

5.7 Onboard DC Grid™

A DC-based power system enables simple, flexible and functional integration of energy sources such as variable speed gensets and shaft generators, batteries and fuel cells.

Onboard DC Grid – a system platform

Onboard DC Grid is a system platform tailored to the needs of the next generation of vessels. It serves applications from low to mid-power range by offering a competitive, flexible and state-of-the-art system platform. It is especially well suited to the integration of variable speed generators, energy storage and new energy sources such as fuel cells in a safe, fault tolerant way. It is highly configurable, enabling a close fit for the simplest to the most demanding application.

It is a modular power system platform comprising modules for sources and loads built using industry leading power and automation products. This approach reduces customer risk by enabling a high quality and efficient engineering process and post-delivery support whilst not forsaking necessary flexibility needed for a tailored application fit.

Some of the main benefits include:

- Footprint reduction of up to 30%
- Variable speed generators for improved SFOC engine characteristic coupled with reduced emissions and maintenance and improved SCR performance
- Most efficient integration of energy storage/fuel cells/shaft generators from perspective of cost, functionality and weight and footprint
- Best in class fault-tolerance is intrinsic to the design
- Highly controllable power plant suited for advanced operation and optimization by overriding

ing controls (Advisory)

- Unique DC distribution capability
- Unique remote diagnostic and service functionality

Protection Philosophy

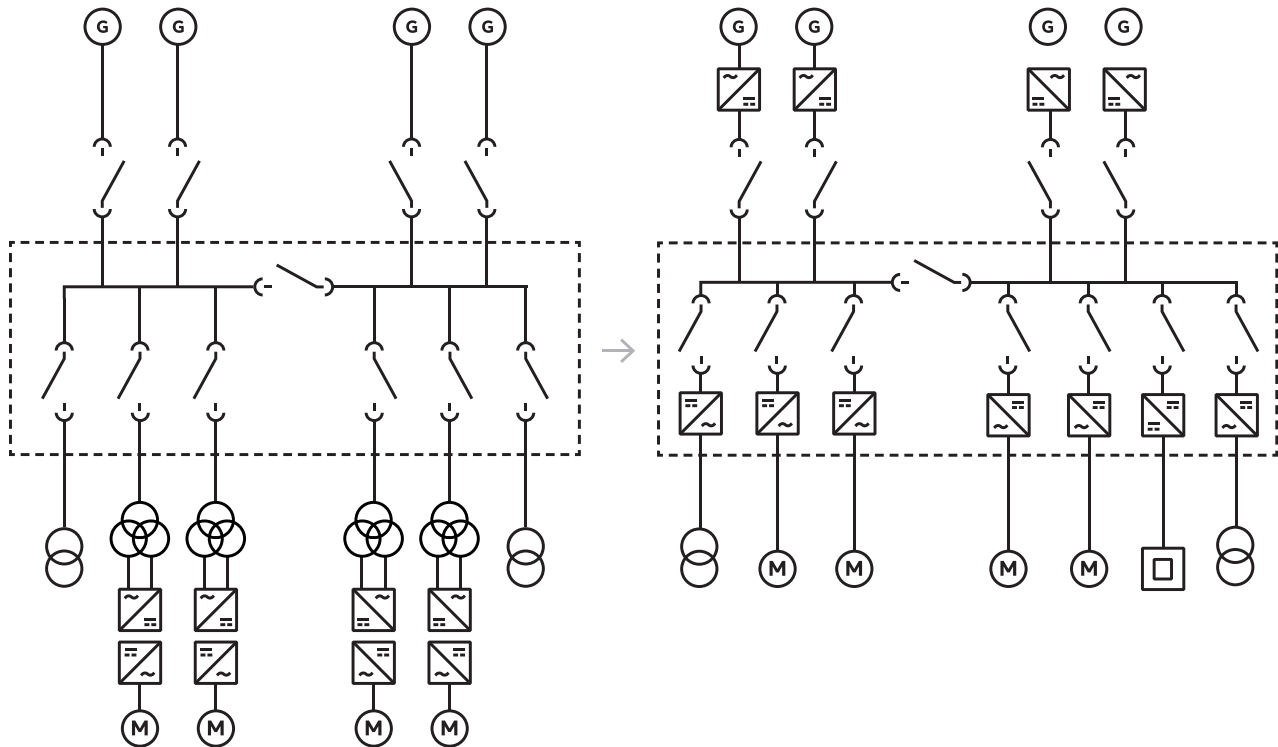
Onboard DC Grid employs a patented protection scheme that uses a combination of fuses, isolators and breakers and converter control to effectively protect the system.

The protection system provides safe and reliable operation of the vessel and high safety for personnel and equipment. This approach relies on input circuits to segregate the system into two types of protection zones:

- Grid (blue): this is the power distribution zone.
- DC-link (red): this is equivalent to the traditional dc-link of a multi-drive.

The input circuit forms the boundary between the link and grid zones and allows free flow of current in both directions during normal operation. In case of faults on the grid side of an input circuit, the input circuit will block near instantaneously, blocking fault current contribution in this direction. Fault currents in the opposite direction are not blocked.

The DC-link zone is characterized by the fact that most converters connected to it have integrated capacitor banks that support the DC link voltage. The capacitive nature of the DC link means that fault currents in this zone have very short time



— The basic transformation from an AC based power distribution to a DC based power distribution

constants and consequently reach high levels very quickly after a fault. This also means that any faults in the zone must be handled extremely quickly to avoid adverse effects on its converters. This environment is ideally suited to solid-state breakers and high speed fuses which clear faults in the range of a few microseconds to a few milliseconds. The input circuit ensures that faults outside the link-zone do not immediately cause the converters to trip on under voltage.

The Grid zone is characterized by fault currents with longer time constants. This means that it is possible to use a slower-acting protection approach such as a fold-back scheme or air circuit breakers in this zone. All entry points into the Grid are guarded by devices that can control fault current (e.g. the input circuits).

As a function of its low fault current level and fold-back or air circuit breaker protection, the grid zone is very well suited to distributing power throughout the vessel. This is an alternative to 690 or 660Vac distribution resulting in >40% reduction in needed conductor cross section and the possibility to use lower cost single-core cables as opposed to multi-core double-screened cables.

Vessel Control System

Onboard DC Grid uses ABB's 800xA automation platform to implement system control functions, including PEMS and VMS. The system integration and control is done in such a way that it plays to the strengths of the various energy sources in the system, and keeps tight control on consumers.

ABB has adopted a new approach to power and energy management in the form of the Power and Energy Management System – PEMS. PEMS manages both the balance of power (traditional PMS responsibility) and energy in the power system. The latter becomes important when adding sources like batteries or super capacitors with very finite amounts of energy available. The balance of power also takes on new dimensions in a DC Grid system when sources like variable speed generators, shaft generators and batteries operate in parallel.

So, what does it mean to “play to the strengths” of a system’s energy sources? For a simple hybrid system this means that ES (Energy Storage) will primarily perform an energy buffering function whilst engines provide the steady-state power. Some of the functionality to achieve this is implemented at lower levels, closer to the converters

and ES – typically functions requiring fast response such as standard load sharing and overload protections. This is done autonomously by the different energy sources. Other functions have been implemented at a higher level such as the traditional PMS domain – typically functions that require a level of coordination between sources. Optimal functionality and performance is achieved through tight horizontal integration between power sources and consumers, as well as tight vertical integration between fast embedded control of converters and generators and the system level application.

Onboard DC Grid has a harmonized control and communication infrastructure that allows for a transparent and lightning-fast flow of information between system components. This ensures a holistic approach to the task of coaxing the best performance, be it for safety or efficiency, out of a power system. The high level of integration also means that high quality information is available to an operator or remote support service engineer should he need it. For vessels with automatic charging from shore, the PEMS coordinates the process of connecting, charging and disconnecting from charging station.

increases the fault tolerance of the system controls by reducing interdependence between energy sources. Sub-system functionality is realized as far as practicable on a sub-system level, only involving the wider system when it becomes necessary. This also means that operation of the vessel remains intuitive and simple even when done so from local control since the majority of sub-system functionality remains intact.

System Benefits – Why Onboard DC Grid

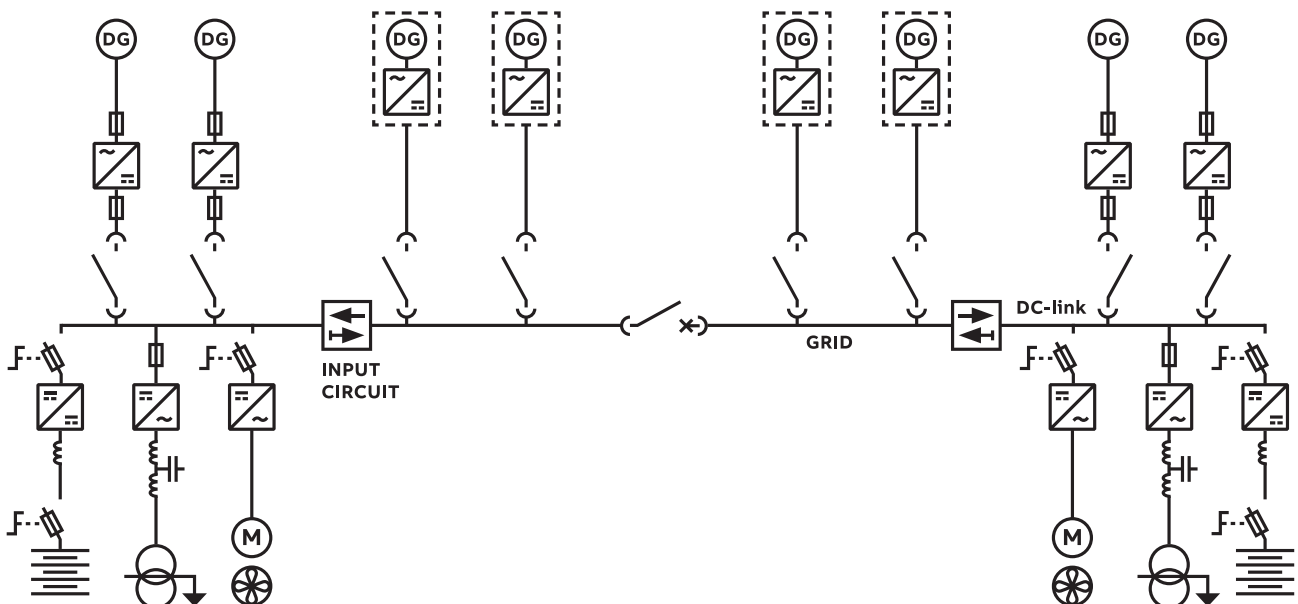
This shift from AC to DC in the form of DC Grid is primarily driven by three main features:

1. Variable Speed Engines
2. The integration of Energy Storage
3. Ease of integrating other types of energy sources such as shaft generators and, in the near future, fuel cells

However the benefits with DC Grid is not limited to these points. The following sections will describe some of main benefits in more detail.

Onboard DC grid protection zones

The PEMS is structured so that each energy source forms an autonomous subsystem. This in-



Variable Speed Engines

Unlike AC based distribution systems where connected generators need to match system voltage and frequency, the DC Grid system only requires the generators to match system voltage. This means that the generator and engine speed can be dynamically optimized to the system load situation. When the engine load decreases, the engine speed is also reduced.

The most immediate benefit of this change is reduced fuel consumption, visualized in the graph above. There are also additional benefits to variable speed operation, summarized below:

- Reduce Specific fuel consumption by up ~20% and ~40% for medium and high speed engines respectively for partial load operation
- Cleaner combustion process with less build-up of soot when operating at partial loads
- Reduced GHG emissions due to lower fuel consumption and reduced particle emissions due to cleaner combustion

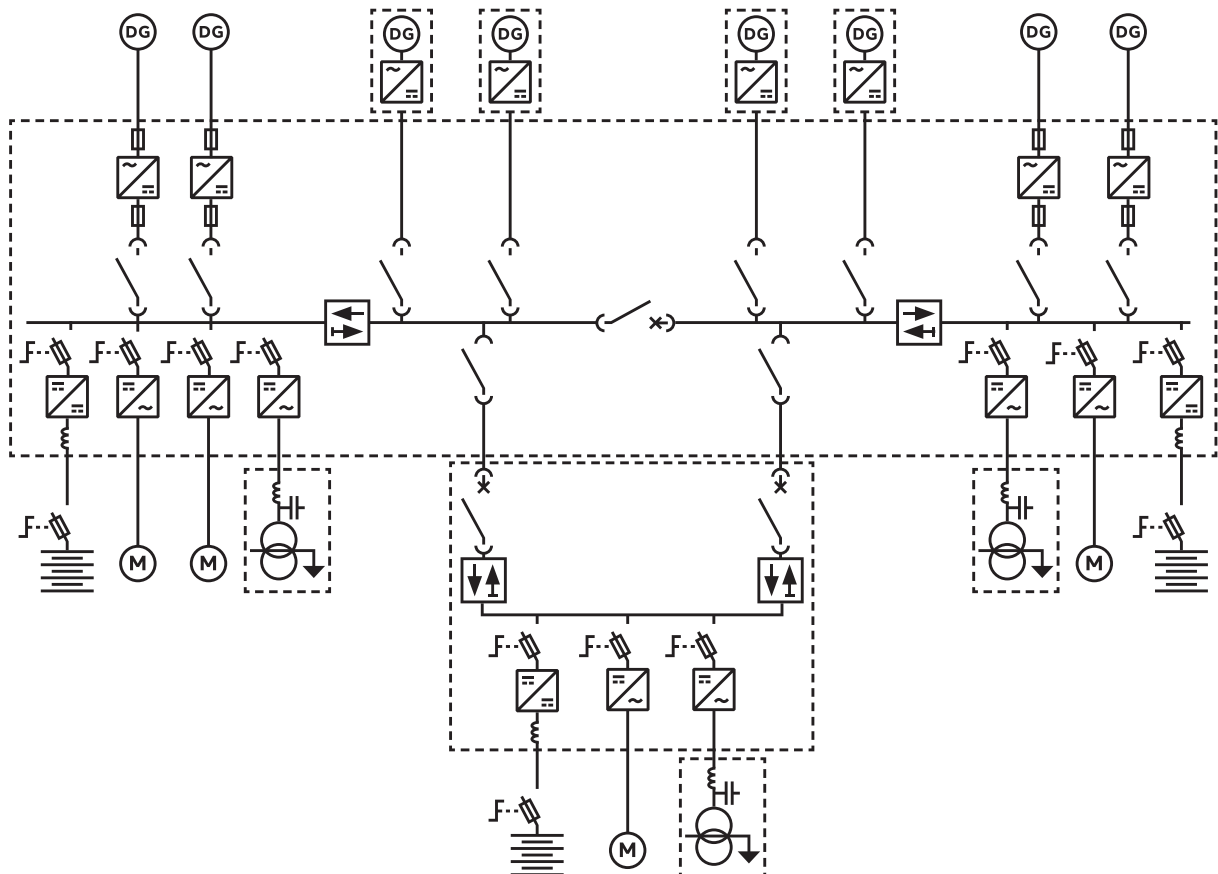
- Increased temperature of exhaust gases at lower loads means that SCRs can be fully operational at all load levels, reducing both NOx emissions and urea consumption
- Potential reduction of audible noise level by more than 5dB
- Reduced maintenance costs due to up to 30% reduced wear and tear on the engine

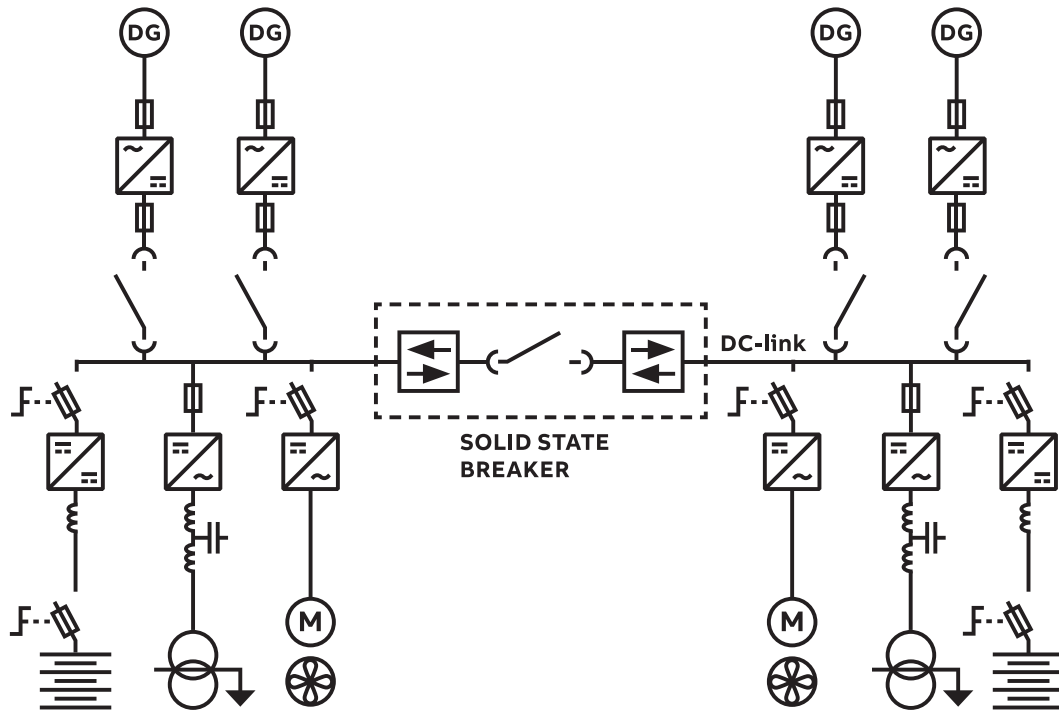
Energy Storage

Energy Storage (ES) and associated technologies have received a dramatic increase in attention in recent years, not least in the maritime industry. Whilst this can be attributed to a number of different factors, what is certain is that ES has the potential to improve safety, efficiency and performance of future vessels.

Integrating Energy Storage into a Power System
The availability of ES is only one part of improved safety, efficiency and performance. First, the energy must be made available to consumers. Since

The double-fed thruster





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A simpler variant of the system – here two input circuits are functionally bundled with an isolator or breaker to make a bi-directional solid-state breaker

most Energy Storage media are DC based, the integration into a DC distribution system becomes simpler and becomes more functional for less added cost than doing the same into an AC based distribution system.

DC solutions require less equipment in general and the converter (if used) also becomes significantly more compact than its AC counterpart. For basic functions where no selectivity or starting scenarios are considered, the AC converter solution is almost twice the length of the DC equivalent. If selectivity, overvoltage and starting scenarios are also considered, then this ratio becomes closer to four.

The option of connecting the ES directly to the DC link can offer a slight reduction in length and improved efficiency compared to the converter option. However, this is at the expense of controllability of the current in and out of the ES and system voltage level.

From a control perspective, this option means that ES power flow is determined by the sum of the actions of all other sources and consumers in the system. This means that this method of con-

nection is only suited to a limited number of applications, typically systems of low complexity where batteries represent a dominant power source.

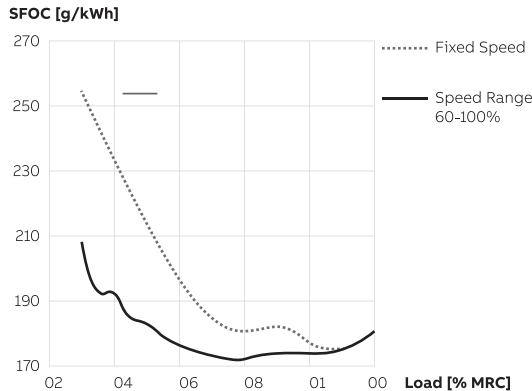
From a system voltage perspective this option means that the system voltage is defined by the ES and its state of charge. This can vary significantly and may therefore require the rest of the system to be over-dimensioned.

For these reasons, direct online solution is often chosen when efficiency is more important than controllability. An example of this is are ferries that operate in zero-emissions mode where large portions of the consumed energy pass through the battery on the way to the propeller. The converted based solution is preferred in applications where controllability and fault tolerance are of higher importance than the efficiency of the ES system. A good example of this is a DP vessel where the battery is used to support the power system by means of functions like peak shaving, enhanced dynamic support and spinning reserve. In these cases ES efficiency does not have a significant impact on power system overall efficiency because the battery is primarily used as an

— PEMS main display



— Reduced fuel consumption with variable speed



energy buffer and relatively little energy is passed through it during normal operation.

Energy Storage & Variable Speed Engines

The combination of ES and variable speed engines offers some additional synergies. In a system with variable speed engines where energy storage is not included, the engine needs to be operated in such a way that it always has enough reserves to be able to absorb load steps. The need to always have some power margins in reserve means that some optimization potential is left untouched.

When a system is equipped with ES and the Enhanced Dynamic Support function is activated, the ES can take on the role of absorbing quick load changes and the engine optimization has one constraint less to consider, and can now optimize its operation even further.

Going from fixed speed to variable speed operation, the speed vs. load path is moved from the vertical 1800rpm axis (red line, see left) to the propeller curve (blue line). When energy storage is added, this path can be moved even further to the

left, sometimes all the way to the MCR curve (green line). The effect this has on the specific fuel oil consumption (SFOC) is shown in the graph below left. The figure shows the SFOC for the traditional AC System (blue), DC grid with variable speed (green) and DC grid with variable speed and energy storage (orange).

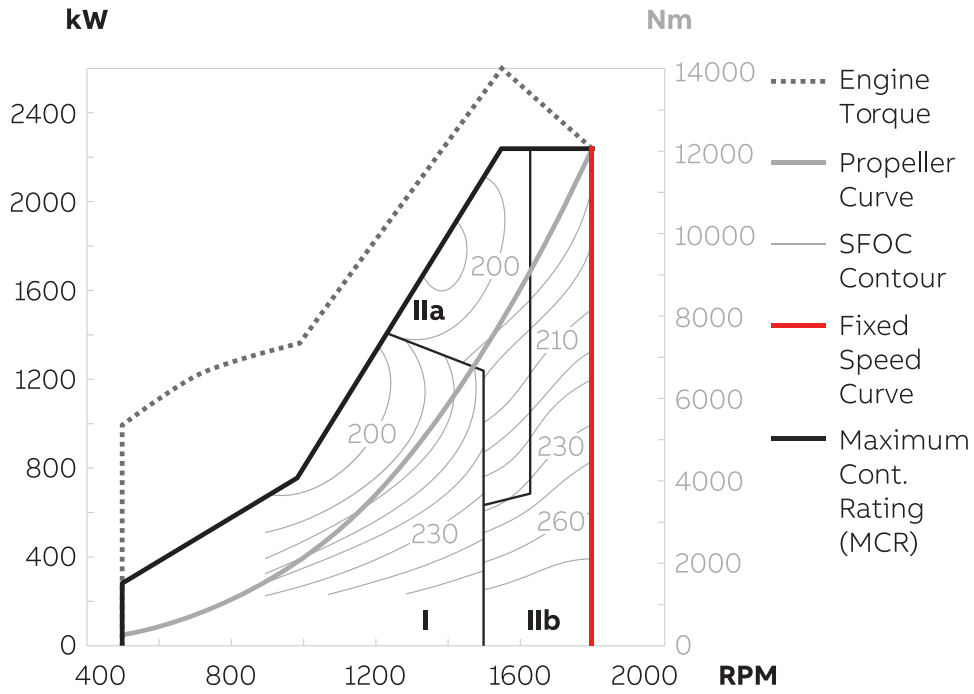
Safety

DC is inherently simpler than AC. When building up a system platform this means that it is easier to predict fault scenarios and devise effective protection against them. For Onboard DC Grid this has resulted in:

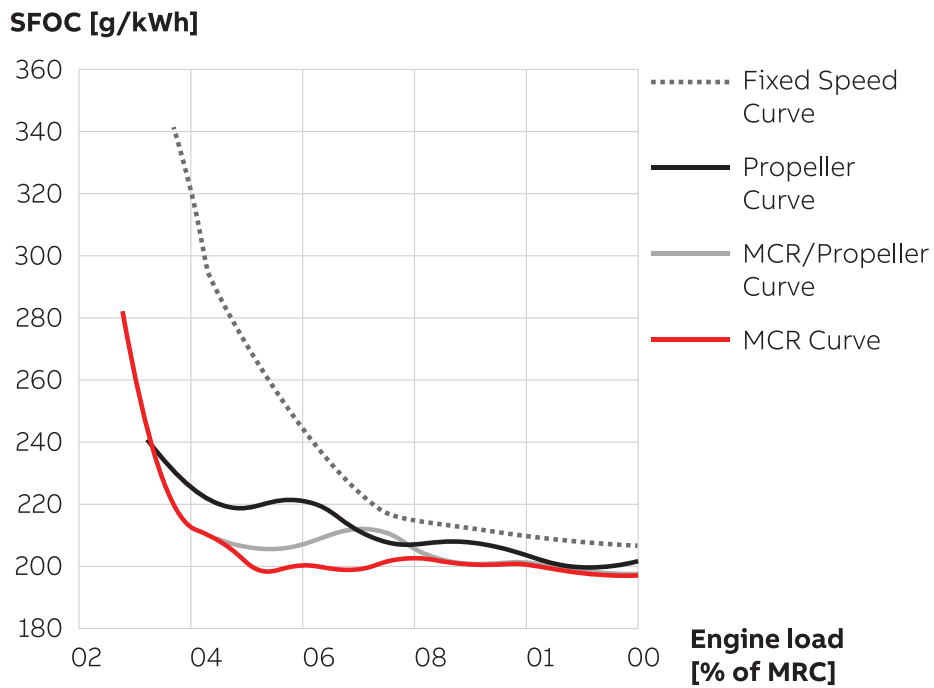
- Closed bus operation in DP2 without additional equipment because common mode faults like governor and AVR failures are handled more effectively.
- Generators that can be online in close to 10 seconds (for high-speed engines) because they don't need to wait for synchronization.
- Engines that are virtually impossible to overload even when operated at lower speeds. This is because each generator has built-in overload protection that limits output power. The end result is that the engine does not stall and remains online.
- Clearing of major short-circuit currents in a "soft" way so that the system recovers quickly and predictably. This is a function of both system capacitance and converter control. The system is therefore not plagued by ugly transients as is often the case in AC systems when large fault currents are interrupted by protective devices.

A safe and fault tolerant system is a benefit in itself, but there is another often forgotten benefit of this. Operators quickly understand that in the rare event that failures do occur, the system will recover quickly and reliably. Such confidence in the system has proven to result in significantly more economical operation of the vessel because the system is not split and additional generators are not brought online until necessary.

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The effect for an
example high speed
machine



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The effect for an
example high speed
machine



Other Benefits

In addition to the benefits described above, there are numerous other benefits with DC distribution. Some of these are summarized below:

- **Power transmission:** Distributing on 1000Vdc instead of 690Vac reduces cable need by as much as ~40% and permits use of lower-cost cables.
- **Voltage distortion:** (THD) common in AC systems with frequency converters is no longer an issue.
- **Shore connection:** If shore connection is done on the DC side, vessels can more easily use shore connections in different ports because network frequency is no longer an issue. Also, starting currents from motors and transformers are not drawn from the shore connection, thus allowing more operational flexibility in ports with low-power feeders. If ES is available onboard, then this can be operated in parallel to take peak loads, improving operational flexibility in port even further.
- **Shaft Generators:** Variable speed shaft generators can be integrated in the same simple way as variable speed generators. Similarly, a PTI/PTO solution can be solved in a very streamlined fashion, analogous with ES.
- **Fuel Cells:** Fuel cells are already making an entry into the marine industry, and the fuel-cell business case may make them a viable power source within a few years. Fuel cell integration into an Onboard DC Grid system is solved in a very streamlined fashion, analogous with ES and shaft-generators.
- **Centralized Drive Lineup:** Collecting all the drives in a central lineup means that the need for ambient conditions (temp and humidity) and cleanliness is reduced in e.g. thruster rooms. This is particularly useful during construction and commissioning.
- **Centralized vs Distributed:** Whilst most systems will be highly centralized, the DC Grid platform also supports fully distributed systems using cables or bus-ducts.
- **Space and Weight Reduction:** The number of components in the system has been reduced, resulting in a reduced footprint of up to 30% as compared with an AC system.
- **Electrical Efficiency:** In the process of going from AC to DC distribution, the electrical system efficiency has improved by 0.5-1 percentage points.
- **Variable Speed Motors:** Fans and pumps represent a large portion of the auxiliary loads onboard modern vessels. Most of these can be operated at significantly improved efficiency by fitting variable speed drives. This enables regulation of flow by means of adjusting fan or pump speed instead of e.g. throttling. The DC Grid platform is uniquely suited to tapping into this potential in a cost-efficient manner.