Next generation control

Traditionally, ship systems have been independent and segregated, largely due the fact that different subsystems are typically provided by different vendors. This leads to subsystems performing seemingly well independently, but less than optimally together, seen in a system-of-systems perspective.

However, system level performance of a ship can be optimised using a novel vertical and horizontal communication concept and closed-loop optimisation, as well as ABB Integrated Solutions for propulsion and remote control, power plant and main switchboard, power management, optimisation, on board advisory and integrated operations.

This impacts the technical performance of the systems, but also their overall fuel efficiency. This article describes how vertical and horizontal connectivity can improve the overall system level efficiency and facilitate smooth operation of a ship. In addition, the integrated solution enables increasing the level of automation, thereby making operation of the ship easier. The article also addresses how ABB's integrated solution utilises the vertical and horizontal connectivity and closed-loop system level optimisation to achieve optimal operation from Office to Propeller.

Vertical layers and horizontal segments of operation

In a complex system-of-systems, the overall system can be broken down to vertical levels and horizontal segments of hierarchies. In principle the vertical levels are defined by the time constants of the operational dynamics typical for that level. Systems working on the same vertical layer have approximately equally dominant time constants. The vertical layers can be divided into horizontal segments, where each segment corresponds to an individual subsystem or a device.

Each vertical layer can be divided into horizontal segments, which concern of certain aspect of the operation. An example of the horizontal segments is shown in Figure 2. The number of segments in each vertical layer is not necessarily the same. However, in the example figure three main horizontal segments can be determined: Propulsion, Fuel and Power, and Waste segments.

Next Generation Control – Connected vertical layers and horizontal segments

Typically the horizontal segments in each vertical layer are isolated. The information is not transferred automatically between the segments and it is

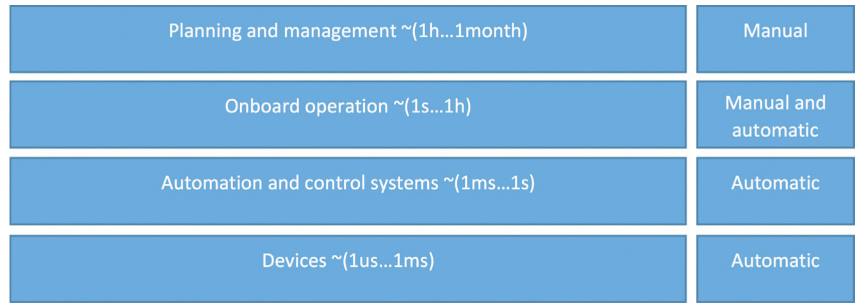

Figure 1: The vertical levels of hierarchies in ship operation and illustrative time constants for each level. The column at right describes whether the operation in this layer is automatic or manual

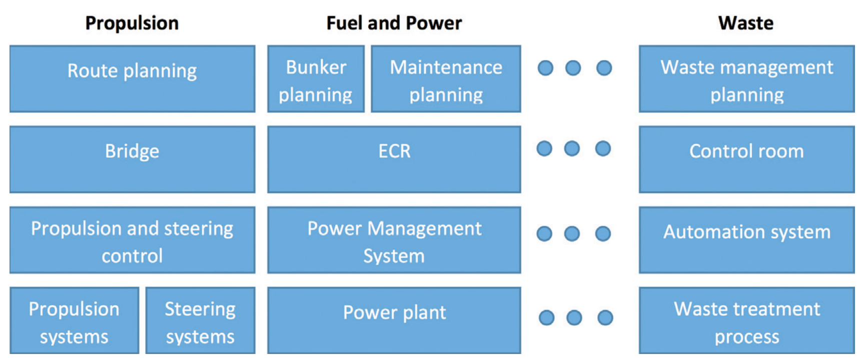

Figure 2: Horizontal segments in each vertical level

not utilised in the most effective way. In addition, the information available in higher levels of hierarchies is not typically automatically utilised in the lower levels to enable optimised system level control in the lower level. Similarly the information available in the lower levels is not typically automatically utilised in the higher levels to enable better planning and decision making. This leads to suboptimal system level behaviour.

The Next Generation Control systems provided by ABB aim at optimal system level operation by introducing novel vertical and horizontal communication, as well as an additional optimisation layer to enable optimal system level operation. The hierarchy of the Next Generation Control is shown in Figure 3. The idea of the horizontal connectivity is to enable the communication of the plans, decisions, constraints and capability information between the different horizontal segments.

The Adaptive closed-loop system level optimisation layer continuously estimates the performance of each subsystem or device based on measurement data and uses the estimated models together with the plans and forecasts from higher levels as well as the diagnostics and performance of the lower levels to operate the ship systems optimally.

Optimal closed-loop operation from Office to Propeller

The Next Generation Control concept described in the previous section has currently been implemented in ABB Marine systems as shown in Figure 4. The top layer contains the ABB Integrated Operations where the full cloud software and service offering can be utilised. The Remote Diagnostics System (RDS) for asset monitoring, maintenance and troubleshooting, and the ABB Advisory Suite for voyage and energy, offer the customers tools to plan the vessel operation optimally and continuously understand the performance and condition of their assets. Based on the planning performed in the top layer, the ABB Advisory suite calculates accurate operation profile forecasts by using semi-physical models trained using machine learning, and weather forecasts. The ABB Onboard Advisory Suite adaptively

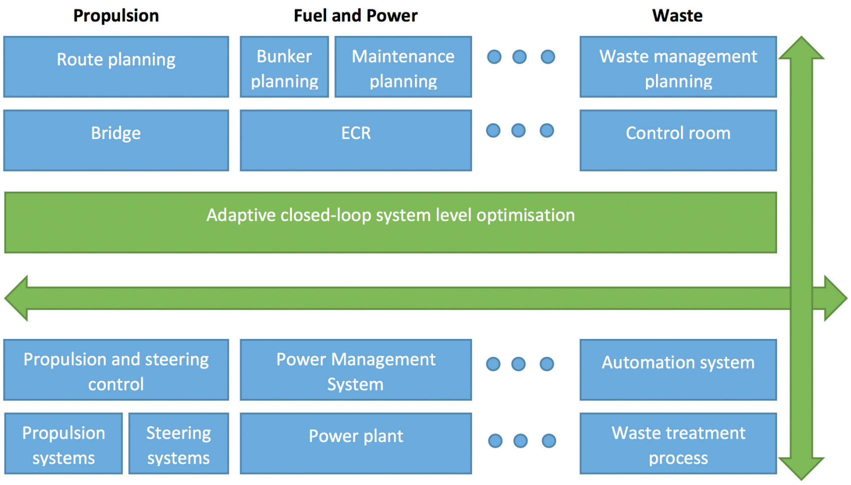

Figure 3: Next Generation Control with horizontal and vertical connectivity as well as the Adaptive closed-loop system level optimisation layer

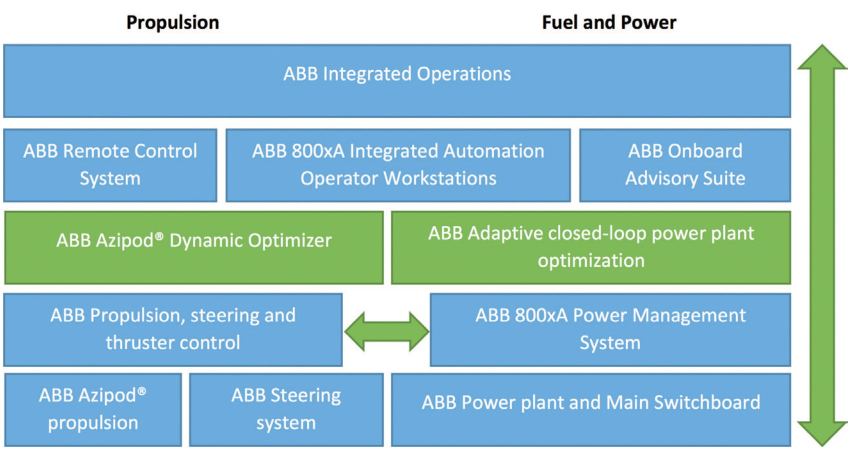

Figure 4: Currently available ABB solutions for Next Generation Control

estimates and tracks the performance of each diesel generator.

All ABB equipment is continuously monitored using ABB software solutions. The monitoring and performance information is automatically transferred to higher levels to enable the systems and users to use the information in decision making and planning. If performance of some device or component has declined, the ABB Integrated Operations centre will observe this and inform the user. In addition, ABB solutions for operation planning and closed-loop optimisation take the decreased performance into account and forbid the use of the faulty component, or at least minimise the running hours of that component until maintenance has been performed. Thus, all layers are continuously tracked in the performance of the systems and the ship and that information is used in planning and decision-making. This enables optimal operation from Office to Propeller.

Advisory Suite for power demand forecasting

The ABB Integrated Advisory Suite consists of technology to enable optimal speed profile calculation based on voyage plan, schedule, weather forecasts, and a ship and propulsion model that is partially trained using measurement data using machine learning. The model takes into account external operation conditions such as wind speed and direction, sea currents, waves, sea depth, etc., and calculates accurate motion response in various operating conditions. The motion responses as well as the forecasts of the other external operating conditions, and other variables such as speed, are used to calculate accurate propulsion power profile forecast for the whole voyage. The propulsion power model has been developed in collaboration with ABB Corporate Research Center (CRC).

In addition to the propulsion power profile forecasting, ABB Machine Learning models in the ABB Advisory Suite can predict the auxiliary power demand very accurately based on ambient conditions, time of day, operation mode, etc. An example of the ABB Machine Learning modelling prediction capability is shown in Figure 5.

Advisory Suite for adaptive SFOC curve estimation

The ABB Advisory Suite includes a module for continuous adaptive Specific Fuel-Oil Consumption (SFOC) estimation for each diesel generator or other power producer. The SFOC curve is estimated from continuous measurement data using technology developed together with ABB Corporate Research Center. Based on literature, the SFOC curve of a diesel engine can vary from 2-5 per cent during maintenance intervals. Therefore it is critical to track the SFOC curves of each engine in order to achieve optimal operation of the power plant at all times. In the ABB Advisory Suite the SFOC module includes a diesel generator monitoring user interface where the user is able to compare the currently measured performance of each individual diesel engine with respect to a baseline from a chosen baseline period, and even a baseline from manually entered data (e.g. test bench results). The SFOC curve is calculated separately for each fuel type. An example view of the SFOC monitoring user interface in ABB Advisory Suite is shown in Figure 6.

Adaptive closed-loop power plant optimisation using Advanced Process Control

The adaptive closed-loop power plant optimisation solution has been developed using ABB Advanced Process Control (APC) technology. The APC is an optimisation platform, which is designed for industrial Nonlinear Model Predictive Control (NMPC) implementation. It also performs nonlinear receding horizon state estimation and can utilise soft sensors to estimate non-measurable values or filter very noisy signal values. The APC can handle binary and continuous decision variables and is therefore ideal for solving production-consumption balancing and planning problems when forecasts of the input signals are available. The APC integrates seamlessly on ABB 800xA automation system.

Thrust optimization using Azipod Dynamic Optimizer (ADO)

The Azipod Dynamic Optimizer (ADO) is a software module for optimization of the towing angle between two or more Azipod® units. The towing angle has significant impact on the hydrodynamic efficiency of the propulsion system. The ADO utilizes measurement data collected from full-scale operation of the vessel, and uses machine learning to estimate a model that can be used to calculate the optimum towing angle in each operating condition. The ADO integrates seamlessly to the ABB Remote Control System. When the ADO mode is activated from the bridge, the towing angle is automatically optimised continuously.

Integrated Propulsion and Power Management System

The ABB Marine Power Management System (PMS) comprises a modular solution built on top of ABB 800xA Industrial Extended Automation system. The PMS has all the basic functionalities such as automatic start and stop of diesel generators, symmetric and asymmetric load sharing using droop or isochronous load sharing principle, etc. In addition, the PMS has seamless integration with ABB Propulsion Control System to enable optimal dynamic behaviour of the power plant even in case of manoeuvring, accelerations and slow-down situations. The closed-loop automatic power plant optimisation is designed for integration with the ABB PMS. The integration of the power management and propulsion control functionalities as well as the closed-loop optimisation enables the ABB integrated solution to provide significant fuel savings throughout the life cycle of the vessel.

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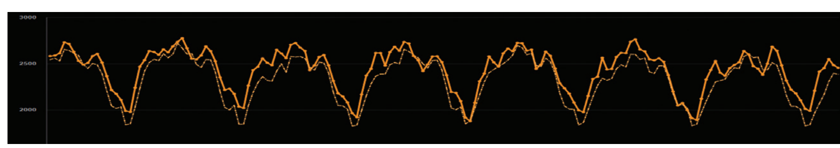

Figure 5: Actual (solid) and predicted (dashed) auxiliary power demand

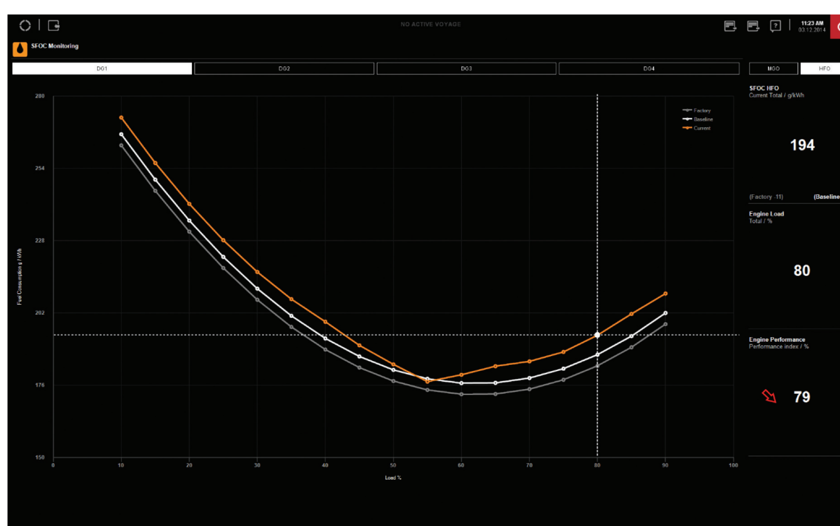

Figure 6: Adaptive SFOC curve estimation in ABB Advisory Suite