Azimuth Propeller Operation in Ice Conditions

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ABSTRACT

The traffic volumes in arctic waters are expected to grow rapidly in forthcoming years. A new fleet of icebreakers and cargo carriers with high ice-class will be needed. One of the most beneficial solution is to use independently icebreaking vessels equipped with high ice-class Azipod propulsion units. The construction of ABB Azipod propulsion units allows full power, maximum rpm and full torque in both directions of propeller rotation. Azipod unit have pulling type propeller enabling enhanced vessel stern first operation in demanding ice conditions. Recently ABB Marine launched the innovative Onboard DC Grid concept which is especially suitable for offshore supply and icebreaking vessels. The Onboard DC Grid concept provides a highly efficient power distribution and electric propulsion with low voltage onboard and power systems up to 20MW. This paper outlines a ship machinery concept with ABB Azipod propulsion and Onboard DC GRID system.

KEY WORDS

DC Grid; Azipod; Propeller; Icebreaker; Electric Propulsion; Energy storage.

INTRODUCTION

In the past twenty years the shipping industry has seen a rapid development in the propulsion of ships operating in ice covered waters. The emergence of podded propulsors with high ice class has widened the classical picture of icebreakers.

Before, rigid shaft lines and propellers, with or without nozzles, were the only options available. All over the world, the predominant choice of propulsion for the state owned icebreakers was electric drive with fixed pitch, open propellers. Prime movers ranged from nuclear power in Russia, steam- and gas turbines in Canada and USA to diesel engines. All these state owned icebreakers had large crews, typically from 50 to about 150 persons and they were expensive to operate.

The oil discoveries in the Beaufort Sea changed this picture. Privately owned and operated ships started to appear in the late 1970. These vessels were built to support the drilling fleet during summertime and to act as research platforms. The machinery lay-outs were typically geared medium speed diesels and controllable pitch propellers with and without nozzles. Main drawbacks of such propulsion configuration were poor capability to handle ice torque and clogging of the nozzles by ice blocks. However, all ice breakers, with the exception of the bow propeller equipped Baltic icebreakers, suffered from maneuvrability problems when performing both icebreaker and ice management duties.

In order to remedy this maneuvrability problem a couple of projects were started in Finland. Two small icebreaking waterway service vessels were equipped with steerable thrusters, one with a mechanical thruster and the other with an Azipod propulsion unit. In this context a mechanical thruster means a thruster where the motor drives the propeller via a number of bevel gears, normally two, and the Azipod is a propulsion unit where the motor is located inside the pod and drives the propeller directly, see Figure 1. In many high ice vessels Azipod has become the preferred solution by the ship owner due to evident design and operational benefits (Heideman, 2011) such as:

- Outstanding icebreaking performance when running stern first in Double Acting mode
- Excellent efficiency which means less fuel consumption
- Azipod is not oil filled, only small oil amount in bearing housing
- Very simple and robust construction, meaning minimum amount of moving parts
- Pulling type propeller enabling stern first operation in ice conditions

During the past twenty years a great number of vessels intended for operation in ice covered waters have entered service equipped with ABB Azipod propulsion units. Azipod system has proven itself in the harshest marine environments. In the beginning of year 2012 the track record of vessels with Azipod units was:

Operation hours	>7 000 000 hrs
Azipod units delivered	close to 250
Ice class Azipod units (>1A Super)	close to 50
Icebreaking vessels with Azipod	close to 30
Vessels	>110

This paper deals with some important design considerations of Azipod propeller unit operation in ice. The simple and robust construction of the Azipod allows full power, maximum rpm and full torque, including required over-torque in both directions of propeller rotation. The Azipod unit has a pulling type propeller enabling stern first operation principle in demanding ice conditions.

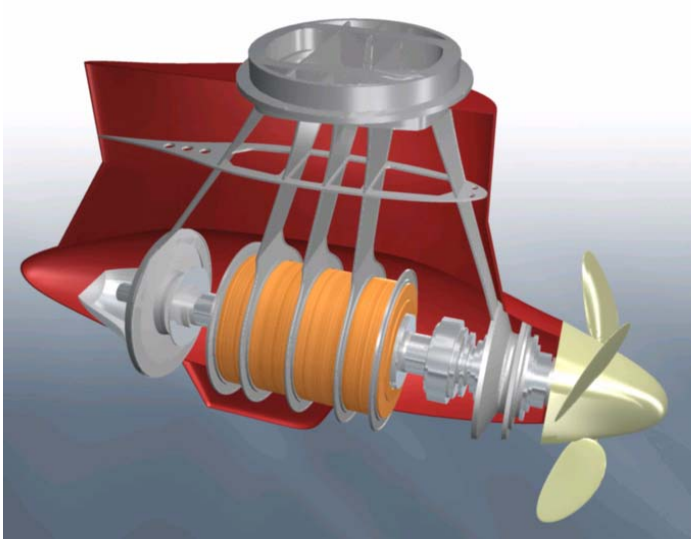

Figure 1. Azipod propulsion unit

In May 2011 ABB launched the innovative Onboard DC Grid concept which is especially suitable for ice class or dynamically positioned offshore vessels. The Onboard DC Grid concept provides a highly efficient power distribution and electric propulsion system for low voltage onboard and power up to 20MW. A typical electrical propulsion system from ABB essentially keeps all of the proven products that are already being used in today's electric propulsion vessels, including AC generators and inverter modules. However, the main AC switchboards and propulsion transformers are no longer required. The result is a more flexible power and propulsion system, which will enable equipment weight savings of up to 30% and will cut fuel consumption and emissions by up to 20%. By adding "plug-in energy storages" to Onboard DC GRID system, it is possible reduce ice-induced load changes to the main diesel engines. Reducing the engine load variation in ice operation, will save fuel and machinery maintenance. This paper outlines a typical icebreaking OSV machinery concept with Onboard DC GRID and Azipod propulsion units.

AZIPOD OPERATION IN ICE

The Azipod propulsion system enables the vessel to break ice using the revolutionary Double Acting (DA) principle. The DA principle means that the vessel can be designed with the stern optimized for icebreaking and the bow optimized for another condition, such as open water or heavily ice-strengthened for multiyear icebreaking by repeated ramming.

Running astern the propellers effectively wash away the broken ice pieces from the aft part of the hull thus reducing the ice resistance by up to 50%.

The effect of Double Acting operation becomes particularly evident when operating in ridge fields. There the proper way of operation is to slowly move astern, giving the propellers time to destroy the ridge by chopping the ice blocks with the propeller blades. Ramming stern firs is not recommended.

Running ahead Azipod vessels are normally operated in ramming so that reverse is obtained by turning the Azipods 180°. In icebreaker applications the standard turning rate is 9°/sec which means that the reversal takes 20 seconds. It worth noting that during the turning of the Azipods the power shall preferably be kept constant to avoid load changes to the diesel engines.

Frequent load changes to diesel engines will lead to increased fuel consumption and shorter time between overhauls for the engines. Also, when Azipods are turned under full power the flushing effect of the propeller streams will effectively clean the area around the aft ship of the vessel and make the backing in the channel easier.

However, it is also quite possible to use Azipod ships in the same way as classical icebreakers with shaftlines and reverse during ramming by changing the direction of rotation of the propellers.

The electric motor inside Azipod is directly connected to the propeller and in this respect it is similar to the classical icebreaker shaftline, the only exception is that the shaftline is extremely short. The construction of Azipod allows full power, maximum rpm and full torque, including required over-torque in both directions of rotation.

When reversing by changing propeller rotation it means that the Power Management System (PMS) of the vessel first will have to reduce the rpm to zero and then accelerate the propeller to full speed and power in the other direction. This operation leads to a situation where the diesels have to reduce power while the rpm decreases and then increase power again when the rpm increases. In practice, this means that the reversal time is totally depending on the power build-up rate of the diesels. This way of operation will result in frequent load change cycles for the diesels with the consequences of increased fuel consumption and emission as well as reduced service interval.

ABB has performed a simulation study on the behaviour of the response of the PMS of a vessel during manoeuvring at zero speed. The vessel was equipped with twin Azipod with 2 x 13.2 MW propulsion power.

The Figure 2 shows the main results of the study. The red line shows the theoretical capability of the PMS assuming that the diesels fully can follow the power demand of the PMS. The blue line shows the behaviour of the PMS when the rate of power build-up is 2 MW/10sec. The green line shows the behaviour of the PMS when the rate of power build-up is 20 MW/10sec.

The upper graph in Figure 2 shows how the rpm in about 1.2 seconds drops from 125 rpm to zero and then accelerates in the opposite direction depending on the rate of power build-up. The theoretical red line reaches full rpm astern, 150 rpm in about 4 seconds assuming that the diesels fully can follow the power demand of the PMS. The green line with 20 MW/10sec reaches 150 rpm in about 8 seconds and the blue line with the slowest build-up ramp will need considerably more time, it was actually not calculated.

The lower graph in Figure 2 shows how the propeller power behaves.
When the bridge levers are pulled from full ahead to full astern the power drops immediately to about 3000 kW and stays there for about 1 second to allow the diesels to adjust. Then it drops quickly to zero when the rpm also reaches zero at about 1.2 seconds. After that the power starts to increase depending on the power build-up rate of the diesels. The red line shows the theoretical maximum taking into

account limitations set by the torque limit of the drive. In about 2.2 seconds full power astern is achieved assuming that the diesels fully can follow the power demand of the PMS. The green line with 20 MW/10sec reaches full power astern in a little less than 8 seconds and the blue line with the slowest build-up ramp will need considerably more time to reach full power.

As a conclusion it can be concluded that during rpm reversals the PMS is much faster than the diesels. The PMS can go from full ahead to full astern in about 2 seconds but the power build-up capability of the diesels will increase the time to about 8 seconds.

This way of operation during ramming is considerably faster than turning the Azipods 180° but it consumes more fuel and stresses the diesels more.

In the next chapter the focus is on ABB innovative Onboard DC Grid system, which can tackle the problem of fast load changes during ramming and ice operation and therefore reduces machinery wear and fuel consumption.

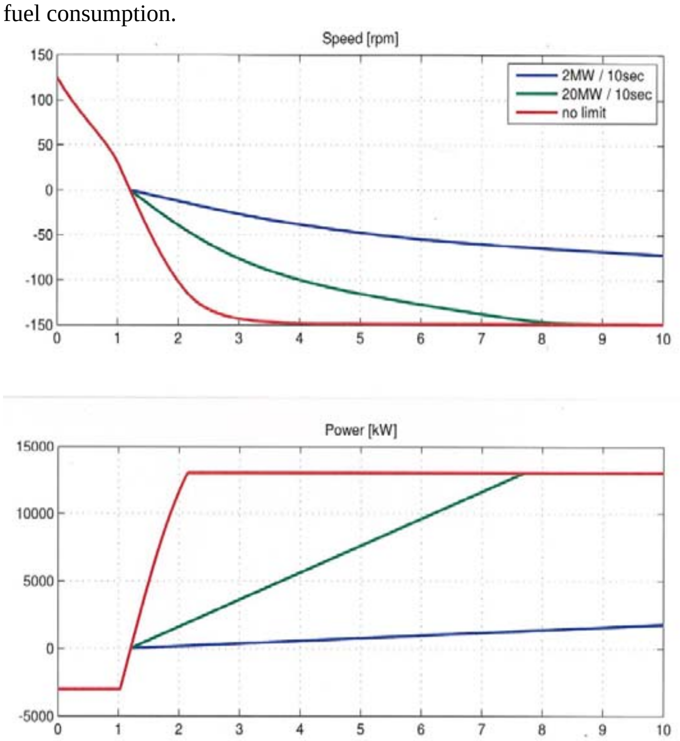

Figure 2. Azipod Power and RPM behaviour in reversing.

ONBOAD DC GRID SYSTEM SECURES EXCELLENT ICE PERFORMANCE

Onboard DC Grid is a novel, new technology which is a further development of utilizing DC-links that already exists in all propulsion and thruster drives, accomplishing for usually more than 80% of the electrical power consumption on electric propulsion vessels. This extension means that we keep all the good and well proven products used in today's electric ships like AC generators, inverter modules, AC motors, etc. The main AC switchboard and transformers are not longer needed. The result is a more flexible power and propulsion system. Further Onboard DC Grid enables a combination of power sources and energy storage. Onboard DC Grid is suitable for vessels with total installed power of up to 20MW and operates at 1000V DC on the main bus. Target vessel type is Offshore Support Vessels (OSVs), but any other vessel type using low voltage electric distribution would also be in the target range.

For example in DP operation this approach gives several benefits. Firstly, the power network is no longer fixed at 60Hz. This means that an additional freedom of controlling the generator engine speed is present, giving the possibility to run engines efficiently even at 50% rpm or lower.

Secondly, use of energy storage gives a possibility to level out the power variations on the engines even if the thruster loads are varying significantly due to vessel movements in ice conditions. This does not only contribute to increased fuel saving, but equally important would be the improved icebreaking and DP performance by the fact that the dynamic response of the thrusters would be independent from the main engine dynamics. Today each thruster will experience ramp limits in power changes due to limitations in engines, however the energy storage take most of these power variations and hence reduce these limitations to a minimum.

To conclude Onboard DC Grid is suited for vessels with total installed power up to about 20MW. It is flexible with respect to use of various power and fuel sources, and it gives clear benefits for vessels operating in ice, with respect to fuel consumption but also with respect to dynamic performance of the thruster system.

In developing the new Onboard DC Grid concept the entire electric propulsion system has been revised as opposed to merely optimizing on a component level. However, some important principles have been carried over from the traditional system and formed the framework for the new system philosophy:

- Equipment shall be protected in case of failures.
- Proper selectivity shall be ensured in such a way that safe operation is maintained after any single failure.

In this paper the focus is on what benefits the Onboard DC Grid would mean for the performance of vessels operating in ice.

Onboard DC Grid System

Onboard DC Grid is a novel, new electric power distribution concept that, while utilizing the well proven AC generators and motors, opens new opportunities for efficiency improvements and space savings. The efficiency improvement is mainly accomplished by the fact that the system is no longer locked at a specific frequency (usually 60Hz on ships), even though any 60Hz power source also would be connectable to the Grid. The new freedom of controlling each power consumer totally independently opens up numerous ways of optimizing the fuel consumption.

Since the main switchboard is omitted, including its generator and feeder circuit breakers, a new design of the protection system is proposed. Proper protection of the Onboard DC Grid is achieved by a combination of fuses, isolator switches and controlled turn-off of semiconductor power devices. Figures 3 show the layout of the machinery and electric distribution and propulsion system for a typical Platform Supply Vessel (PSV) with Onboard DC Grid system.

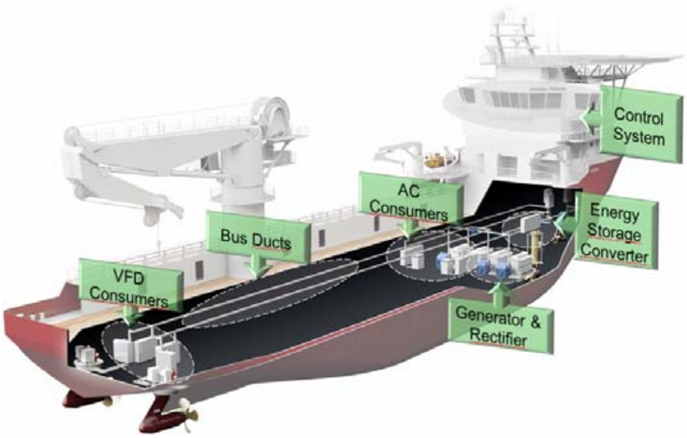

Figure 3. Layout of Onboard DC Grid system in Platform Supply Vessel.

There are several ways of configuring the Onboard DC Grid from a multi-drive approach to a fully distributed system. Common feature is that the main AC switchboard and all converter transformers are omitted in the new concept. Instead all generated electric power is fed directly or via a rectifier into a common DC bus that distributes the electrical energy to the consumers. Each main consumer is then fed by a separate inverter unit.

Where AC distribution network is still needed (e.g. “230V hotel load”), it will be fed using island converters, specially developed to feed clean power to these more sensitive circuits.

Further, converters for energy storage can be added to the grid. Energy storage media like batteries or super-capacitors can be used for a wide variety of functions like load leveling, peak power and zero-emissions operation. Schematic single line of DC Grid system is shown in Figure 4.

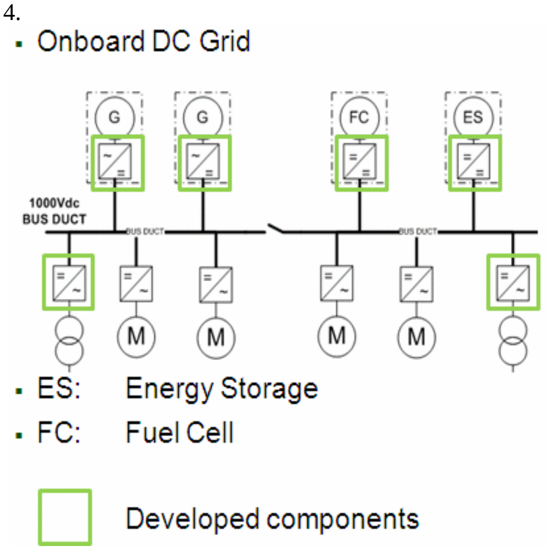

Figure 4. Schematic single-line drawing for Onboard DC Grid System.

ONBOARD DC GRID SYSTEM PROVIDES SEVERAL BENEFITS FOR ICE OPERATION

Overall System Efficiency

Today almost all energy producers on electric ships are combustion engines, most operating on liquid oil (HFO/MDO), some on gas (from LNG mainly), and even some with Dual Fuel capability (liquid fuel or gas). When operating these engines at constant speed the specific fuel consumption is lowest at a small operating window, typically around 85% of rated load. With the possibility to adjust the speed, this operating window can be widened to 50-100%. This is especially beneficial for vessels operating in Dynamic Positioning, where average electric thruster loads are normally low due to low propeller speeds in normal weather conditions, and the number of running engines is higher than really needed for safety reasons. The pure electrical efficiency will also be improved with less installed components (no main switchboard and thruster transformers).

Operational optimisation

Onboard DC Grid enables new ways of thinking for operational optimization. As the system is flexible by combining different energy sources like engines, turbines, fuel cells, etc., there is a huge potential for implementing a real energy management system, taking into account varying fuel prices and availability of different fuel. This kind of optimization may be some years ahead, but with Onboard DC Grid the vessel is prepared for the future and any electricity producing energy technology that may be available in the future. This will enable an owner to adapt a vessels power plant during its lifetime with relative ease.

What is available today with Onboard DC Grid, and would help in solving the traditional challenge for DP operation, is the fuel efficient running of engines at part load. In the most severe DP operations today the electrical plant is operated by a minimum of 2-split configuration for safety reasons. This gives the vessel possibility to keep its position even if one side of the power plant fails. However, running in split mode does not utilize the full benefits of electric propulsion in general as a total optimization of running engines is not possible. With Onboard DC Grid the split mode operation can be run more efficiently as the engine speed can be adjusted and optimized to the required load without the need for changing the number of generators online. Also, with the Onboard DC Grid concept there is no need for generator synchronization prior to going online. As a result a rotating generator can be connected and loaded with minimal delay. This opens up new possibilities with respect to for example “hot standby” generators and alternative operational philosophies.

Thruster Ramping

The classic issue with ramp limits on thruster RPM and power will also be different in this new setup. In traditional AC power systems with variable speed controlled thrusters, the rate of change of RPM (or Power) is strictly limited by the control system based on available (and usually relative slow) engine ramps. These engine ramps are restricted by the allowable frequency and voltage variations on the main AC SWBD. With Onboard DC Grid these restrictions can be relaxed to certain extent, and less stringent ramps can be utilized in the thruster control.

Further, another feature with Onboard DC Grid is the possibility to integrate energy storage in the power plant. Such storage facilities (like batteries or super capacitors) are mostly using DC voltage as input, and hence can easily be integrated anywhere in the DC distribution system and optimized on system level. A DC/DC converter is though needed for control and protection. The operational benefits of using these kind of energy storage is quite obvious, however the size and cost of adding this type of equipment is also important parameters to consider in he total optimization task.

The total effect is that thruster ramps can be faster, first by the fact that there are no problems with frequency variations on generators, and secondly that energy storage can provide the necessary fast power for fulfilling the thrust command from the DP controller. In total this should give a better DP performance with less fuel consumption.

Balancing load variation in icebreaking and ramming operation

While engine behaviors are considered in ice breaking vessels, there are few special cases offering big potential in terms of cost optimization and ice breaking performance.

First, variable ice load in propeller will lead variation in engines power. Therefore, engines operation point will vary widely hardly being optimum longer periods. In consequence of power fluctuations fuel consumption is increased and shorter overhauls periods for engines are required.

Easy integration of energy storage to Onboard DC Grid is a way to tackle above mentioned challenge and operate with higher performance and optimized operational cost.

The figure 5 shows the operation of energy storage by stabilizing the engines power during fluctuating ice load. With optimally dimensioned energy storage, engines are running with stabile load and optimally chosen rotation speed best suiting for each loading condition. In well optimized cases that lead less installed power and no need to run “extra” engines to supply peak power demands.

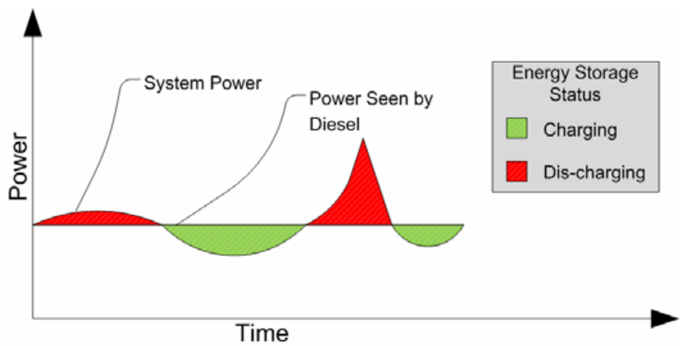

Figure 5. Balancing of load variation

Secondly, in some special occasions while propeller is facing rigid ice bank, propulsion drive may reach its torque limit leading drop of propeller speed and engines power. Even it is over in seconds, consequences takes longer because recovery of full ice breaking capability (torque) depends on power build-up rate of engines.

Combination of the energy storage and Onboard DC Grid is a natural way to overcome this challenge. The engines power can be kept constant even there is downfall in propeller power demand. Therefore full torque (also dimensioned over torque) is available also in all special situations improving ship performance in most hard ice conditions.

Below is a summary of achievable benefits of Onboard DC Grid with integrated energy storage:

- Energy Storage
    - Load levelling – reducing load fluctuations seen by engine
    - ”Spinning reserve” – reducing number of engines online
    - Gas turbine/engine with better dynamic performance
- Power and Energy Management
    - Active Load sharing
    - Load optimizing – charging and discharging when this will improve diesel engine’s efficiency
    - Load scheduling
    - New possibilities with”hot standby” diesel engines

Validation of DC Grid System and Pilot Project

An extensive simulation and test program has been done for the validation of the DC Grid concept. One of the first tests that were made was to check the consequence of running a diesel engine at variable speed. A test engine at Helsinki University of Technology was used for that purpose. The specific fuel oil consumption (SFOC) was measured at various RPM and torque.

The result is shown in Figure 6. The dark blue regions of the figure are indicating where the SFOC is at the lowest. The test results clearly confirm that the engine can run at lower powers in combination with lower RPM and still have the best efficiency.

In November 2011 ABB secured a first pioneering order for its innovative DC Grid Concept. Newbuild Platform Support Vessel (PSV) with ice class will be equipped full ABB Onboard DC Grid system, including all power, propulsion and automation system. The vessel had to be very fuel efficient with low emissions and evidently ABB Onboard DC Grid will help to achieve these goals.

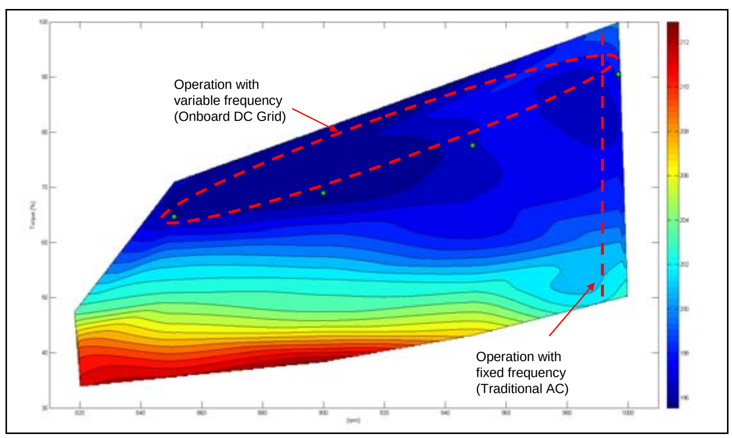

Figure 6. SFOC as function of RPM and torque

CONCLUSIONS

The Onboard DC Grid system is a new way of distributing energy for LV installations in ship. It can be used for any electrical ship application up to at least 20MW and operates at a nominal voltage of 1000V DC. The power distribution can be arranged with all cabinets in a single line up (multidrive approach) or distributed throughout the vessel by short-circuit proof DC busbars.

For the ship-owner following main benefits are expected with Onboard DC Grid:

- Up to 20% fuel saving if taking full advantage of all features including energy storage and variable speed engines.
- Reduced maintenance of engines by more efficient operation.
- Improved dynamic response by use of energy storage, which may give a better DP performance with lower fuel consumption or more accurate positioning.
- Improved response time in ice ramming operation by use of energy storage. Reverse of propeller rpm is possible in few seconds
- Increased space for payload through lower footprint of electrical plant and more flexible placement of electrical components.
- More functional vessel layout through more flexible placement of electrical components.
- A system platform that affords simple "plug and play" retrofitting possibilities to adapt to future energy sources.

Onboard DC Grid combines the best of both AC and DC components/systems available, it is fully compliant with rules and regulations, and it helps to meet the future with low emission and low fuel consuming ships.

The Azipod propulsion system enables the vessel to break ice using the revolutionary Double Acting (DA) principle. The DA principle means that the vessel can be designed with the stern optimized for icebreaking and the bow optimized for another condition, such as open water or heavily ice-strengthened for multiyear icebreaking by repeated ramming. Running astern the propellers effectively wash away the broken ice pieces from the aft part of the hull thus reducing the ice resistance and needed power by up to 50%.

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