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Problems of propulsion systems and main engines choice for offshore support vessels

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Abstract

It was presented the problems of configuration choice of the power system and the propulsion system for offshore support vessels during the design process. It becomes more complicated when the vessel ought to have the dynamic positioning system. Due to long term engine work on low loads (idling) during station keeping process or dynamic positioning process and possible quick and heavy changes of power demand for the industry part there is an important problem for the correct choice of the components of power system configuration. There are possible three types of propulsion: Diesel mechanical (DM), Diesel electrical (DE) and hybrid (HP). The choice has an influence on many parameters: the specific fuel consumption, the propulsion and total efficiency, the costs of vessel's operation. Some of those problems were presented.

Introduction

The design of a propulsion system (main engines, gearboxes, propellers and control systems) for offshore supply vessels is an important task. The components of propulsion system interact each other and have an influence on the vessel's performance. The most important one is an interaction between the propeller and nozzle with the hull [1].

Due to high manoeuvrability the offshore support vessels are highly powered and designed in minimum two propellers (CP propellers or active propellers). The most important parameter of OSV tug is the bollard pull. It depends mainly on the power transmitted to propellers but also other parameters like the main engine efficiency, the power losses in the propulsion system and the propeller efficiency should be taken into consideration. The different propulsion configuration giving 90 ton (900 kN) bollard pull for a twin propeller AHTS is presented in table 1.

Table 1. The different propulsion configuration giving 90 ton bollard pull for AHTS [3]

Engine		Propeller		Power density	Specific bollard pull	
Type	Power	Speed	Diameter			
–	kW	rpm	mm	kW/m^2	kg/HP	N/kW
7L27/38	2380*2	150	3300	278	13.9	185.3
8L27/38	2720*2	206	2750	458	12.2	162.6
9L27/38	3060*2	276	2400	676	10.8	144.0

The difference in power reaches up to 21% leading to the same bollard pull. An accurate determination of the bollard pull is important as a possible bollard pull guarantee.

The oceangoing OSVs have the bollard pull up to 200–300 ton. The increasing power (depending on the propulsion design) leads to the increased fuel consumption and the cost of tug operation.

Types of OSV propulsion plants

The configuration of the propulsion plant has many possibilities especially for offshore supply vessels (OSV). The propulsion plant may be divided on types as follows:

- Diesel mechanical (DM) – most popular on vessels;
- hybrid propulsion (HP) – popular on OSVs;
- Diesel electrical (DE) – becoming the most popular on OSVs.

There can be variations of multiple engines working on one shaft, multiple shafts, the number of Diesel generators, installing the electric machines on the shafts that can produce power (PTI) or take power (PTO) and all combinations between these. The interested possibility is using two engines on one shaft not equal in power with the difference in the cylinder number (father/son configuration). In some modes it makes sense to run one engine on a efficient setting, in some modes it is better to run the other one, for demand of full power run both. For example when the needed vessels speed is up to 60% of nominal works the smaller engine, when needed about 60–80% works the bigger one, in case of speed over 80% work both engines.

The figure 1 presents the possible configuration of propulsion plant for OSV (the bow and stern thrusters are in the part of electrical consumers).

The presented configuration is a hybrid type, because the electric machines may work as generators or motors. The hybrid propulsion plant combines features of Diesel mechanical system with features of Diesel electric plant. Connected to the gearbox is an electric machine which can operate in generating mode or in motoring mode. The concept has a potential of redundancy and more efficient work due to Diesel engine loads on regimes of 60–90% nominal load [3].

In essence a hybrid propulsion concept becomes attractive for OSVs when one of the following characteristics of a vessel's operational profile is the case [2, 4, 5]:

- large variations of both, required propulsion and electrical power occur, in transit mode high propulsion power demand, in dynamic positioning mode (more often) low propulsion power demand;
- maximum demand of propulsion power and electric loads do not occur simultaneously;
- the maximum electric power is determined by the auxiliary load and is not that large or constant that a fully Diesel electric system would be a feasible solution [2];
- the dual redundancy is required.

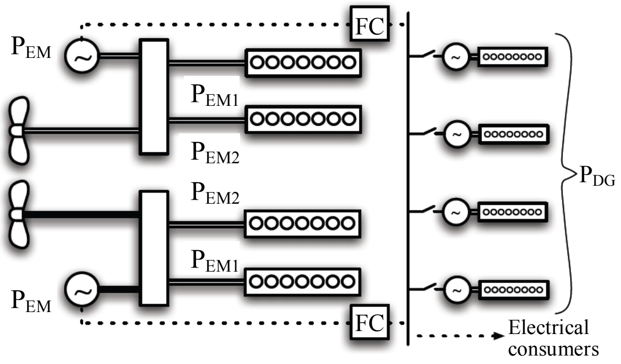

Fig. 1. Configuration of propulsion plant for OSV [2]

The vessel can be operated in one of three ways (f.e. *mv Havila Venus*, *mv Havila Jupiter* [5] up to 284 ton of bollard pull):

- full DE electrical propulsion for low speed manoeuvring, transit and low load DP;
- full DM mechanical propulsion for tugging and high-speed transit;
- hybrid HP electrical and mechanical propulsion, where electrical components can be used as a booster for the mechanical propulsion to maximize the bollard pull.

The Diesel electrical (DE) propulsion concept for OSVs becomes attractive when required the following demands (better more than one) [6, 7, 8, 9, 10]:

- cost-efficient building and installation (smaller engines as genset but more in number);
- increased safety and redundancy;
- flexible design that improves ship utilization;
- availability of propulsion and station keeping systems used for DP operation;
- minimization of the constraints lead to suboptimal performance (important during DP operation);
- lower emissions due to efficient loads of Diesel engines;
- remote and onboard support;
- high ice-breaking performance;
- low maintenance costs;
- ease to maintenance in the region of operation, often worldwide (at sea);
- reduced fuel consumption.

Reduced fuel consumption in DE propulsion plant is possible due to variable speed control of the propeller (reduces the non-load and low-load losses) and the automatic start-stop engines dependently on power demand (control of the power management system PMS) and more smaller engines working parallel (Fig. 2) [6, 11].

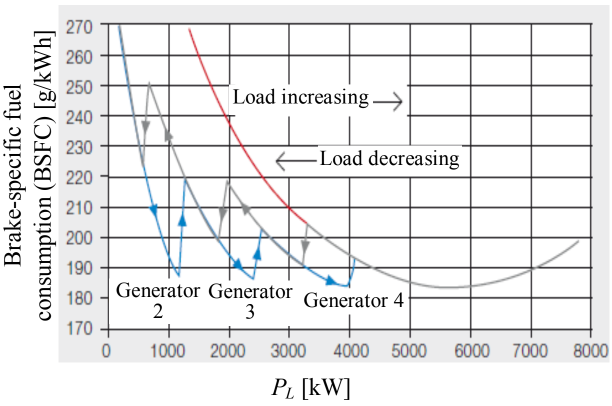

Fig. 2. Fuel consumption per kWh of produced energy for one large engine (red line) and four smaller (equal power) [6]

Four equally sized Diesel engines running in parallel, with automatic start and stop functionality of the power management system to one large Diesel engine providing the same total power are compared.

The choice of power plant configuration depends on operational profile of designed vessel. The examples of these profiles for AHTS vessels are presented in tables 2 and 3.

Table 2. An example of operational profile of the AHTS vessel 1 [2]

Number of mode	Mode	P_D (delivered power)	Auxiliary load (power)	Time of work
–	–	kW	kW	Hours/year
Mode 1	Port	0	150	438
Mode 2	Transit 16 kn	4500	650	3854
Mode 3	Transit towing	5000	1050	263
Mode 4	Anchor handling	4000	3050	964
Mode 5	Bollard pull	9600	1150	88
Mode 6	DP low	210	2490	1050
Mode 7	DP high	4100	3550	263
Mode 8	Standby low	420	890	1314
Mode 9	Standby high	1000	1120	438
Mode 10	Fire fighting	4500	5100	88
Mode 11	Failure	No data	No data	No data

Table 3. An example of operational profile of the AHTS vessel 2 (200+ ton of bollard pull) [6]

Number of mode	Mode	Time of work	Fuel consumption	
			DM propulsion	DE propulsion
–	–	Hours/year	kg/h	kg/h
Mode 1	Port	526	26	25
Mode 2	Transit supply	2190	1276	1036
Mode 3	Transit towing	1314	1898	2053
Mode 4	Anchor handling	438	2280	2295
Mode 5	Bollard pull	88	2451	2795
Mode 6	DP low	2803	1015	620
Mode 7	DP high	1402	1377	1020
Total fuel consumption per year	[kg/year]	difference 1896 ton	11,293,005	9,396,661

The probable operational profile of OSV has a decisive influence on a design process. It is better for that process to take into account the average operational profiles of a vessel group working on needed sea area. The time of transit (data in table 2) is about four times longer than the time of anchor handling (the main designed mode for AHTS vessel), for the data in table 3 it is about ten times longer and may be different for other vessels or other sea operation place and it may change accordingly to the vessel destination modification.

The difference in yearly fuel consumption is presented in table 3 for two types of AHTS propulsion: Diesel mechanical DM and Diesel electrical DE. It shows that the DE propulsion is more efficient. The difference in yearly fuel consumption is about 17% lower for DE propulsion.

The investment cost is an important factor in design process as well. Taking the indication from table 4 it is possible to estimate the investment cost of power plant components for different configurations.

Table 4. Indication for investment costs of OSV power plant components (estimated) [2]

Component	Cost [€/kW]	Remarks
Diesel engine 4-stroke	360	Line type
Diesel engine 4-stroke	340	V-type < 32 cm bore
Diesel engine 4-stroke	280	V type ≥ 32 cm bore
Diesel generator set	400	< 32 cm bore
Diesel generator set	360	≥ 32 cm bore
Electric machine	50	Induction
Single stage gearbox	30	Extra input adds ±15%
Frequency converter	120	Both PWM and LCI
Frequency converter	135	With active front end
CPP + shaftline	100	–

The data in table 4 is an example of costs but it may be utilized as estimated investment cost in a first stage of design process.

The configuration of propulsion systems for OSVs with DP systems

The offshore support vessels with dynamic positioning systems have mostly the hybrid or Diesel electric propulsion systems due to the configuration with bow and aft thrusters and often with one up to eight azimuth thrusters. The bow and aft thrusters are electrical driven. The azimuth thrusters may be mechanical or electrical driven with FP propellers or CP propellers. When the number of azimuth thruster is at least four in that case they will be electrical driven.

In case of work in long time period in transit mode or anchor handling mode the hybrid propulsion may be more efficient, when the vessels work long time period in DP modes it seems to be better the DE propulsion system (Table 3).

It must be remembered that the DE propulsion system is less efficient than DM propulsion due to the more number of possible losses (Fig. 3) [7, 8, 12]. It is true only in situation where the demand

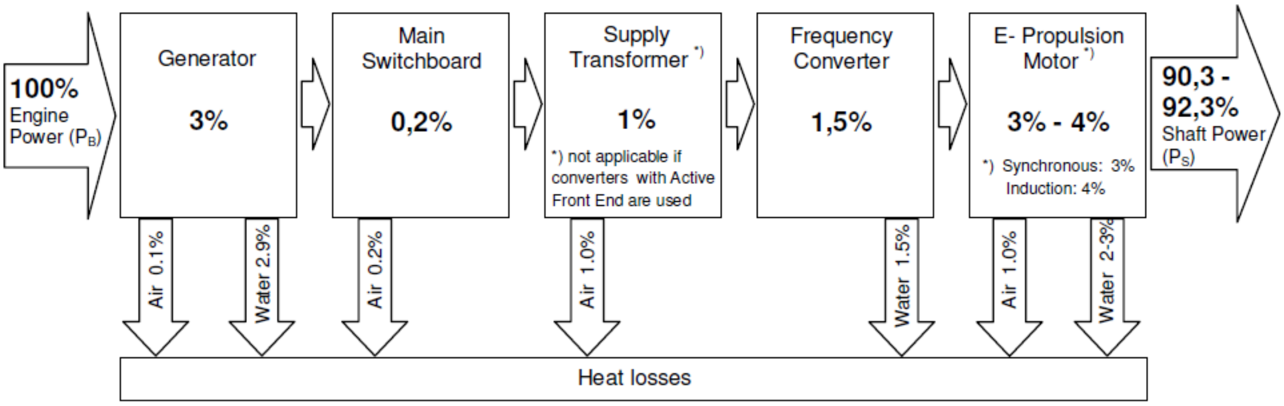

Fig. 3. The typical efficiencies and losses of standard components in DE propulsion plant [7]

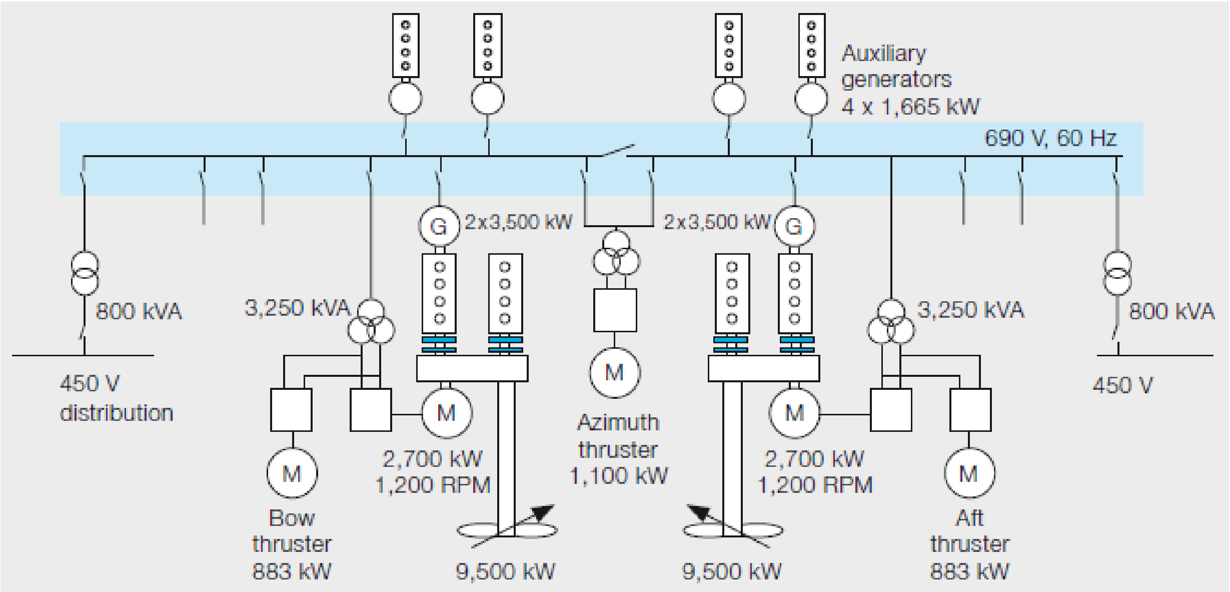

Fig. 4. Hybrid propulsion system for AHTS of 200+ ton of bollard pull [13]

for power is big estimating over 50% of nominal. In case of the demand of power below 50%, often about 10–30% it is changed because the losses in DM are biggest than in DE propulsion.

The installation costs of hybrid propulsion system are more economical than pure electrical solutions and are quite comparable in terms of fuel consumption. In case of high bollard pull demand several new AHTSs have been based on hybrid propulsion (Fig. 4).

The increased mechanical complexity of such hybrid propulsion systems needs the crew must be more active and manually select the optimum operational modes for the prevailing conditions. The crew must be actively involved in selecting the optimal configuration for varying operations.

It is much easier in DE propulsion systems to optimize the configuration of the power and the components of propulsion plant automatically. It may be ensured the system will always operate as closely as possible to optimal conditions, with or without minimal manual interaction. DE propulsion system is the norm in vessels which frequently require dynamic positioning or station keeping capability. Initially, these vessels mainly used variable speed motor drives and FP (fixed pitch) propellers [7, 10]. Nowadays, they mostly deploy variable speed thrusters. An example of DE propulsion system is presented in figure 5.

DE propulsion system offers some clear benefits compared to DM or HP propulsion. This has made it possible to increase the length of the cargo hold or other application.

It must be told that the DE propulsion system offers the benefits associated with [6, 9, 14]:

- Flexibility – the installed prime mover capacity can be used for different purposes in different situations.
- No need for separate small auxiliary generator sets.

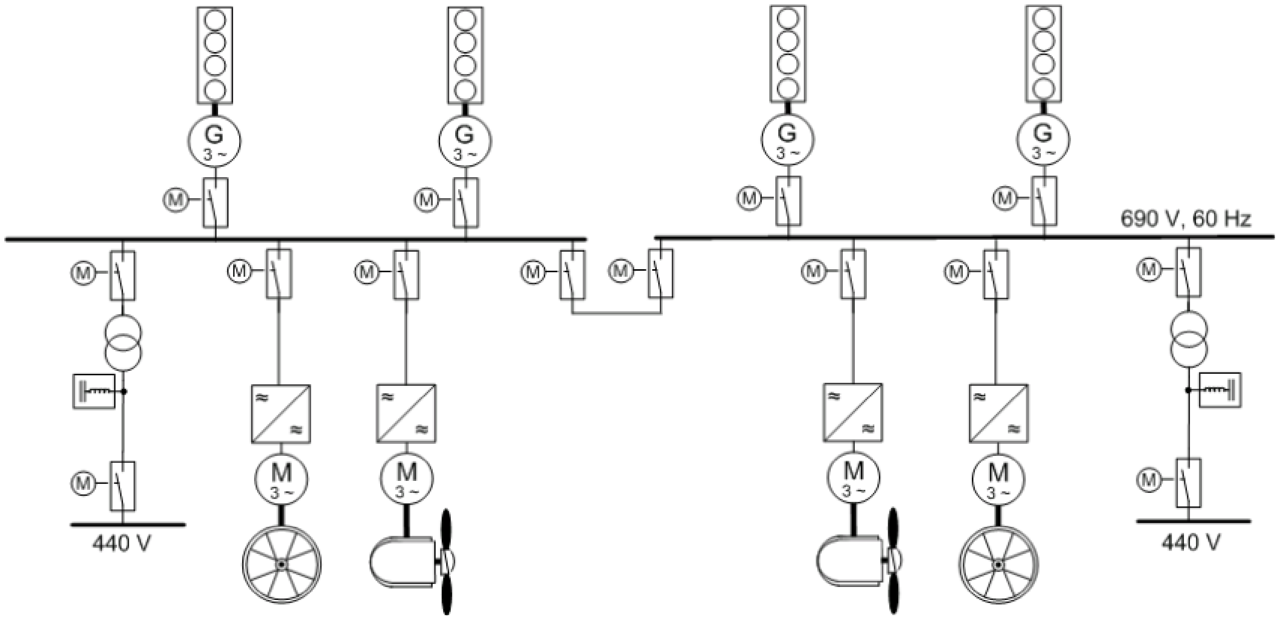

Fig. 5. An example of DE propulsion system for PSV vessel (platform supply vessel) [7]

- No need for large shaft generators to power the bow thrusters. Sufficient generator capacity is available when the bow thrusters are needed.
- The Diesel engines can be run at constant speed and closer to the optimum load to get lower specific fuel oil consumption;
- Freedom in location of generating sets.

A great number of very successful vessels use custom designed retractable transverse thrusters (mv Sedco 445, mv Sedco 417, mv Sedco 472, mv Discoverer 534). These thrusters are stored inside the hull during transit. Upon arrival at the DP location, the thrusters are lowered hydraulically into an operation position with the propeller/nozzle positioned under the hull. While tunnel thrusters can be used also for manoeuvring, a retractable thruster is usually in the stowage position during transit and manoeuvring. It must be remembered the thruster in the extended position increases the draft of the vessel and may be used up to about of 6 knots speed. After manoeuvring when vessel change to transit mode and the speed increases the retractable transverse thruster ought to be stored.

To be effective for yaw manoeuvres, during DP operation or station keeping, the thrusters are often grouped at the bow and stern of the vessel. In response to certain vector commands, situations can occur in which the thrusters are positioned in such a way that the exit jet of one thruster is directly aimed into a second thruster. The thrust output of the second thruster is greatly reduced if the propeller axis coincides. The trust deduction may reach level of 0.3–0.4. The second thruster operates in a condition of a higher advance coefficient. Thrust decreases with increased inflow velocity. This applies even if it is possible to maintain the power load on the propeller by increasing the pitch of a controllable pitch propeller or the RPM of a fixed pitch propeller. It is searching other propulsion arrangements to meet required parameters, like dynamic positioning accuracy, minimum thrust deduction [1].

The choice of manufacturer of propulsion system components

There are some factors were behind the choice of one big manufacturer for all propulsion components [4, 12, 14, 15, 16, 17]:

- the ability to procure a total propulsion package, from the same manufacturer, including main engines, gearboxes, shafting, propellers, the propulsion and management system etc.;
- the capability of having the same series engine to cover more of their propulsion power requirements on varying-sized AHTSs;
- the capability of having the possibility of interchanged ability of spare parts, trained engineers (transfers from vessel to vessel);
- the willingness to “tailor” a perfect matching propulsion package.

There are only a few meaningful manufacturers in the world and they present and advertise their own propositions of OSVs design, often with the suggestion of type propulsion system. In my opinion the analysis of propulsion systems parameters on existing vessels and the close consultancy with the owners are the better way of design the best offshore supply vessel. On the figure 6 one of the new delivered AHTSs from STX OSV Niteroi shipyard is presented.

Fig. 6. AHTS mv Skandi Vitoria delivered from STX OSV Niteroi [13]

Conclusions

The proper design of propulsion system for offshore supply vessel is still an important task.

The fulfillment, all required possibilities and accuracy of ship dynamic positioning or/and station keeping by chosen propulsion system specified in the project data, is the most important design problem to obtain the minimum investment costs. The aim of designer is the choose optimum solution of propulsion system, which is fulfills all expectations of ship owner and crew, and performs all project assumptions. The proper choice of propulsion arrangement and power system configuration for OSVs are the most important problem during design and has results in the whole time of ship exploitation [9, 15]. The proper EMS (energy management system) may cause further improvements in blackout prevention and ship safety.

In a practice, ships equipped with Diesel-electrical propulsion system, give a crew an enhanced comfort of work during manoeuvring because of their reliability and redundancy, especially when equipped in DP systems. It must be seen that unconventional thrusters have excellent future as electrical driven ones as well. The total efficiency drop of propulsion is about 6–8% in comparison with conventional propulsion system and increasing fuel consumption, but this is the only one disadvantage. Forecasted development and rise of DE propulsion systems quantity would cause increased interest of unconventional thrusters, especially azimuth thrusters. Propulsion of marine thrusters by electrical motors is more and more popular and well-founded. An improvement of propulsive efficiency with unconventional thrusters (for minimizing the efficiency drop) would take to theirs popularization and domination in the end [18, 19]. The interested solution and often applied in new delivered vessels is hybrid propulsion of OSVs, especially when it is possible that vessel can be operated in one of three ways of propulsion system: Diesel-mechanical DM, Diesel-electrical DE or hybrid HP as required the operation mode.

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