emission of diesel engine generator while berthing in the port

No.	P_{el}	P_e	P_{er}	B	NO_x	SO_x	CO	HC	CO_2
	[kW]	[kW]	[%]	[kg/h]	[kg/h]	[kg/h]	[kg/h]	[kg/h]	[kg/h]
1	450	504	40.0	128.3	6.86	3.14	0.62	0.40	373.8
2	500	560	44.4	139.6	7.42	3.42	0.64	0.44	409.0
3	550	616	48.9	150.9	7.93	3.71	0.66	0.48	444.1
4	600	672	53.3	162.1	8.42	4.00	0.67	0.52	479.3
5	650	728	57.8	173.4	8.87	4.31	0.69	0.56	514.5
6	700	784	62.2	184.7	9.30	4.62	0.70	0.60	549.7

Marking: P_{el} - electric power, P_e - effective power, P_{er} – relative effective power, B - fuel oil consumption, NO_x, SO_x, CO, HC, CO_2 – exhaust gas components mass flow rate

5. Predicted operating costs vs. shore connection

Mooring in the port and predicted operating costs connected with that may be easily analyzed on the basis of the electric load histogram found in the ship electric system. Fig. 8 illustrates an example of a ship's electric system load distribution while berthing in Świnoujście and Ystad.

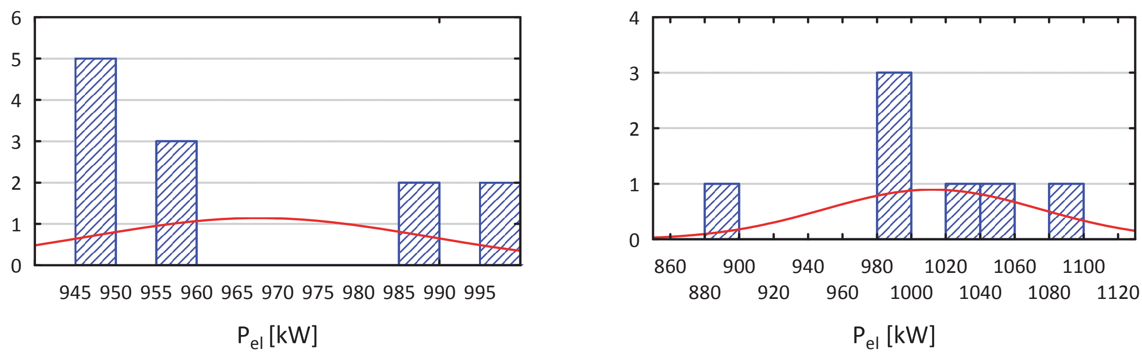

Fig. 8. Electric load histogram while berthing in the port; Świnoujście (left diagram) and Ystad (right diagram)

Operating costs connected with the ship electric energy generation can be reduced at this preliminary stage to the costs of fuel consumed by diesel engine generators.

Summarized, fuel oil expenditures and predicted land electric energy costs presented in Tab. 6. The costs of the engine maintenance resulting from the engine running hours and its costs have not been included.

Tab. 6. The cost comparison between the vessel electric supply system and land electric grid

No.	Port	Electric load	Hotelling	Fuel amount	Electric power consumption	Energy costs ship*	Energy costs land**
		kW	hrs	kg	kWh	$	$
1	Świnoujście	950	3	804 kg	2850	724	356
2	Ystad	1000	7	1954 kg	7000	1759	678
TOTAL		1950	10	2758 kg	9850	2483	1034

**LSMGO (0.1% Sulphur) – Rotterdam [10]*
***Europe's Energy Portal [11]*

6. Conclusions

The preliminary analysis of the shore connection concept for Ro-Pax ships at ferry terminals in Świnoujście and Ystad shows the existence of a technical possibility to build such a system. The ship electric system performance measurement, extended by the measurement of auxiliary engine and heating boiler emission, allows to evaluate the influence of ships lying in the port over the natural environment. The measurement was made in the ship's standard operating condition so the results illustrate realistic levels of the exhaust gas emission and the quantity of consumed fuel. Exclusively, the operating costs of electricity production onboard the ship shows substantial higher value than supplied from shore. For evaluated typical Ro-Pax vessel – m/v Skania specifically, fuel oil expenses are roughly 140% higher than predicted land electricity energy bill. The next evident advantage of shore connection are environmental issues and exhaust gas emission reduction form uncontrolled diesel engine generators. To estimate all economic matters, taking into account port electricity assembly construction and ship's system investments further examination is expected.

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