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Onboard DC Grid for enhanced DP operation in ships

By Jan Fredrik Hansen*, John O Lindtjørn*, Klaus Vanska**

** ABB AS (Norway)*
*** ABB OY (Finland)*

ABSTRACT

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. Typical target vessel is Offshore Support Vessels (OSVs), but any other vessel type using low voltage electric distribution would also be in the target range.

For 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% loading or lower. Today's discussion of operating the power plant with open or closed bustie breakers can then be closed.
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 bad weather conditions. This does not only contribute to increased fuel saving, but equally important would be the increased DP performance by the fact that the dynamic response of the thrusters would be independent from the 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 DP, with respect to fuel consumption but also with respect to dynamic performance of the thruster system.

1. Introduction

Electric propulsion emerged as the preferred choice for DP drilling vessels in the late 80s and 90s with variable speed drive applications using AC to AC frequency converters [1]. By using the power plant principle and total integrated solutions with advanced control systems, new ways for optimizing the performance of the vessels, and also protecting the system for failures were opened [2]. This technology was also transferred to smaller vessels and today most of the DP class Offshore Support Vessels is built with electric or hybrid propulsion [3], mainly using low voltage power distribution and propulsion.

The further development of these systems has been dominated by stepwise evolution with focus on single components. For example additional protection functionality has been added as advanced Diesel Generator Monitoring Systems [4]. Still during all these years the main configuration has still been the classic one with generators producing electric power at fixed voltage and frequency, and AC to AC frequency converters to control the propeller and thruster RPMs.

ABB has over the last two years run a development project dedicated to looking at the whole onboard chain of energy conversions from a new point of view, by using DC as main distribution platform. The primary focus has been on LV systems and using OSV type of vessel as one reference example [5]. Further the system is targeting all vessels types with total installed power up to 20MW. The project has involved several collaboration partners in the design, verification and review process. These partners include ship owners, ship designers, classification societies, and external consultants.

In developing the new Onboard DC Grid concept the entire 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 on DP. The system build-up is described in section 2. Further the benefits of using Onboard DC Grid are discussed in section 3 with a special focus on DP applications. Section 4 is describing the new safety and protection philosophy that is designed for this new approach. Finally in section 5 we are presenting some of the simulation and test results that have been carried out to this date.

2. System build-up

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 1a and 1b show the layout of the machinery and electric distribution and propulsion system for a typical Platform Supply Vessel (PSV) with traditional AC distribution and the new Onboard DC Grid respectively.

Fig. 1a: PSV with traditional AC system

Fig. 1b: PSV with Onboard DC Grid

There are several ways of configuring the Onboard DC Grid from a multidrive approach (fig. 2a) to a fully distributed system (fig. 2b). In the multidrive approach all converter modules are located in one or multiple lineups and occupies the same space as today's main AC switchboard. For the distributed system each converter component may be placed more freely around the vessel, normally close to the respective power source or load, and the rectifier can be integrated in the synchronous generator.
Common for both alternatives 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.

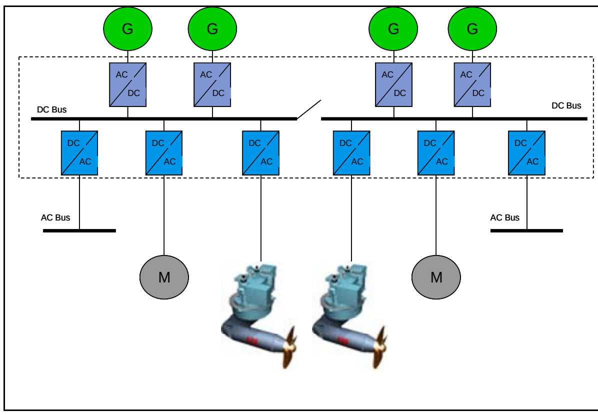

Fig. 2a: MultiDrive approach

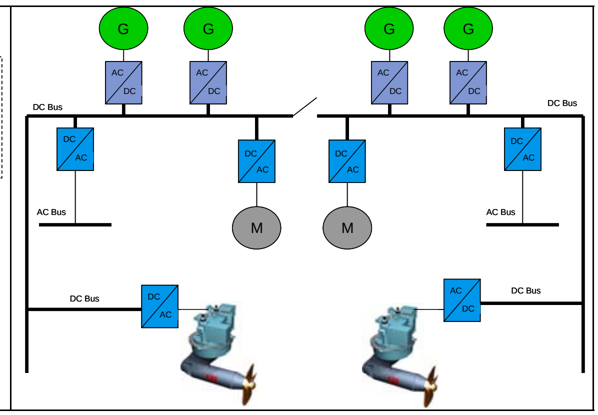

Fig. 2b: Fully distributed system

3. Benefits for DP Operation

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).

Operation:
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.

4. Safety and protection

Since the main AC switchboards with its AC circuit breakers and protection relays are omitted from the new design, it has been essential to devise a new protection philosophy that fulfills class requirements for selectivity and equipment protection. In doing so it has been aimed to keep the footprint low by minimizing the use of circuit breakers. Proper protection of the Onboard DC Grid is achieved by a combination of fuses, isolating switches and controlled turn-off of semiconductor power devices. Since all energy producing components have controllable switching devices (thyristor rectifiers for AC producers and DC/DC converters for DC producers) the fault current can be blocked much faster than what is possible using traditional circuit breakers with associated protection relays.
In this new protection scheme, fuses are used to protect and isolate inverter modules in case of serious module faults. This is no different to current LV frequency converters. In addition, input circuits separate the inverter modules from the main DC bus and afford full control of reverse power, both in fault and normal conditions (as for example in propeller braking mode). This means that faults on a single consumer will not affect other consumers on the main DC

distribution system. In the event of severe faults on the distributed DC bus, the system is protected from generators by means of a controllable thyristor rectifier which also doubles as a protection device for the generator. Isolator switches are installed in each circuit branch in order to automatically isolate faulty sections from the healthy system.
In sum, the Onboard DC Grid fully complies with rules and regulations for selectivity and equipment protection. Further; any fault current will be cleared within maximum 40ms. This results in a drastic reduction in fault energy levels as compared with traditional AC protection circuits where fault durations can reach up to 1s. This low energy fault protection scheme, in combination with a new freedom in designing generator parameters, enables the Onboard DC Grid system to be used for installed power up to at least 20MW.

5. Simulation and test results

An extensive simulation and test program is ongoing for the validation of the 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 3.
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.

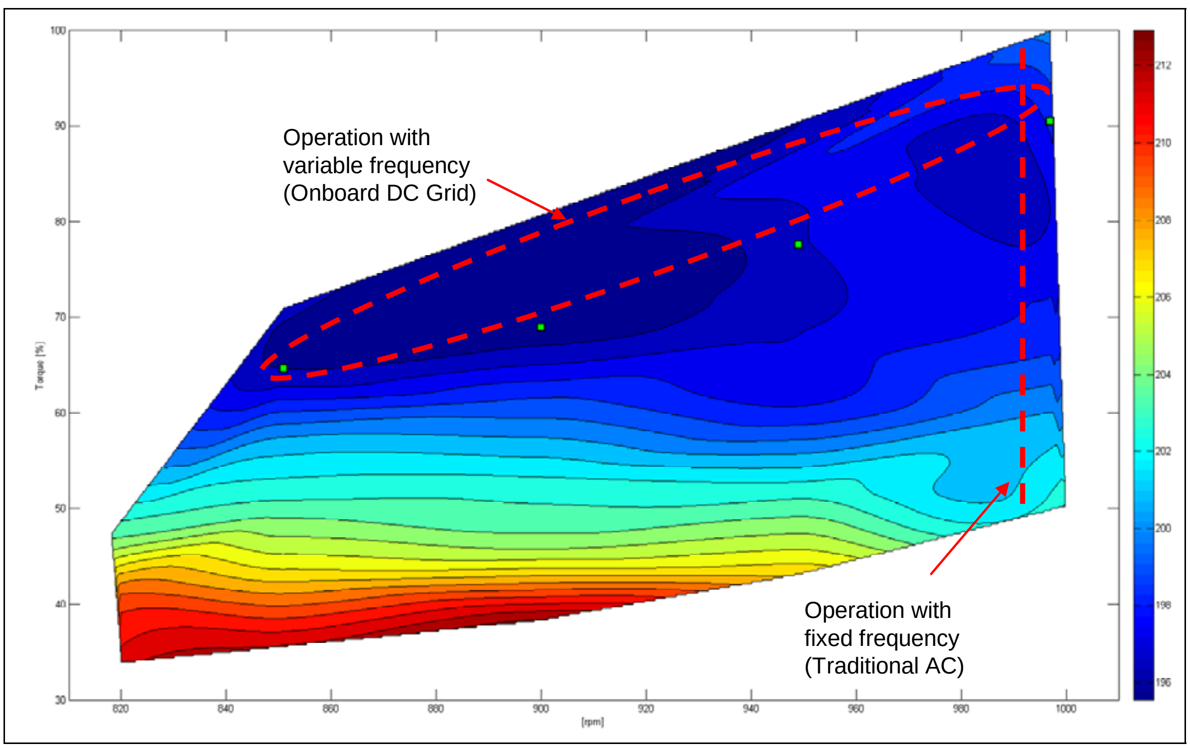

Fig. 3: SFOC as function of RPM and torque.

Simulations have also been performed to check the stability and sensitivity of the system. Figure 4 shows example results by running plots of the system with different parameters. The plots are created by the generalized admittance method. The left plot is indicating an unstable system (intersection of the two planes), while the right plot is indicating a stable system (no intersection). By these simulations we have established models for determining in which range we can select the parameters of the system. The lower graph also show an example of time domain simulation of a stable system where a load ramp is applied and the corresponding DC voltage is simulated.

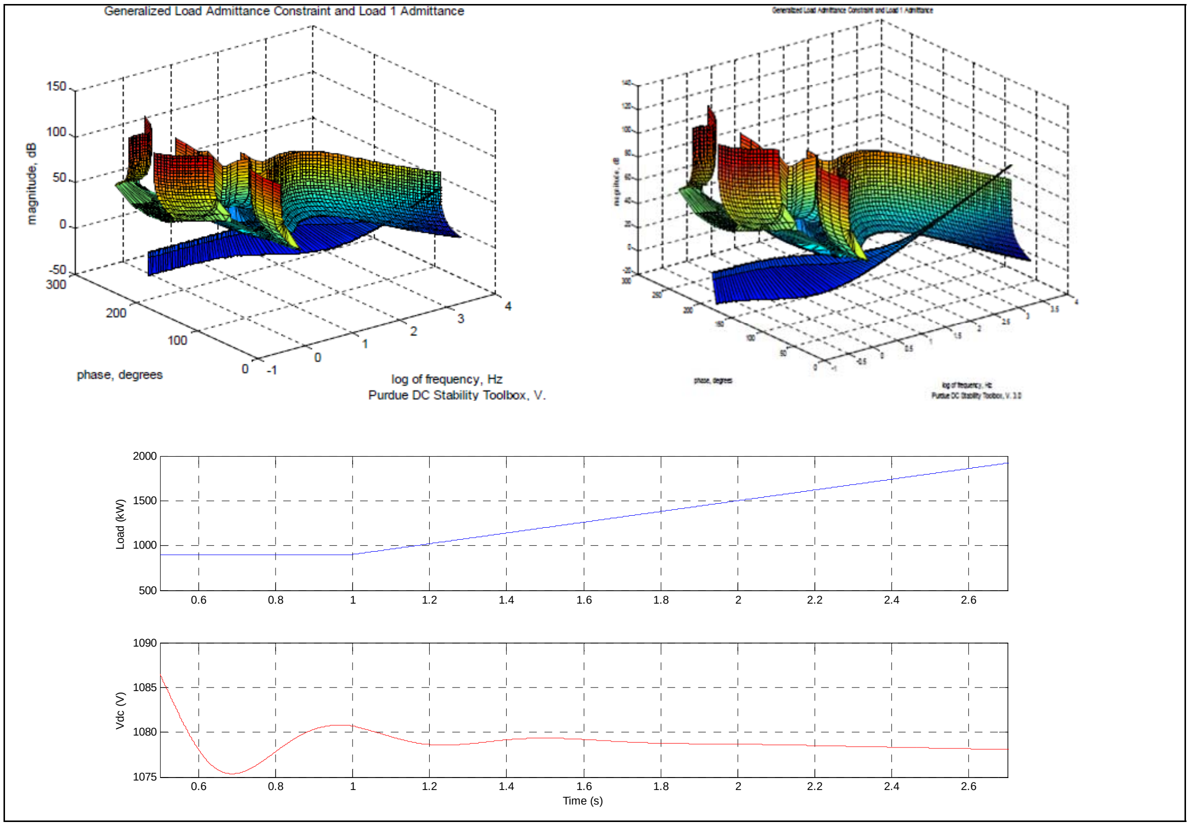

Fig. 4: Stability plot and simulation of Onboard DC Grid.

6. Concluding Remarks

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:

- 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.

- 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 provides advantages including low emissions and low fuel consumption.

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References

[1] Ådnanes, A.K, Sørensen, A., Hackman, T.; Essential Characteristics of Electrical Propulsion and Thruster Drives in DP Vessels; Dynamic Positioning Conference; Houston, October 1997.

[2] Lauvdal, T,; Power Management System With Fast Acting Load Reduction For DP Vessels; Dynamic Positioning Conference; Houston, October 2000.

[3] Ådnanes, A.K.; Fuel Saving and Reduction of Environmental Emissions in OSV and AHTS by use of Electric and Hybrid Propulsion; 3th International Conference on Technology and Operation of Offshore Support Vessels; Singapore August 2009.

[4] Hansen, J.F and Ådnanes, A.K.; Blackout Prevention & Recovery; Dynamic Positioning Conference; Houston, October 2009.

[5] Hansen, J.F, Lindtjørn, J.O, Ødegaard, U.U., Myklebust, T.A.; Increased operational performance of OSVs by Onboard DC Grid; 4th International Conference on Technology and Operation of Offshore Support Vessels; Singapore August 2011.