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Dynamic AC concept
For variable speed power generation

Variable speed power generation can provide significant fuel savings with diesel electric propulsion, when the operational profile of the vessel has a lot of variation in speed and power demand. The Dynamic AC (DAC) concept by ABB enables to optimize the total fuel consumption in the vessel by adjusting the rotational speed of the main engines and allowing the system frequency to vary within the specified range. The main power system in the ship is specially engineered for variable frequency, including component design and system integration. Distribution for the auxiliary and hotel loads is provided by frequency converters or directly from the variable frequency system. Integration with the power management and advisory systems assures high level of optimization and provides tools for continuous improvement during the whole life cycle of the vessel.

Cruise ship operation and route planning

Design of a new cruise ship is based on the routing between her home berth and intended ports of call. Itineraries may e.g. include longer transits to warmer waters and island hopping once there. Respectively, the speed and power demand will vary substantially on the route.

Diesel electric power plant conventionally runs at constant speed. Generators are called online or disengaged to match power production with the actual demand. Modern cruise ship typically accommodates 4 to 6 main engines. Low number of generators translates into large increments in terms of available power. These steps further dictate preferable speed windows based on fuel economy. In turn, certain speed ranges should be avoided as they require the power plant to run at poor efficiency.

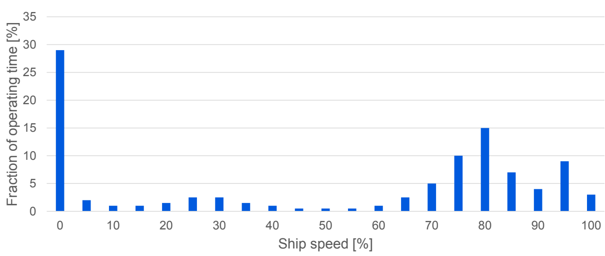

Figure 1: Typical speed profile for a cruise vessel

Figure 1 presents a speed profile for a cruise vessel operating on various routes. The corresponding power profile is presented in Figure 2. These profiles are only examples but similar to actual cruise vessels.

Routing and power plant design can be matched so that the speed profile leads to optimized fuel consumption. However, a cruise ship very seldom does the same itinerary over her entire lifetime. Moving to another route might require completely different speed and power profile and further lead to unattractive fuel economy. This might even reduce the Owner's possibilities or willingness to relocate vessels.

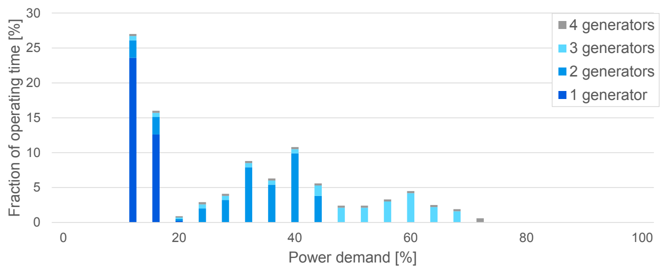

Figure 2: Typical power profile for a cruise vessel

Fuel economy by adjusting the engine speed

Between the generator steps, it is possible to improve the power generation efficiency by adjusting the rotational speed of the engines. Figure 3 presents an example of specific fuel oil consumption (SFOC) of a diesel engine as a function of engine speed and load. Consumption is typically minimized at around 85 % load, when the engine is operated at constant speed. However, adjusting the speed allows for finding the optimal consumption at all operating conditions. Difference in SFOC between constant and adjustable speed is presented by an example in Figure 4. The difference at partial loads is due to more efficient combustion process, which reduces the fuel consumption as well as emissions. With liquefied natural gas (LNG) the difference may be even higher. Engine speed adjustment also reduces the methane slip in LNG powered engines.

Total savings are determined by combining the SFOC characteristics with the operational profile. For example, the above profile and fuel characteristics result in 4 % savings in annual fuel consumption, when the power plant of the vessel comprises 4 main engines. Depending on the operational profile, power plant configuration and fuel type, the annual savings can be even higher.

Variable frequency power plant

Frequency of the generators will naturally vary as the engine speed is adjusted. Converting the generated voltage into constant frequency by full-sized power converters would result in unreasonably high investment and space requirements. Utilizing DC network is also not feasible at the power range of large cruise vessels. Savings would still not justify the investment cost. Neither is the technology for medium voltage DC solutions yet mature to be utilized in commercial passenger vessels.

In the Dynamic AC (DAC) concept, the electrical system is similar to a conventional AC system but designed to operate at variable frequency. Figure 5 illustrates a system, where the main engine speed can be adjusted and the electrical system operates at a frequency proportional to the engine speed.

The generators in this concept are designed to operate within the specified frequency range. Especially the magnetic circuit and windings need to be dimensioned with care. The same also applies to other electromagnetic equipment that are directly connected to the variable frequency network, such as transformers and electrical motors.

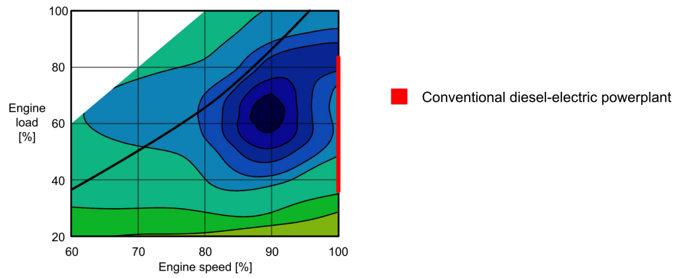

Figure 3: Example of specific fuel oil consumption (SFOC) diagram for an internal combustion engine

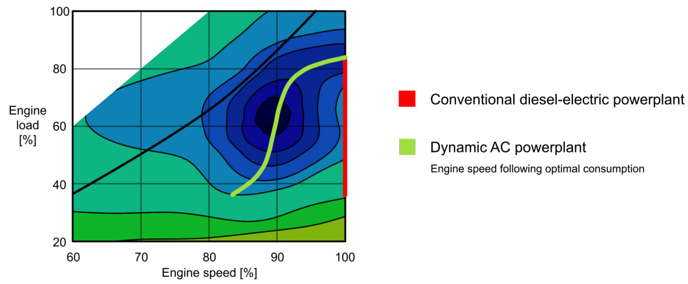

Figure 4: Comparison of SFOC between constant and adjustable speed power generation

Other equipment in the electrical network typically withstands variable frequency without notable changes in the design. Nevertheless, it is important to pay attention to the selectivity and protection functions so that they operate correctly through the entire frequency range.

System integration, including short-circuit and harmonic analyses, becomes more complex with variable system frequency. For example, variation of the reactances with the frequency must be considered.

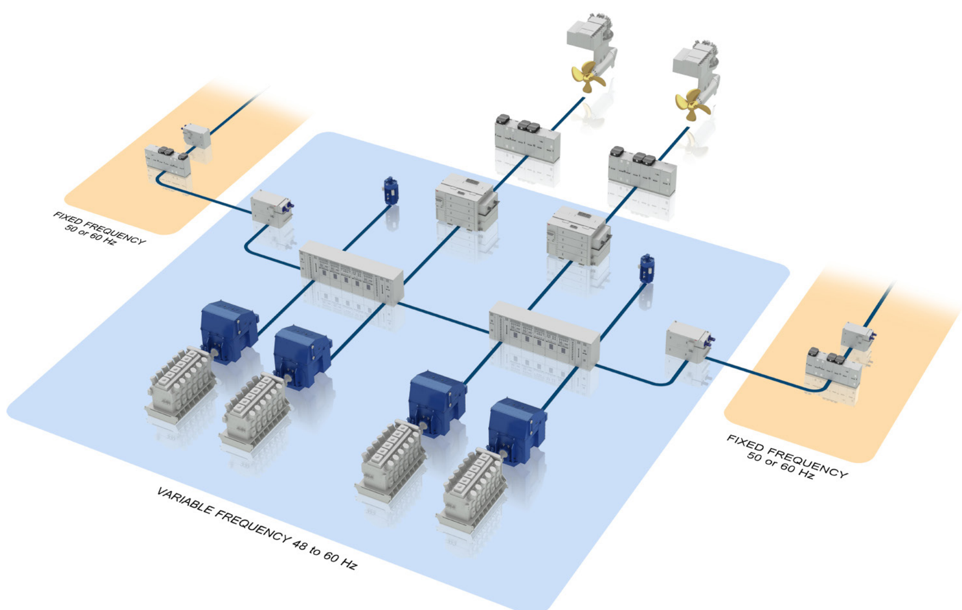

Figure 5: Illustration of Dynamic AC (DAC) concept

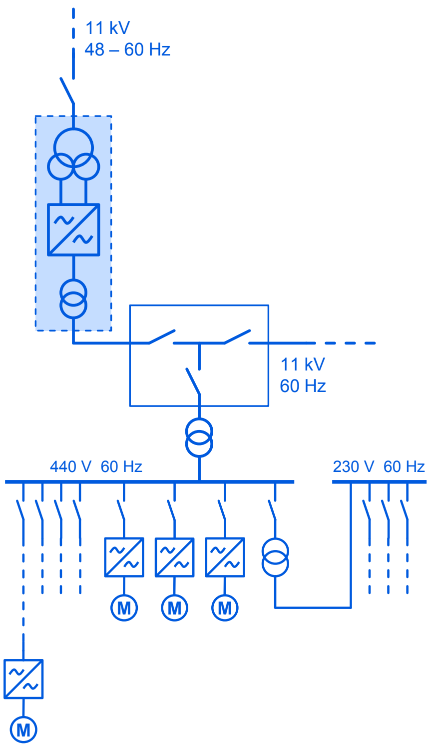

Figure 6: Single line diagram of a basic configuration for downstream distribution.

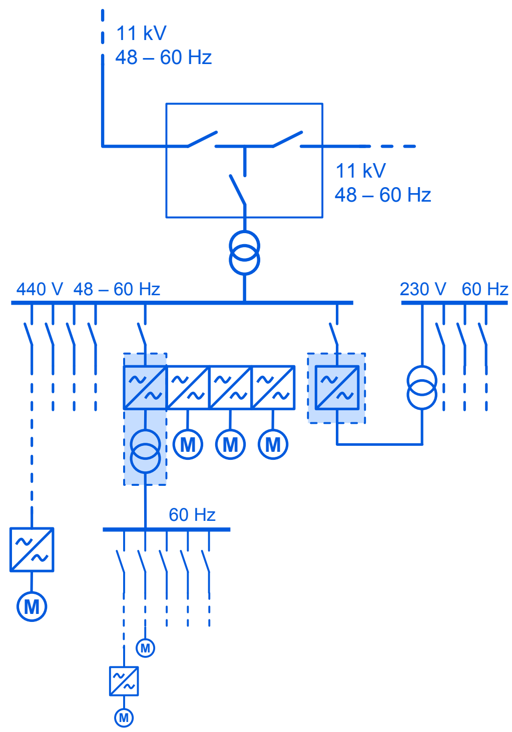

Figure 7: Single line diagram of an optimized configuration for downstream distribution.

Constant frequency for selected consumers

There are numerous rather small consumers in a vessel that are supplied by the engine room switchboards or by the fire zone substations. This low voltage distribution is normally 400 – 690 V with constant frequency, 50 or 60 Hz. The DAC concept is flexible with respect to the low voltage distribution and provides a few different configurations that can be customized according to the needs and preferences of the ship's Owner.

The basic solution is to use centralized frequency converters (island converters) to feed constant frequency at desired value to the engine room and to the fire zone substations. This is quite straightforward approach and allows the downstream distribution network to remain unchanged. The basic configuration is illustrated by a single line diagram in Figure 6.

Alternative solutions for downstream distribution

A more optimized solution is to feed variable frequency directly to the substations and split the downstream network into groups of variable and constant frequency supplies, see Figure 7. The island converters at the substation switchboards are much smaller than the centralized converters in the basic solution, as they supply only a portion of the loads with constant frequency. This configuration requires a little more engineering but has a great benefit of reducing the installed power and size of frequency converters.

In order to avoid unnecessary power conversions, the amount of consumers in the constant frequency network should be kept as low as possible. Several auxiliary and hotel loads are based on technology that tolerates variable supply frequency. This applies to motor drives, electronics, heating and lighting systems. Naturally the compatibility with variable frequency must always be confirmed, although nowadays many devices are already specified to operate on a wide range of supply voltage, for example 110 – 240 V, 50 – 60 Hz. With proper optimization, substantial part of the load can be supplied directly by the variable frequency without having to install large amount of island converters onboard.

To achieve higher level of integration,it is possible to combine the island converters with motor drives in multi-drive configuration. This solution would reduce the size of island converters even more and in some cases make separate converters for single motors unnecessary.

The low voltage distribution is an architectural design task as such. The DAC concept with its basic configuration allows an easy approach of using traditional method. However, close co-operation between the main power plant manufacturer and distribution designer can result in significant reduction of cost and space, as the complete system is optimized instead of single components.

Optimizing the performance

The Dynamic AC (DAC) concept by ABB provides substantial fuel savings for a large cruise vessel at moderate investment cost. An example with a typical operational profile shows 4 % reduction in annual fuel consumption, as even 6 % is possible in some cases. The electrical system in DAC is designed to operate at variable frequency, which allows for controlling the engine speed for fuel economy.

In addition to optimizing the consumption at the planned operational profile, the fuel savings are in place during the whole lifetime even if the vessel is later relocated to other routes. This provides additional degrees of freedom and flexibility in the ship design and route planning, even if the constraints by the world economy and customers' preferences are changing over the years.

The best energy efficiency over the lifetime is achieved, when the power management system is fully integrated with all the automation and advisory systems in the vessel. Having the information and operational history from different systems available, the optimization functions can adapt to different route plans and operating conditions as well as account for the changes in the performance of machinery and the vessel in general.

Dynamic AC is a platform for energy efficiency that can be integrated with other solutions, such as Battery Energy Storage Systems, Integrated Marine Automation, ABB´s Advisory Suite or Azipod® propulsion.

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