Feasibility analysis of shaft generators application for optimum electric power generation at sea in new built ships

J. Listewnik
Institute of Marine Propulsion Plants Operation, Maritime University of Szczecin, 70-500 Szczecin, Poland

Abstract

The paper reviews and analyses today's applied and practically feasible methods of electricity production on board ships. Technical, economical and last but not least ecological aspects are taken into consideration during a pros and cons selection process for the optimum electricity generation installation. A revision of opinion on the unifuel ship concept is made in the light of expected annex to Marpol 73/78 (Marine Pollution) which will impose means of reducing air pollution from marine sources.

Finally the paper contains also a very thorough economical appraisal of various electrical power generation alternatives. Examples based on realistic data reveal the normally hidden investment costs as far as it concerns a delivered to the shipyard classical diesel generator sets (D.G.). If a price comparison is made between the investment cost of a HFO diesel generator set and a shaft driven generator of a hydro-mechanical option the price gap normally immensely exaggerated by the HFO D.G. protagonists dwindles away to a figure allowing recover the additional investment after approximately 3-4 years, this applies for cases where the required electricity production is in the range 300-600 kW but for electrical powers exceeding 1000 kW the shaft generator is a cheaper solution.

1 Introduction

Electricity supply on board ships is not just an auxiliary duty. The production of electrical energy for ship operation purposes requires a certain defined amount of fuel.

With the continuous increase of fuel prices and at the same time growing installed electrical power which may constitute from 6% to even 40% of the main engine output on certain type of merchant ships (e.g. container ships with a large number of refrigerated containers), minimalization of electricity production costs has gained in the last decade a vital meaning, hence a steady progress in electricity production methods on board ships built in shipyards all over the world.

The traditional ship's power plant system consisting of 3 diesel generators run on diesel oil is now often replaced by other design solutions, in order to obtain the best economical results during ship operation.

Other means of electricity production are main engine driven shaft generators as well as steam driven turbo-generators. The selection of a ship electricity production system depends generally on type and size of the ship but particularly on the magnitude of installed main engine power.

The obtainment of the cheapest electrical energy produced by a turbogenerator is unfortunately limited by the magnitude of the main engine power installed on board a ship. It is generally accepted that for a 2 stroke slow speed engine installation the engine power must exceed 20 000 kW and for a 4 stroke medium speed engine 12 000 kW or so, thus only at higher engine outputs turbogenerators or/and exhaust gas power recovery turbines exploiting surplus of exhaust gas can be arranged to drive alternators in conjunction with the main engine or independently. Turbogenerators producing electrical energy from waste heat are adding to the complexity of the ship's propulsion plant and require a high initial investment input, as well as higher skills from the engine crew, therefore shipowners are these days more reluctant to install a turbogenerator even if this is feasible.

2 General Selection Criteria of Ship Electrical Power Plant Type

When the selection is limited to ships where the main engine output (2 stroke – slow speed) is below <20.000 kW or so, then for such ships the following configurations of ship electrical power generation systems are the only possible alternatives (for propulsion plants with fixed pitch propeller).

1. 3 Diesel Generators burning Marine Diesel Oil (MDO)
2. 3 Diesel Generators burning Heavy Fuel Oil (HFO)
3. 2 Diesel Generators burning MDO, 1 Main Engine driven Shaft Generator of constant frequency type
4. 2 Diesel Generators burning HFO, 1 Main Engine driven Shaft Generator of constant frequency type as under p.3.

Out of the four mentioned alternatives of electricity production on board, Alternative "1" is due to the high marine diesel oil price economically least profitable and is therefore generally at present not considered during the design stage of modern ship machinery plant. So further only Alternatives "2", "3" and "4" are considered.

The choice of a constant speed shaft generator is between a shaft generator of electronic or electric nature – i.e. thyristors and a synchronous condenser or of rotary type, the other choice is a mechanical – hydraulic type of shaft generator i.e. an epicyclic (planetary) gear which is a variable gear system equipped with a hydraulic speed compensation maintaining constant frequency of the alternator with varying main engine revolutions from 100% down to 70% of its nominal revolutions. A typical example of that kind of shaft generators are the made by Renk Tacke in Germany (Augsburg).

The shaft generator with the variable planetary gear drive system having an efficiency of 88% – 92% (compared with only 76% to 83% of the rotary or thyristor frequency convertor) without a complex set of electrical – electronic appliances is an excellent alternative to the electrical converter, being generally as well a 20% or so cheaper investment [1].

The strong points of shaft generators application on board ships are numerous and well known to shipowners it's enough to mention that the shaft generator is producing electrical energy with a 20% higher efficiency than the traditional diesel due to lower specific fuel consumption, i.e. 30–40 g/kWh less when compared with a diesel gen. set (see data in table 2).

The maintenance costs are significantly lower for the shaft generator by a ratio 1:15 when compared with a HFO diesel generator. Replacing one of the diesel generators by a shaft generator we safe on costs involved with erecting a separate foundation for a diesel generator, we safe also on fitting a separate cooling water system, exhaust gas system and a heating water piping system from the main engine to the diesel generator for stand by readiness.

When installing HFO diesel generators there is also a need of having a lubricating oil purification system (lub. oil purifier, oil heater, piping, control fittings etc.). The required above mentioned extra items in a HFO diesel generator system (3 HFO D.G) where a shaft generator is not envisaged are making up the necessary installation costs thus increasing the total cost of a D.G. set., therefore when comparing investment costs a shaft generator versus a HFO D.G. set, realistic figures should be considered like those quoted in table 2. From table 2 it becomes obvious that the investment cost difference between alternative "2" the todays still often favoured choice and alternative "4" is only about $110x10^3$\$ lower if a side mounted on the main engine BW III/RCF type shaft generator is applied. But if space restrictions are not essential and a free standing connected to the fore end of the main engine shaft generator of a BW II/RCF type is used then alternative "4" is a lower investment cost.

Last but not least a shaft generator installed on board ships can also act in a reverse manner, namely as a shaft mounted electric motor driven by electric power supplied from conventional diesel generators. This is a very valuable contribution to the ship's utmost safety giving total redundancy in the event of main engine failure, in such a case the shaft generator can act as a so-called "take home" propulsive power for single – engined ships.

Finally it is also worthwhile to mention that in considering various selection criteria the reliability aspect should be given preference. Shaft generators especially these of the mechanical – hydraulic type have a high degree of reliability, the statistical TBF (time between failures) according to service experience of Renk Tacke is over 30.000 hours [2] what is more than four years of ship operation.

3 Economical Analysis of Feasible Electricity Production Plant Alternatives for a 12 – 16 000 DWT Bulk Carrier Series

Parameters which influence the economical analysis evaluation in a choice of an electric power generation plant on-board a ship are as follows: 1) Initial (capital) investment cost, 2) Machinery installation cost, 3) Fuel and lub. oil consumption cost, 4) Market rate of interest & inflation rate, 5) Overall efficiencies of power generation set 6) Magnitude and profile of electricity consumption at sea and in port, 7) Consumable (spare) parts cost, 8) Maintenance time (man-hours required for maintenance).

The above mentioned parameters can be evaluated quantitatively, other which are qualitative nature but not less important in everyday operation should also be taken into account namely such as: 1) level of noise and vibration, 2) cold start performance (start-up time, preparation time for standby, etc.), 3) difficulty of operation, 4) assurance of recovery from random failures in minimum time, 5) recurrent frequency of trouble, 6) technical knowledge and skilled work required for operation and maintenance, 7) ease of inspection.

The presented economy program comprises all before mentioned quantifiable data and is exemplified by means of a simple case study in tables 1&2, and Fig.1. The quoted case was chosen purposely to make evident contrary to some prevailing in certain circles of shipowners misapprehension that a shaft generator (especially if a ship requires a smaller amount of electrial energy < 500kW) is a very expensive extra investment which cannot be recovered within the ship 20 years or so life. A belief that 3 generator sets run on HFO are the best and optimum choice in making a unifuel ship has not stood the proof as calculations based on true and realistic figures indicate. The made analysis leaves no doubts that even for a relatively small electrical power demand on board the proper choice is: 2 diesel gen. operating on MDO and a shaft generator using HFO. The extra investment if any for a shaft generator will be paid back in a relatively short period depending on the fuel prices difference between MDO and HFO. The net present value relative to alternative 1 (Fig. 1) shown as function of years in service after investment, indicate, based on the data given that the shaft generator is the best one economy - wise, giving the shipowner substantial savings. Going back to last years trendy fashion to install on ships heavy fuel diesel generators it can only be said that this is for today a wrong design step. In brief it can be stated that soon the environmental aspects will impose on ships certain restrictions concerning the pollution of air by nitric oxides (No_x) and sulphur oxides (SO_x).

The International Maritime Organisation (IMO) will call for So_x reduction of all new marine diesel engines > 100 kW, the initial goal of a 50% So_x reduction

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by the year 2000 will be required for designated "special areas" like harbours, coastline areas etc. Having these developments in mind there is no good reason for a shipowner to buy 30% or so more expensive HFO diesel generators to burn in ports MDO therefore proposed alternative "3" is the optimum solution.

For ships with higher electricity demand like larger container ships, installation of a shaft generator is a straightforward solution, as price comparisons for shaft generators (Renk Tacke) and diesel generator sets (MAN -B&W - A/S Alpha Diesel) show that if the required electrical powers are in exess of 1000 kW then the free standing diesel generator sets are becoming more expensive then shaft generators of comparable power output e.g. a Renk Tacke 1400 kW shaft generator cost is about 1.200.000 DM wheras a Alpha Diesel Holeby generator set cost (inclusive 30% installation costs) amounts to 1.300.000 DM.

4 Summary

This paper illustrates that there is a quite comprehensive techno-economic method to assist in making an optimum choice when selecting various technically possible alternatives for a ship's electrical power plant. As demonstrated it is possible to obtain by taking into detailed consideration all various quantifiable and un-quantifiable factors of technical-economical and environmental nature an optimum electrical power plant configuration. With the optimum choice for all ship's engine room systems and optimum operation can the shipowner expect to get the best return on his investment.

Literature

[1] Prof. G. Grossman – "Evaluation of Electric Power Generation Systems for Container Ships with High Cooling Capacity" – ICMES'87

[2] R.Peter – "Development of Mechanical Superposition Systems for Current Generation Aboard Vessels", ISME Kobe'90, Kobe October 1990.

Table 1. Alternative prime movers for electricity generation on board a 17.000 DWT bulk carrier with a maximum electrical power consumption 350 kW.

Type of Alternator Drive	Maker	Type	No. of cyl.	Output MCR (kW)	Revs. r/min	Specific Fuel Oil Consumption (SFOC) g/kW (g/BHPh) 100% MCE						Price[1)] $x10^3	Fuel
						100% MCR W_d = 42700 kJ/kg		W_d = 40000 kJ/kg		50% MCR W_d = 40000 kJ/kg			
Diesel Eng.	Sulzer	A20	6	570	900	206	151.5	——		——		177.5	MDO
Diesel Eng.	Sulzer	S20	4	580	900	194	(143)	207	(152)	218	(160.3)	288	HFO
Diesel Eng.	Wärtsila	R22	4	560	750	192	(141)	205	(151)	216	(159.3)	292	HFO
Diesel Eng.	MAN-B&W	L23/30E	5	550	750	193	(142)	206	(151.5)	222	(163.3)	325	HFO
Shaft Gen.	RENK TACKE	BW III/RCF	–	411[2)]	1800	175[3)]	(126) (128.7)	187	(137.4)	184[4)]	(135.3)	540	HFO
Shaft Gen.	RENK TACKE	BW II/RCF	–	411[2)]	1800	175[3)]	(128.7)	187	(137.4)	184[4)]	(135.3)	400	HFO

1) Prices valid for mid 1995 quoted by Szczecin Shipyard (Poland) based on offers from particular producers of equipment in question. Prices do not include installation cost.

2) Max. power taken by the shaft generator of installed power 450 kW from the M.E. at shaft generator overall efficiency $\eta_{S.G.}$ = 0,90 shall be:

$$\frac{370}{0,90} = 411\,kW.$$

3) Specific fuel oil consumption of M.E. (MAN B&W) L50 MC at MCR.

4) Specific fuel oil consumption of M.E. at service load 85%.

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Table 2. Electricity Production on Board Ships,
Investment and Operating Costs Calculations.

	Alternatives			
	1	2	3	4
Elect. Consumption Max.: (kW) Average: (kW) in port at sea	370 200 300	370 200 300	370 200 300	370 200 300
Investment Cost x10^3 $	639.0[1]	1160.0[2]	966.0[3a] 826.0[3b]	1270.0[3a] 1130[3b]
Difference in Investment Costs x10^3 $	0	+521.0	+327.0[3a] +187.0[3b]	+631.0[3a] +491.0[3b]
Engine SFOC (g/kWh)[8] in port at sea	230[4] 180	235[4] 216	230 D.G[5] 184 S.G	230 D.G[5] 184 S.G
Fuel Consumption in port (t/day) at sea	1.22 1.74	1.25 1.73	1.22 1.47	1.25 1.47
Fuel Use /year	assumed – 110 days in port, 250 days at sea			
in port (tons) at sea Total:	134.2 435.0 569.2	137.5 432.5 570.0	134.2 367.5 501.7	137.5 367.5 505.0
Fuel Cost/year x10^3 $	88.22[6] 79.68[7]	57.00[6] 42.75[7]	57.55[6] 46.35[7]	50.50[6] 37.87[7]
Cost Difference in port ($/day) at sea	Reference Base	−77.1[7] −140.0	0[7] −159.4	−77.1[7] −159.4
Yearly Fuel Cost difference in port ($/year) at sea Total:	Reference Base	−8476.0[7] −28462.0 −37208	0[7] −33337.0 −33337	−8476.0[7] −33337.0 −41813
Maintenance costs ($/year)	4560,0[9]	8400.0[9]	1705.0[9]	2878.0[9]
Total yearly operational costs $/year	92786[6] 84248[7]	60840[6] 46590[7]	60406[6] 49205[7]	52182[6] 39557[7]
Total yearly savings $/year	Reference Base	31946[6] 37658[7]	32380[6] 35043[7]	40604[6] 44691[7]
Net Present Value (NPV) x10^3 $ after n= 20 years	Reference Base	−91.6[6] −14.9[7]	+248.3[6] +284.0[7]	+54.9[6] +108.8[7]

Remarks: relevant to table 2:

1. 3 Diesel Gen. Sets with 6 cyl. Sulzer A20 engines at price 177,5 x 10^3 \$ each, to total investment costs added are installation costs ~ 20% of one Diesel Gen. Set price. The system does not require a separate lub. oil purification system. Price of 1 Diesel Gen. Set with installation is then $177{,}5 \cdot 10^3 + 0{,}2 \times 177{,}5 \cdot 10^3$ \$ = $213 \cdot 10^3$ \$.
2. 3 Diesel Gen. Sets with 4 cyl. Wärtsila R22 engines at price 292 x 10^3 \$ each, to total investment costs added are installation costs: ~ 25% of one Diesel Gen. Set price + $65 \cdot 10^3$ \$ for the l.o. purification system (lub. oil purifier, heater etc.) serving the three Diesel Gen. Sets.
3. The RENK TACKE type B III L 50/RCF 450 shaft generator cost is a) $540 \cdot 10^3$ \$ or as an alternative a BW II/L 50/RCF 450 shaft generator cost is b) 400 \$ $\cdot 10^3$.
4. Specific fuel oil Consumption at part load of Diesel Gen., (50-60%) at sea and 35% in harbour.
5. Specific fuel oil consumption – for D.G. at harbour and S.G. at sea.
6. Fuel prices April-May'95 spot Rotterdam were: MDO-155 \$/t, IFO 380 – 100 \$.
7. Average fuel prices in year '94 at Rotterdam, Singapore, New Orleans, MDO – 140 \$/ton HFO – 65 \$/t

   Alternative 1 – 3 Diesel Gen. Sets operating on MDO
   Alternative 2 – 3 Diesel Gen. Sets operating on HFO
   Alternative 3 – 2 Diesel Gen. Sets (MDO) + 1 Shaft Generator
   Alternative 4 – 2 Diesel Gen. Sets (HFO) + 1 Shaft Generator
8. To all specific fuel oil consumption figures the l.o consumption of the auxiliary engines was added i.e. 10g/kWh of fuel consumption represents the difference between 2.0 g/kWh of l.o. consumption of medium speed engines (average value for Sulzer S20) and 1.4 g/kWh of L.O. consumption by the main engine driving the shaft generator, thus there was not a correction made of fuel consumption for the M.E. L.O. consumption.
9. Assumed maintenance and spare parts costs (MAN – B&W) data):

   DG run on HFO – 15 \$/kW/year
   DG run on MDO – 8 \$/kW/year
   SG run on HFO – 1 \$/kW/year

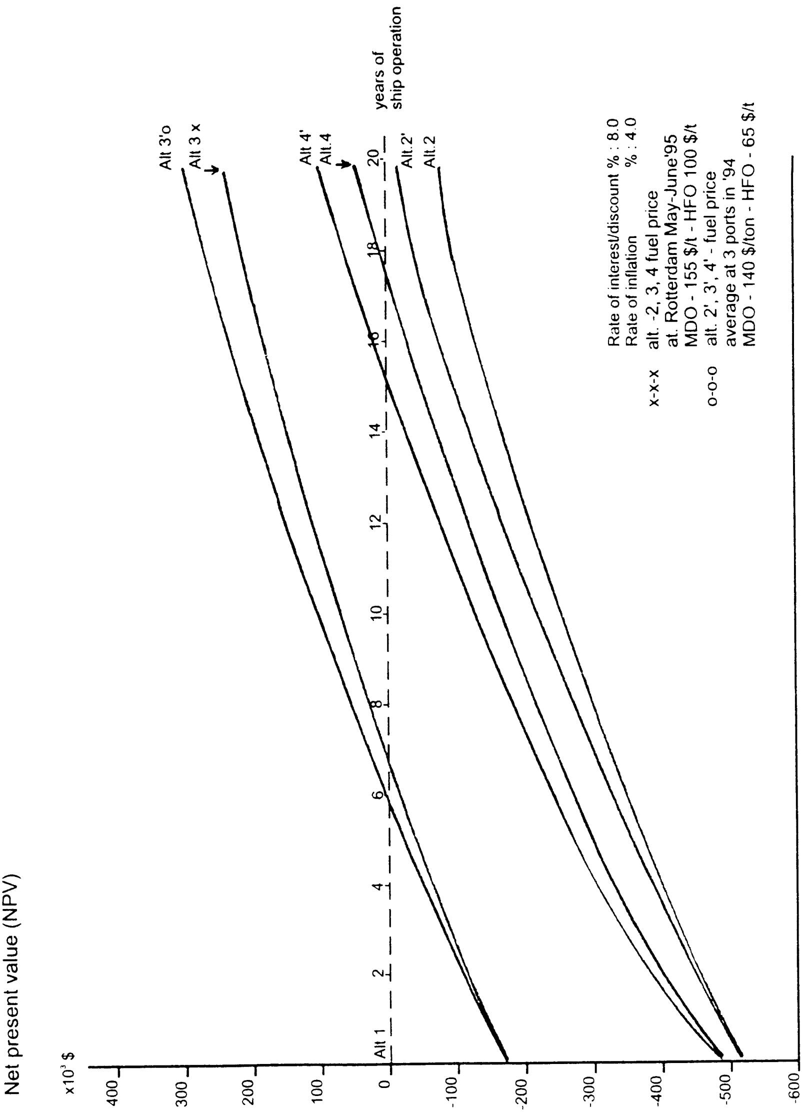

Fig. 1: NPV for alternatives 2, 3, 4 with reference to alternative 1 (for two levels of fuel prices).