Onboard DC Grid
The step forward in Power Generation and Propulsion

Imagine a ship with an efficient and modern propulsion system. It is electric. It has state-of-the art propellers and thrusters chosen from a variety of available designs (electrical/mechanical), it has the most advanced converters for smooth and efficient speed control, it has modern engines with common rail injection and it can be fuelled by gas (Liquefied Natural Gas). Take this ship and reduce the electric equipment footprint and weight with up to 30%, and the fuel consumption and emissions by up to 20%, that is today's ship with Onboard DC Grid.

Fig. 1 Platform Supply Vessel with Onboard DC Grid

In its simple way the Onboard DC Grid is just an extension of the already multiple DC-links already existing 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 already used in today's electric ships like AC generators, inverter modules, AC motors, etc. All main AC SWBDS and transformers are however no longer needed and you have the most flexible power and propulsion system to date. The main innovations with this new Onboard DC Grid are the design and control of the protection system and optimized energy flow.

This technical note describes the design and configuration of the Onboard DC Grid system, with a discussion of the various benefits.

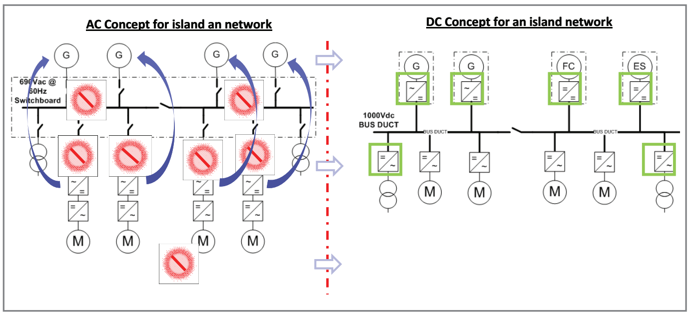

Fig. 2 From AC to DC (single line old vs. new design)

Onboard DC Grid

There are several ways of configuring the Onboard DC Grid from a multidrive approach (fig. 3) to a fully distributed system (fig. 4). In the multidrive approach all converter modules are located in the same lineup within the same space layout as today's main AC switchboard. For the distributed system each converter component is located as near as possible to the respective power source or load.

Common for both alternatives is that the main AC SWBD and all thruster 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. The 220V AC distribution (e.g. "hotel load") 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. This energy storage could for example be batteries or super capacitors for leveling out power variations.

The main benefits of this approach are, besides an efficiency increase of up to 20%, space and weight savings by up to 30% and flexibility of placement of electrical equipment. This allows for significantly more cargo space and a more functional vessel layout, where the electrical system is designed around the vessel functions and not vice-versa.

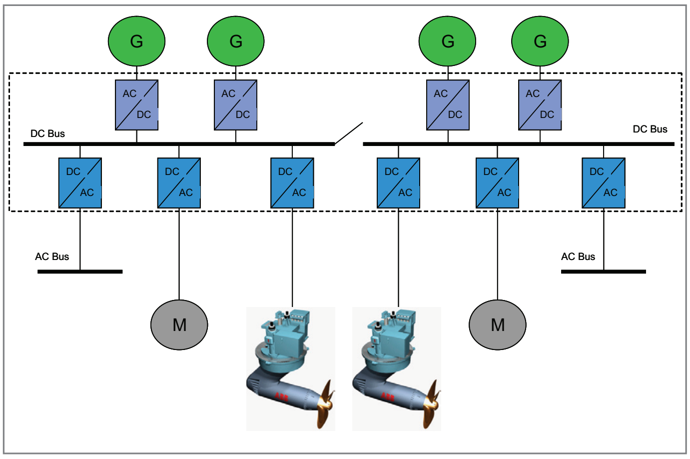

Fig. 3 Onboard DC Grid; Multidrive approach.

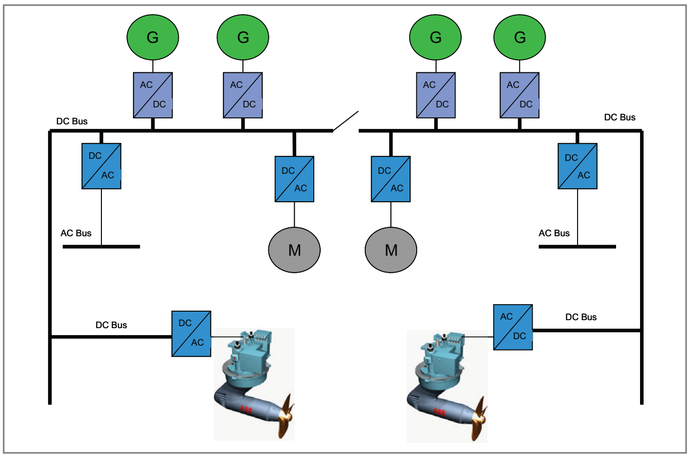

Fig. 4 Onboard DC Grid; Distributed approach.

The main traditional challenges with DC distribution in general have been to achieve full selectivity and equipment protection in similar way as for AC distribution. AC currents are by nature far simpler to break because of their natural zero crossing every half cycle. DC circuit breakers do exists to some extent but are more complex, larger and more expensive than comparable AC circuit breakers.

By designing the Onboard DC Grid we have looked at the whole concept and layout from a totally new perspective, instead of just replacing component by component. Keeping in mind class rules and regulations as the frame, the design is based on following two main principles:

- 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 failures.

Onboard DC Grid is a 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 thought 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. 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 fuel consumption is lowest at a very small operating window around 85% of rated load. With the possibility to adjust the speed this operating window can be extended down to 50% without any increased fuel consumption (fig. 5).

In the most distributed version of the Onboard DC Grid, each power converter is located as close as possible to the respective consumer or producer. Each production unit has the possibility of an integrated rectifier mounted directly on the unit itself or alternatively in a separate cabinet close by. There are no needs of collecting all these units in a centralized "switchboard room" as in a classic design.

Since the main AC SWBD with its AC circuit breakers and protection relays is 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 also been a key requirement to minimize use of expensive and space consuming DC circuit breakers. Proper protection of the Onboard DC Grid is achieved by a combination of fuses and controlled turn-off of semiconductor power devices. Since all energy producing components have controllable switching devices (either thyristor rectifier for AC producers and DC/DC converters for DC producers) the fault current can be blocked much faster than what is possible with traditional circuit breakers with associated protection relays.

Exploring the benefits

Efficiency

Figure 5 shows the test results of fuel consumption as a function of applied torque and RPM for a small test engine. It can be clearly seen from this picture that it is possible to run this type of engine with the lowest possible fuel consumption at least down to 50% loading. This is especially beneficial for vessels operating in Dynamic Positioning, where average electric thruster loads are normally low due to low propeller speeds and normal weather conditions, but number of running engines is higher than really needed because of safety reasons. The pure electrical efficiency will also contribute to the improved efficiency with less installed components (no main switchboard and thruster transformers).

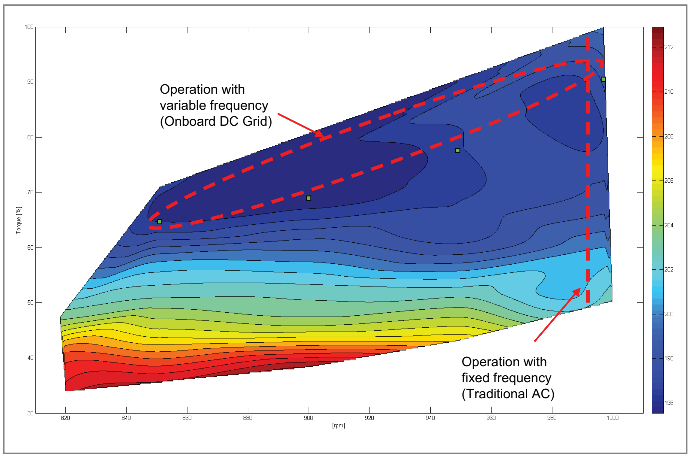

Fig. 5 Engine fuel tests at variable speed (color scheme indicates Specific Fuel Oil Consumption (SFOC) in g/kWh .

However, the biggest fuel savings potential lies in the ease with which energy storage devices, like batteries or super capacitors, can be added to the system. In this area the technology has developed quite much the in the last decade and is expected to develop further. Energy storage will help the engines level out load variations from the thrusters and other large loads. No real measure data is ready available for this type of comparison but it can be somehow compared with the difference of driving a car in a busy city centre and motorway. Similar effects of fuel consumption savings are expected by installation of energy storage and together with above benefits the total yearly fuel consumption reduction is expected as high as 20%.

The exact savings will of course depend on vessel type and operation profile, but as an example a Platform Supply Vessel (PSV) with DP capabilities is one ship type that has the potential for utilizing the full capability of the new Onboard DC Grid.

Weight and space arrangement

One obvious benefit with Onboard DC Grid is the reduced weight and footprint of the installed electrical equipment. The exact figures will of course vary depending on ship type and application, however a summary of a study done for a PSV is shown in Table 1.

Equipment	Q'ty	Rating	Weight Traditional	Weight Onboard DC Grid
Generators w/aux	4	2500 kVA	38000 kg	39000 kg
Main AC SWBD	1	690 VAC	4450 kg	0 kg
Main DC distribution	1	1000 VDC	0 kg	2400 kg
Distribution AC	1	450V/230V	14490 kg	16530 kg
Propulsion drives	2	3500 kVA	31980 kg	13680 kg
Thruster drives	3	1200 kVA	26600 kg	13750 kg
Total			115520 kg	85360 kg

Table 1: Comparison of weights for installed electrical equipment for an example PSV. Traditional AC concept vs. Onboard DC Grid.

The figures in Table 1 give the savings by comparing installed HW only. Further savings are expected as a result of more flexible equipment placement and we believe that with careful design a more functional vessel with increase space for payload can be achieved.

Operations

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, taken 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 within the next 5 to 10 years.

What is available today 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 is failing. 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.

Protection and safety

As already mentioned, the protection philosophy is based on a combination of fuses and controlled switches. In short; 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. Isolators 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 Onboard DC Grid fault energy levels as compared with traditional AC protection circuits where fault durations can reach up to 1s. This low energy fault protection schemes enables the Onboard DC Grid system to be used for installed power up to at least 20MW.

Concluding Remark

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 possiblities to adapt to future energy sources.

Benefits for shipyards and designers can be summarized as follows:

- More flexible placing of electric components.
- Reduced footprint and weight of electrical equipment by up to 30%.
- Less cabling and cabling connection, by means of reduced number of components and use of bus ducts.

Even though use of bus ducts is a relative new type of installation work for many ship yards, several benefits can also be listed for this; such as: Reduced cross section, no bending radius, and drastic reduction of fire load compared to traditional cables.

Onboard DC Grid is here now; it combines the best of both AC and DC components/systems available, it is fully compliant with rules and regulations, and is the choice for the future with low emission and low fuel consuming ships.

For more information, please contact:

ABB AS
Bergerveien 12
1375 Billingstad
Tel. 03500 / +47 22 87 20 00

www.abb.no