CHALLENGES OF SHIP PROPULSION SYSTEMS DURING DP OPERATIONS

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Abstract

Ship propulsion configurations with dynamic positioning systems are commonly used as diesel-electric. In particular, situations for ship transfer on longer distances may be used conventional mechanical propulsion system with controllable pitch propeller. Combination of mechanical and electric propulsion system called hybrid propulsion is met as well, where the thrusters of DP systems are driven through the gear by mechanical engine or electric motor independent or both. For the sake of the necessity of limitation of total installed power on the ship may occurred problems with power distribution between the ship propulsion and industry part. It will especially concern those situations when we need to keep power supply to the industry part and there is a necessity to increase the power delivered to ship propulsion part for the purpose of keeping the ship position or heading. The primary task of power management system (PMS) is blackout prevention in ship energetic network and so power distribution to overcome critical conditions of it. Temporarily it may occur the worsening of positioning operation accuracy without any critical situations of industry part. The possibility of momentary overloading of energetic network is primary condition of safety. The critical duration of overloading is one minute. This is indispensable time for increasing the accessible power in the energetic system through switching on the next genset to work. It is a necessity of quick analysis in critical conditions to value what key-actions ought to do in the aim of overcoming emergency situations. The next one is a usage of energy storage devices. It is possible through AC/DC conversion. It was tried to find solutions of equalization the load of gensets to the ship electric energy demand.

Keywords: *propulsion system, dynamic positioning, challenge, dynamic positioning operation, safety of propulsion system, energy storage devices*

1. Initial remarks

Ship propulsion configurations with dynamic positioning systems are commonly used as diesel-electric. This is a trend in the marine market of multimode ships. D-E systems give more flexibility in mechanical design of propulsion as well as use of different sources of electric energy. It is used the AC generators which are cheaper and have the possibility of voltage transforming. In the future, the DC-system is looked more interesting to investigate. An example of structure of ship's power plant was presented on Fig. 1. It was shown six main elements from the engines to the power receivers. The power range of ship's plant is a total sum of energy sources/producers installed on board. Commonly in D-E systems it was used 3-10 main gensets with the possibility of parallel or independent work on ship electric network. Harmonics generated by power electronics may influence main generators as well as other equipment on board and should be carefully take into analysis. The influence of power electronic converters in the grid with respect to control strategies as well as failure modes should be take into consideration too [1, 3, 4]. Nowadays in marine power systems it will arise on significance the energy storage devices due to variable in time the power demand (Fig. 2). It needs a big total nominal electric power from generators (to protect of overloading) and a big margin of electric power. Looking for the average power demand the average load of generators is often about 60-70% of nominal power.

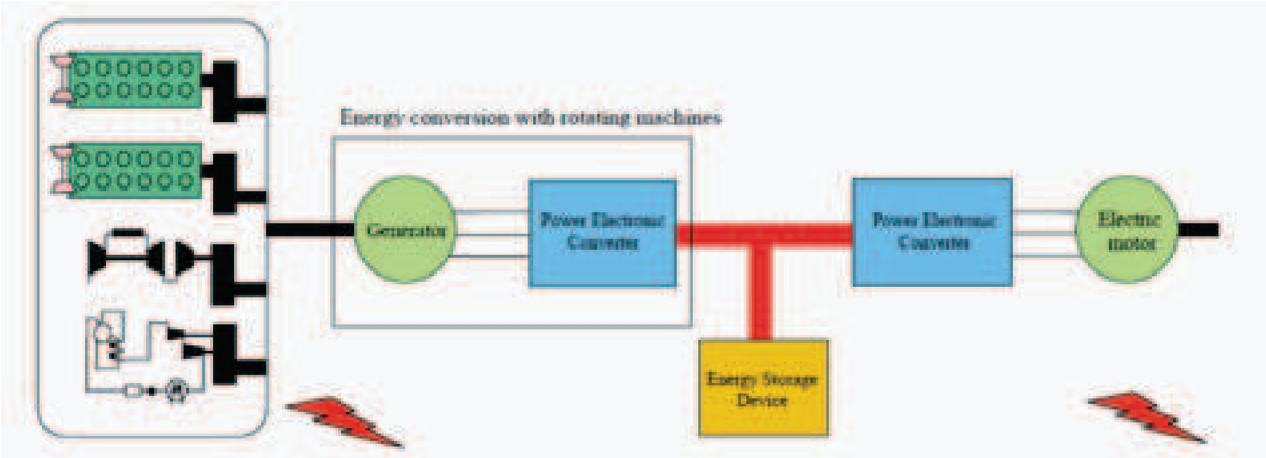

Fig. 1. Structure of combined ship's power plant [1]

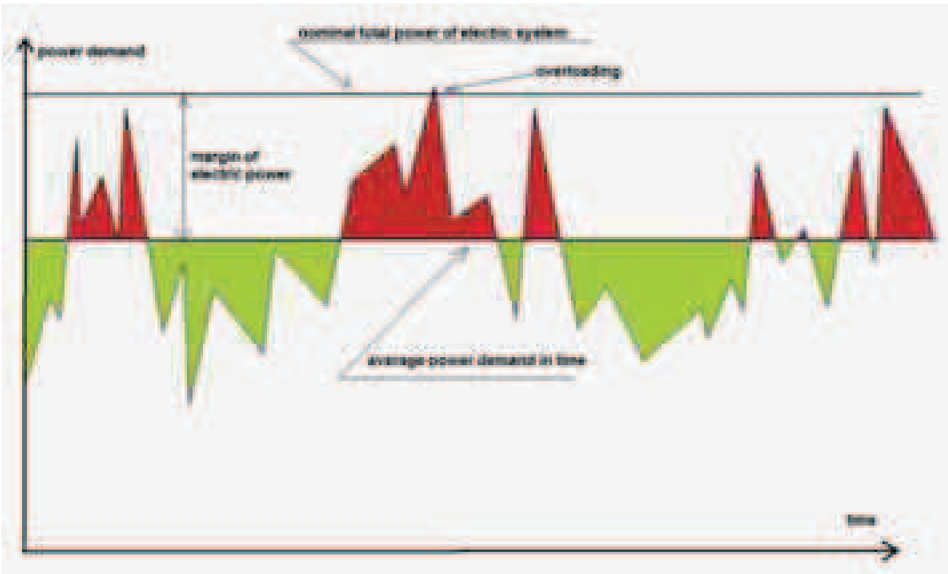

Fig. 2. An example of electric power demand during DP or drilling operations

It is a reason of increasing fuel consumption due to bigger specific fuel oil consumption (SFOC) of diesel engines working on partial loadings and often one or two more gensets work on electric network due to needed margin of power.

2. The methods of energy storage

The possibility of ship generator overloading is restricted to 110% of nominal power and time from 15 minutes up to 1 hour. In case of bigger overloading the time of generator switching off from energetic network is considerable decreasing. It depends on the level of overloading and type of ship's power management system (Fig. 3). For the exploitation reasons the minimum needed time for start the genset being on standby mode, excitation of generator and synchronization with electric network is about 1 minute. During that time the PMS system ought to prevent blackouts. Is any possibility to assist the PMS system? The simplest way is to restrict the rise rate of the load. It gives time for preparing the next genset for work. The big disadvantage of that method is the worsening of DP system quality (ship's position) and power limitation for the industry part. The second way is to switch off the less important receivers (Meyer's system) but there are only main receivers: propulsion (DP system) and industry part (i.e. drilling equipment).

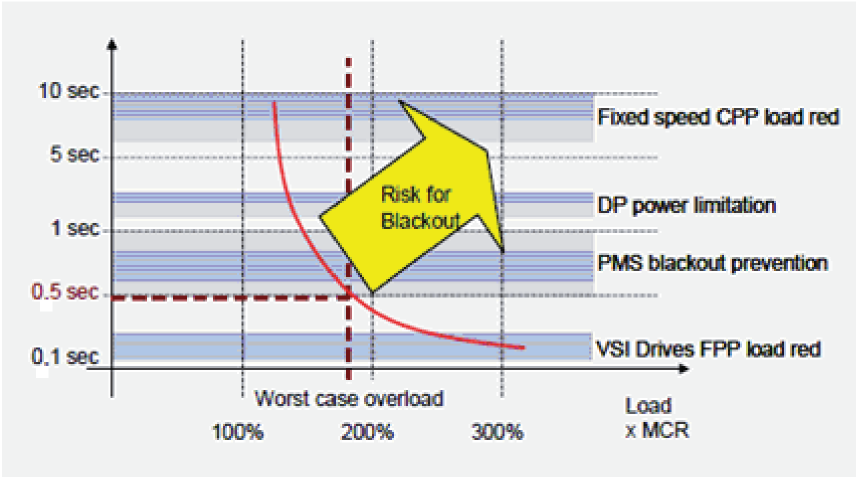

Fig. 3. Risk for blackout of different power management systems and level of overloading [9]

How to improve the power production level to the power demand? The electric systems give possibility for energy storage (Fig. 1). The types of energy storage device are:

– super capacitors,
– batteries,
– flywheels.

They need the conversion the AC energy on DC energy for storage and once more after that the conversion from DC energy to AC energy needed by receivers. An example of change in power demand is presented on Fig. 4.

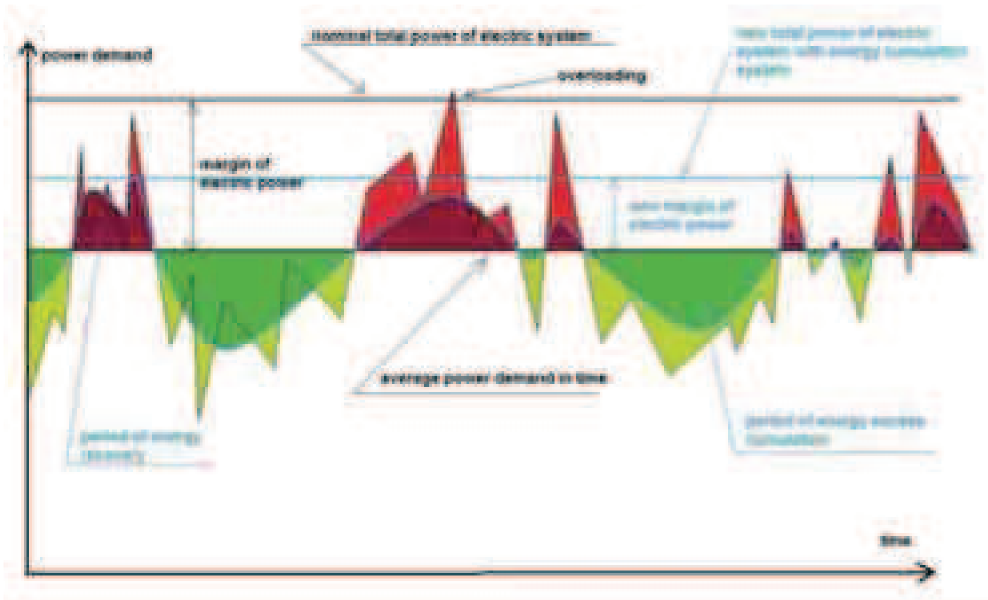

Fig. 4. The power demand with energy accumulation method

The advantage of that method is a smaller needed power margin, the average load of gensets is in the better range (decreased the total fuel consumption) and often it is possible that the number of actually working gensets would be less. The aim, what to do, is known but how to reach it. The possibility is enumerated.

The ship total power on multimode vessels is often between 20-40 MW [6]. The power deficiency may occur on the level maximum about 5 MW (the power of one nominal genset) during time for preparing the genset for work it means about 1-2 minutes. The energy deficiency is about 100-250kWh. Nowadays it is impossible to accumulate so energy in any storage device.

3. D-E ship's systems advantages

The cost of fuel in ship exploitation is the main part of all costs. It is sought methods for decreasing the fuel consumption [5, 7]. Taking into the analysis a 200+ ton bollard pull AHTS (Fig. 5) it was shown that electric propulsion systems are interesting for these types of ships.

	Fuel oil consumption		
Operation mode	Base case D-mech (kg/h)	Electric propulsion (kg/h)	Operation profile (h/year)
Anchor handling	2.280	2.295	438
Bollard pull condition	2.451	2.795	88
Transit towing	1.898	2.053	1.314
Transit supply	1.276	1.036	2.190
DP/standby HI	1.377	1.020	1.402
DP/standby LO	1.015	620	2.803
Harbor	26	25	526
Total FOC* (kg/year)	11.293.005	9.396.661	
Total FOC* (t/year)	11.293	9.397	
Difference (t/year)	0	**1.896**	

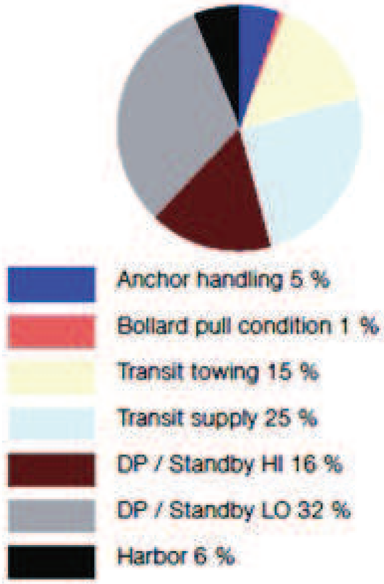

Fig. 5. Comparison of fuel oil consumption for two types of main propulsion: electric propulsion and direct mechanical propulsion for a 200+ ton bollard pull AHTS [3]

The estimate fuel oil consumption reduction is about 15%. Of course the reduction depends on the time of considered operation mode, especially increased during DP operations.

Optimum allocation of prime movers and power control for all subsystems is a field where fuel consumption, regularity and safety are very important parameters. The next advantage is a possibility of physical and functional integrity of power system and automation system (freedom in design of ships) [2, 5]. The driving forces are mainly:

- environmental considerations due to IMO regulations,
- several aspects of optimization will have to be considered due to complex machinery systems,
- technology development allows new combined power plant which can meet requirements not attainable for each component alone [8, 9];
- a complex power configuration allows for advanced protection and relaying philosophies.

4. Possibility of energy storage

A global and marine industry exists for Uninterruptible Power Supply (UPS) systems. It was needed a source of high energy in the emergency situations: inefficiency, failure, peak of power demand, etc. As it was mentioned for multi-mode vessels the needed energy storage is about 100-250 kWh with possibility of feeding during 1-2 minutes with the power up to 5 MW. This is a challenge for energy storage devices. What possibilities are available? In the Tab. 1 it was presented the storage devices and theirs basic parameters.

In marine appliances only the first three would be taken into consideration but only flywheels are best for high cyclic and high power applications. On Fig.6. was presented the energy delivered versus energy rating for battery and flywheel. It must be remembered that the battery cyclic life is reduced with high power draw and depth of discharge. The charge/discharge rate (C-rate) could be about 5-10 for flywheel.

Tab.1. Energy storage devices and basic parameters [8]

type	storage mechanism	common duration	cycles
capacitor	electrical charge	seconds or minutes	100,000’s
flywheel	kinetic energy	seconds or minutes	1000’s-100,000’s
battery	electro-chemical	minutes or hours	100’s-1000’s
pumped hydro	potential energy	hours	1000’s
thermal	ice, molten salts	hours	1000,s

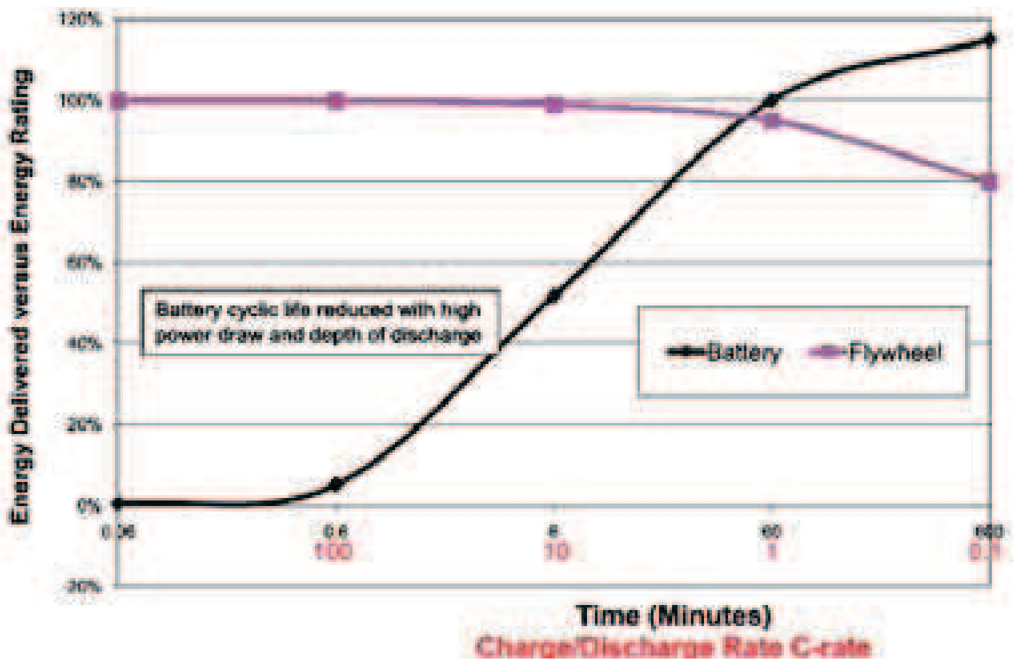

Fig. 6. Energy delivered versus energy rating for battery and flywheel [8]

It was investigated in 2008 (delivered 2011) by Beacon POWER the new 100 kWh ARPA-E flywheel (Fig. 7). The wheel is completely magnetically levitated with no rotating elements. There is no contact between rotor and stator. The ARPA-E flywheel is for a different application, supplying energy to an hour or 15 minutes [10]. At full speed the rim strains about 1% and the internal diameter (ID) increases about 1.7 cm (0.7 in.). The ARPA-E flywheel cost is about 400,000$ per unit [8]. It is about 10 times more than battery unit but the estimate lifetime delivered energy cost is about 0.03/kWh for flywheel up to 0.24$/kWh for battery [8].

A 20MW power plant, based on mentioned flywheels has constructed in Stephentown (NY, USA) in 2011 and was presented on Fig.8. As a replacement for battery-based UPS systems, flywheel technology has an advantage of being virtually maintenance-free compared to maintenance-intensive and less-reliable battery-based UPS [10].

The challenge for market acceptance of flywheel-based UPS is still cost. The Beacon POWER product is assigning for frequency regulation and equalization of the delivered power to the power demand with very low parasitic losses and efficiency AC to AC with electronic converters is about 85% [8]. This is a source of electric energy in emergency situations as well because the response time is below 4 seconds.

Fig. 7. Flywheel technology of Beacon POWER [8]

Fig. 8. A 20 MW plant constructed in Stephentown based on flywheels (NY, USA) [8]

5. Possibility of marine appliances of flywheel units

A large number of applications (ship power plant as well) exist that collectively can be categorized under "peak power support". For example, drilling vessels and drilling platforms maintain a number of diesel engines as D-E systems to meet the peak power needs. The generators working parallel loads the engines at idle or at low capacity factor due to irregular power demands of drilling units and/or DP operations. A flywheel system could augment the capacity of the diesel generators, making possible to meet the peak power demand requirements with smaller number of working gensets. In that case it will be the ability to reduce needed investment cost due to application of smaller total number of installed gensets. The added value of that application may derive from reduced wear and tear on generating equipment and reduced air emissions, especially important on ECA areas (mandated air pollution limits or taxes).

The dimensions of 100 kWh ARPA-E flywheel and mass (about fifteen tons) are convenient for marine appliances (omitting small ships below 60 m of length). The Beacon POWER proposition was given to naval ships with smaller units. The biggest one was presented on Fig. 8. There is a flywheel of 10MW power with the energy storage of 27.8 kWh.

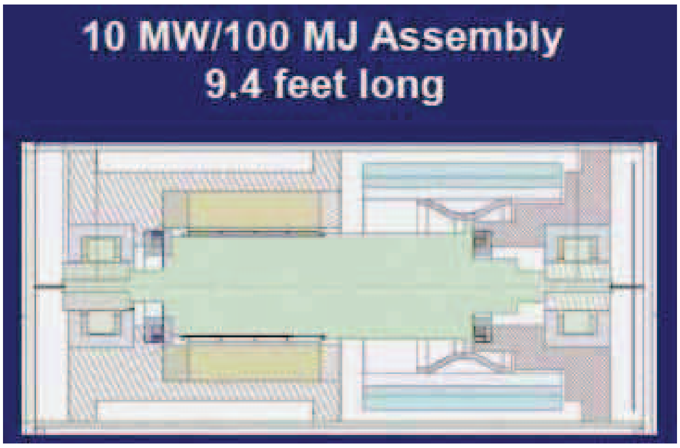

Fig. 9. Beacon POWER proposition of flywheel for naval ship of 10 MW (27.8 kWh) [8]

6. Final remarks

One of the most important issues is to minimize fuel consumption for the actual operation profile and service speeds. Station keeping mode necessary for DP operation wastes a lot of energy, especially during bad weather condition. Using suitable solutions in the generating, delivering power with energy storage devices it is possible better utilization of propulsion system during DP operation. This way is improving the safety and reliability of DP operation.

The development of energy storage devices allow to maintain them on vessels in many applications. The most interesting energy storage device, which may fulfil the requirements of ship electric network, is flywheel. Diesel-electric power plant with energy conversion through DC energy gives higher overall reliability and high flexibility, minimize the risk of overloading and blackouts allows at the end on reduction of fuel consumption. In a practice, vessel power plant equipped with energy storage flywheels will be more complicated but will prevent many dangerous situations and will improve the safety of DP and industry operations. In my opinion during next five years, such system will be installed on multi-mode vessels and will be more popular in the future.

References

[1] The KMB Project, *Energy-efficient all electric ship,* 2005.
[2] Myklebust, T. A., *Laying the course*, ABB Review 03/10.
[3] *Diesel-electric propulsion plants. A brief guideline how to design a diesel-electric propulsion plant,* MAN 2010.
[4] Adanes, A. K., *Maritime electrical installations and diesel-electric propulsion,* ABB AS Marine 2003.
[5] Herdzik, J., *Wymagania stawiane systemom dynamicznego pozycjonowania oraz możliwości ich weryfikacji*, Logistyka nr 5/2011, ISSN 1231-5478, pp. 635-640.
[6] Herdzik, J., *Problems of propulsion arrangement choice of multi-mode ships,* Journal of KONES Powertrain and Transport, Vol. 17, No. 2, pp. 129-135, Warsaw 2010.
[7] Herdzik, J., *Propulsion characteristics of multi-mode ships in aspect of dynamic positioning application,* Journal of KONES Powertrain and Transport, Vol. 17, No. 3, pp. 127-134, Warsaw 2010.
[8] Lazarewicz, M., *Joint ARPA-E/ASD(R&E) Workshop Energy Storage,* Beacon Power Corporation, 2011.
[9] *The Ship Power Supplier*, Marine News 1/2003.
[10] http://machinedesign.com/article/reinventing-the-flywheel-0811.