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Integrated power systems in small passenger ships

Lidija Runko Luttenberger[1], Ivica Ančić[2], Ante Šestan[2], Nikola Vladimir[2]

[1]*Komunalac d.o.o., St. Lipovica 2, 51410 Opatija, Croatia, lidija.luttenberger@komunalac-opatija.hr*
[2]*University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Lučića 5, 10000 Zagreb, Croatia*

Abstract

This paper deals with the application of integrated power systems in small passenger ships. Namely, integrated power systems were up to now mostly used in naval and large passenger ships, primarily for financial reasons. However, despite their complexity, such systems allow for much more versatility and their application in small passenger ships seems to be advisable in the context of environmental issues. Environmental aspects of maritime transportation are discussed, the needs for environmentally-friendly ships in the Adriatic Sea are elaborated and a review of actual IMO Regulations is provided, pointing out the effects of introducing new fuel-efficient and electrified ships. Different power systems of a ferry operating in the Adriatic Sea are analyzed in detail, with particular emphasis on gas emissions. Direct mechanical propulsion system and integrated power system in real operating conditions are considered and some advantages and drawbacks of both are examined. Finally, discussion of the results is presented and valuable conclusions are drawn. It should be mentioned that selection of proper power system, based on a holistic approach, can significantly reduce environmental pollution without affecting ship operational characteristics.

Keywords: integrated power system, hybrid propulsion, passenger ship, pollution prevention

1 Introduction

Shipping offers many advantages over the land-based transportation modes. It is more energy efficient, in certain respect could be even more environmentally-friendly and shows better safety record than other types of transport. Maritime transport uses so to say a no-cost infrastructure, the sea. Also, maritime transport and ports take up less unspoiled land and require much less impervious surface. It is the way of mitigating highway congestion and reducing highway noise, and rescues the communities from being split by roads, orienting them toward their waterfronts [1,2,3].

However, shipping should still meet environmental challenges in achieving sustainability, it being associated with a number of negative externalities. Besides greenhouse gas emissions, the emissions to air - such as sulphur dioxide, smog-forming nitrogen oxides and black carbon - are typically very high for shipping, especially when no abatement technologies are applied, with coastal zones and port communities being the worst affected. Besides atmospheric pollution, the share of shipping in the environmental impact is also through noise emissions, as well as underwater noise. Shippers could improve their environmental performance by lowering ship emissions while at port, where most of their external costs occur [4] by using shore power (cold ironing). However, in light of the advances in battery technologies and the commercialization of electric and hybrid cars, such solutions could be viable for ship propulsion as well, resulting in performance benefits, fuel savings and emissions reduction, which should obviously be weighed against capital investments, limitations in range and safety. Hybrid power systems avoid operation at low and varying loads resulting in decreased energy efficiencies and increased specific emissions loads by using the battery as an energy buffer that absorbs the load variations [5].

These new regulations and the possibilities of new energy efficient ship designs are considered within the paper. Concepts of "green" small passenger ships already exist. Still, main barrier is financial and is dependent on particular features of each region. Specific exploitation conditions require holistic approach in ship power system design. This leads to integrated power systems that have been used primarily in naval ships. They are now common in large cruise ships, and are under consideration for smaller passenger ships and other ship types as well. Integrated power systems are more complicated, but allow much more versatility. Moreover, the paper provides detailed technical analysis of a small passenger ship with integrated power system compared to the conventional power system.

2 Need for environmentally-friendly ships in the Adriatic Sea

Croatia is a highly attractive tourist destination in the Mediterranean, having well-indented coast with numerous islands, famous protected inland water areas, a long tradition in high-quality shipbuilding, prestigious maritime training institutions and the need to protect its environment [6]. Existing historical ports in small coastal communities would be sufficient to accommodate smaller green passenger plug-in ships complying with stringent environmental standards. Local public maritime transport of passengers would certainly complement the infill of historical and abandoned port facilities, thus further contributing to the reduction of the carbon footprint of further urban development. Rerouting the transport from roads to environmentally-friendly shipping services for shuttling people and goods between local coastal communities could apply to other coastal states as well. It would certainly result in better integration of islands with regard to education, health care, markets for own agricultural and other products, lesser island depopulation, facilitating the access to insular heritage for visitors, and last but not least, exploiting solar power for propelling plug-in ships.

On the other hand, northern part of the Adriatic is very indented in the European mainland, making it all the more interesting for intense maritime transport. Therefore the need arises to foster the initiative of proclaiming it the Emission Control Area (ECA). This would allow for more stringent regulations to be applied with the view of reducing NO_x and/or SO_x.

3 IMO Regulations

Total amount of pollutants produced by small ships is much lower in comparison with larger ships, but it has to be emphasized that the pollution originated from small ships occurs mainly in and near ports. Small passenger and ro-pax ships (ferries) operate on short routes and often maneuver in ports. In these regimes the diesel engines, which are usually used for the propulsion, have very high SFOC and produce particularly high emissions of NO_x, SO_x and PM, that contributing greatly to the pollution of ports.

Marine Environment Protection Committee (MEPC), an IMO committee, adopted the Resolution MEPC.203 (62) at its 62nd session in July 2011 [7]. It includes amendments to MARPOL Annex VI and adds new chapter 4 intending to improve energy efficiency for ships through a set of technical performance standards. These include Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). If a ship complies with these standards, it will be granted the International Energy Efficiency Certificate (IEEC). For the time being, small ships (<400 GT) and ships engaged in domestic shipping are not included in new amendments of MARPOL Annex VI, i.e. EEDI does not apply to them. The reason for that is the small total amount of CO_2 produced by them, and the inability to determine the required EEDI. In many cases, port authorities adopted new regulations aiming to reduce this kind of pollution. In figure 1 the authors outline the factors which should prevail in making the ships and shipping in the Adriatic more sustainable.

IEEC is an addition to the International Air Pollution Prevention (IAPP) certificate. While IEEC certifies ships energy efficiency, IAPP certifies ships environmental eligibility considering NOx emission of diesel engines. While IEEC observes ship as a whole and applies to ships of 400 GT and above, IAPP observes only diesel engines in strictly defined conditions and applies to engines with a power output of more than 130 kW [8,9].

According to Tier II which entered into force on 1 January 2011 for engines with rated engine speed above 2000 rpm the NO_x emission limit is 7.7 g/kWh. Stricter Tier III regulation, intended for ECA-s, should have entered into force on 1 January 2016 limiting the NO_x emission for engines above 2000 rpm to only 2.0 g/kWh. But at the last MEPC session the draft amendments were prepared with a view to adoption at MEPC 66 adjusting the effective date for Tier III to 1 January 2021. [10]

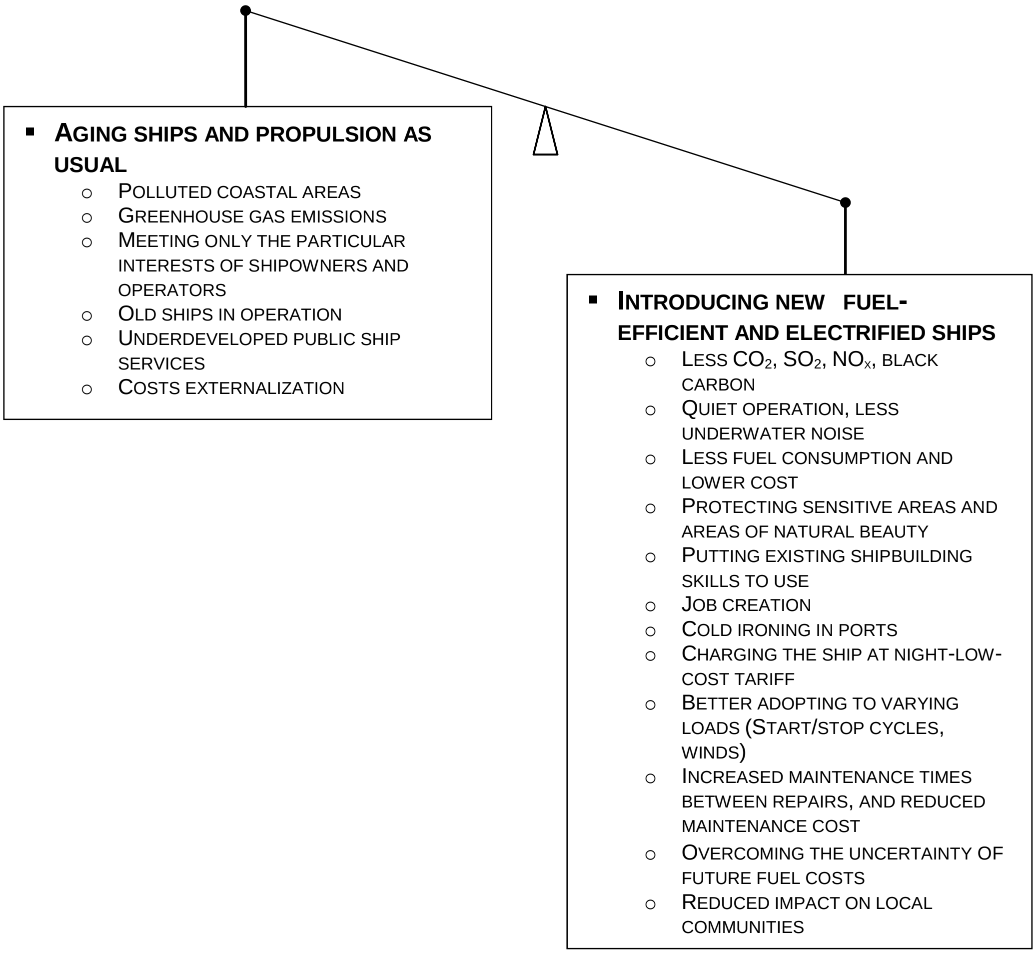

Figure 1 The effects of introducing new fuel-efficient and electrified ships

4 Analysis of the ship power system

Power system of a ferry operating in the Adriatic Sea is analyzed. Ship particulars are provided in Table 1. In this paper a route Zadar – Mali Lošinj – Zadar is observed, see table 2. It is about 60 nautical miles long and the trip in one direction lasts about 6 hours and 45 minutes. The ship is twin screw, has two MTU main diesel engines, each with rated power 570 kW and can achieve 11 kn. These diesel engines were installed prior to the introduction of the NO_x requirements from MARPOL Annex VI and they do not hold an IAPP Certificate. Since this ship is more than 30 years old, an adequate replacement is required. Since in the last 30 years regulations concerning energy efficiency and environment protection have developed significantly, today's ships have to comply with much more stringent rules. This especially applies to the marine power system.

Table 1 Ships Particulars

Ship type	Ro-Ro passenger ship
Lpp	45.6 m
Breadth	9.6 m
Draft	3.2 m
Tonnage	759 GT
Number of passengers	300
Number of vehicles	45

Two options are considered: direct mechanical propulsion system (DMPS) and integrated power system (IPS), Table 3. In DMPS two diesel engines are used for the propulsion and two diesel engines are used for the auxiliary system. In IPS every ship system is powered by the electricity produced by three diesel generators and stored in zebra type batteries. Both configurations have the new generation Caterpillar diesel engines.

Table 2 Route Zadar – Mali Losinj - Zadar

Port	Arrives	Departs
Zadar (Gaženica)		09:00
Ist (Kosirača)	11:30	11:35
Olib	12:20	12:25
Silba	13:10	13:20
Premuda (Krijal)	14:00	14:05
Mali Lošinj	15:45	16:00
Premuda (Krijal)	17:40	17:45
Silba	18:25	18:35
Olib	19:15	19:20
Ist (Kosirača)	20:05	20:10
Zadar (Gaženica)	22:45	

Table 3 Prime movers

	DMPS	IPS
ME type	CAT C18	CAT C18
ME power, kW	535	372
ME speed, rpm	2100	1800
Power rating	C	A
Number of ME	2	3
AE power, kW	100	-
Number of AE	2	-
Capacity of batteries, kWh	-	60
Total installed power, kW	1270	1116

As can be seen from Table 3, the total installed power of IPS is about 10 % lower. It has to be noted that this is not accidental. Engines in DMPS must have power reserves sufficient for sailing in rough weather when propeller's curve changes. Because of that, engines can not achieve full speed and thus full power, and must have sufficient power at lower speed. In IPS, engines operate at constant speed and can achieve maximum power regardless of propellers curve. So actually, power available for propulsion is greater in the IPS, which is very important for a ro-pax ship caught in rough weather. It has to be noted further that these engines are of the same type, but with different power rating. Power rating A applies to vessels operating at rated load and rated speed up to 100% of the time without interruption or load cycling. Power rating C applies to vessels operating at rated load and rated speed up to 50% of the time with cyclical load and speed. Also, in DMPS two auxiliary engines are installed, but only one is in operation, while the other is on stand-by.

Tables 4 and 5 present the data on NO_x emission for diesel engines in IPS and in DMPS arrangements. According to the NO_x test cycle prescribed by the NO_x technical code [11], CAT C18 in the DMPS has the NO_x emission of 6.22 g/kWh at E3 test cycle. In the IPS CAT C18 has the NO_x emission of 4.54 g/kWh at E2 test cycle, which is about 27 % lower. But the SFOC at 75 % of MCR of the engines in the DMPS is 212.8 g/kWh, and is lower compared to the engines in the IPS which have SFOC 228.8 g/kWh.

Table 4 D2 Cycle for IPS main engine

Speed rpm	Power kW	NO_x kg/h	NO_x g/kWh
1800	372	1.958	5.246
1800	280	1.123	4.020
1800	186	0.758	4.069
1800	93	0.637	9.828

1800	37	0.391	10.544

Table 5 Cycles E3 and C1 for DMPS main engine

Speed rpm	Power kW	NO_x kg/h	NO_x g/kWh
2100	535	3.413	6.378
2100	402	2.316	5.768
2100	268	1.506	5.624
2100	54	0.443	8.197
1913	402	2.470	6.144
1681	268	1.720	6.418
1500	433	2.630	6.074
1500	325	1.967	6.054
1500	217	1.288	5.943
1324	134	0.780	5.821
600	idle (4.5)	0.106	23.534

During the route described in Table 2, some characteristic regimes can be observed:

- Sailing at cruise speed
- Sailing at reduced speed while approaching a port
- Maneuvering
- Boarding of passengers
- Sailing at reduced speed while leaving a port
- Waiting in port

While sailing at cruise speed in the DMPS, main engines are 75 % loaded and the ship sails at 10 kn. Only one auxiliary engine is in operation, at the load of only 25 %. Diesel engines in IPS have to produce slightly greater power to cover losses in the propulsion power transmission due to the mechanical-electrical-mechanical energy transfer.

When approaching a port, the ship has to reduce speed to 2 kn. This is required by port authorities for safety reason. In the DMPS main engines load is very low and it can be observed from Table 5 that their specific NO_x emission is particularly high. Also, one auxiliary diesel engine has to be in operation to provide necessary electric power on board. On the other hand, in the IPS batteries satisfy the ship's power needs in that regime. In this way both the fuel consumption and the NO_x emission are reduced. During calm weather, excessive maneuvering is not necessary. In rough weather, the DMPS is especially pernicious for public health since the NO_x and the PM emissions during maneuvering are the highest. These effects are not visible in the NO_x technical file since these regimes are not a part of the test cycle. The IPS, especially if additional power sources are used (such as batteries), is much more environmentally-friendly and, if well designed, able to turn off the diesel engines. During boarding of passengers main engines in the DMPS could also be turned off. But, since the time required for boarding of passengers is usually 5-10 minutes, main engines are rarely turned off. Auxiliary engine load is increased to 50 % in this regime. In the IPS diesel engines could be turned off. While leaving a port, in the IPS one diesel engine would have to be operating to cover ship's power needs and to recharge batteries. While waiting in the port of Zadar before 09:00 and after 22:45, in the DMPS main engines are turned off and only one auxiliary engine is operating. In the IPS diesel engines can be turned off since batteries can provide necessary power.

5 Results and discussion

Results of the analysis are presented in tables 6 and 7. They reveal a great benefit from the IPS. Its NO_x emission during one day is about 31 % lower. Transient states during maneuvering could not be analyzed since this kind of measurement is not conducted in the test cycle for the IAPP Certificate. If these regimes were included in the analysis, the difference between the IPS and the DMPS NO_x emission would be even greater. But even without these regimes, a significant difference in the NO_x emission in and near ports can be observed. There the ship with DMPS emitted about 3.64 kg of NO_x, while the ship with IPS only about 1.64 kg, that being about 55 % lower. This represents a significant reduction in the NO_x emission and air pollution.

Fuel consumption of the IPS is slightly higher while sailing at 10 kn due to the losses in the power conversion. This is somewhat compensated while in and near ports when diesel engines are turned off. Batteries in the ship could also be recharged by cold ironing which would reduce fuel consumption. Some other innovative energy efficient technology could also be used, like power cells [12]. Also, since diesel engines in the IPS have power rating A, their maintenance interval is much longer so the maintenance cost is much lower.

Additional diesel engine, batteries and propulsion electric motors in the IPS increase weight, but allow that weight to be distributed in the ship more evenly. Since the capacity of this type of ship is limited by space, and not by displacement, this added weight does not have a significant impact on ship's carrying capacity.

Table 6 Total emissions DMPS

		Specific NO_x emission g/kWh	Power required kW	Total hours in operation h	Total emission kg
Sailing 10 kn	Main engine	6.144	803	9 h	44.40
	Auxiliary	9.828	25		2.21
Sailing 2 kn port approaching	Main engine	23.534	9	1 h 50 min	0.39
	Auxiliary	9.828	25		0.45
Boarding	Main engine	23.534	idle	1 h 5 min	0.23
	Auxiliary	4.069	50		0.22
Sailing 2 kn port leaving	Main engine	8.197	110	1 h 50 min	1.65
	Auxiliary	9.828	25		0.45
Waiting in port	Main engine	-	-	1 h	-
	Auxiliary	9.828	25		0.25
Total in open sea					46.61
Total in and near ports					3.64
Total					50.25

Table 7 Total emissions IPS

	Number of engine	Specific NO_x emission g/kWh	Power required kW	Total hours in operation h	Total emission kg
Sailing 10 kn	3	4.020	917	9 h	33.18
Sailing 2 kn port approaching	-	-	35	1 h 50 min	-
Boarding	-	-	50	1 h 5 min	-
Sailing 2 kn port leaving	1	4.069	220	1 h 50 min	1.64
Waiting in port	-	-	25	1 h	-
Total					34.82

6 Conclusion

The analysis in this paper confirmed one of the benefits of the IPS, their lower NO_x emission. The difference between the DMPS and the IPS proved to be even slightly higher than the NO_x technical code indicated. This is due to the specifics of the route and the use of batteries in the IPS. These specifics also revealed another great benefit, much lower NO_x emission in the area in and near ports. There the NO_x emission was reduced by more than 50 % which undoubtedly represents a major step towards the port air pollution reduction. The IPS configuration analyzed in this paper is only one of the possible configurations so perhaps another configuration would prove even more environment friendly. The selection of a proper power system, based on a holistic approach, can significantly reduce environmental pollution without affecting ship operational characteristics.

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Authors

Lidija Runko Luttenberger started her mechanical engineering education in Sao Paulo, Brazil and she graduated at the University of Rijeka in 1983. In 2010 she was conferred PhD in environmental engineering at the Technical Faculty of the University of Rijeka. She worked in the Shipbuilding industry 3. Maj as vice-president and is presently employed in the municipal utilities company of Opatija.

Ivica Ančić graduated in Marine Engineering at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb in 2011. Currently he is preparing a PhD thesis on the subject of energy efficiency and environmental impact of ship’s integrated power systems.

Ante Šestan is full professor and the head of the Chair of Marine Engineering at Faculty of Mechanical Engineering and Naval Architecture at University of Zagreb, Croatia.

Nikola Vladimir, graduated in Naval Architecture at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb in 2007, and obtained his PhD degree in 2011 at the same university. Currently holds the position of Senior Research Assistant.