Closing the loop from office to propeller with ABB Ability™

In most ship segments, fuel cost is one of the biggest cost elements in the ship operation. In addition to fuel costs, fuel consumption and the efficiency of power plant operation play a major role in the total emissions of the ship.

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Traditionally, power plant control systems are designed only for maintaining the balance between power consumption and production. In diesel-electric power plants this typically means that the Power Management System (PMS) starts engines if the average load of the engines is above a predefined load-dependent start limit for a defined period of time. Similarly the engines are stopped if the average load is below defined load-dependent stop limits for a defined period of time. Typically there are constraints related to the operational situation, which define the minimum power plant capability required in the operational situation at hand. The constraints are related to minimum number of running engines, minimum dynamic capability, etc.

When a traditional PMS operates the power plant, the typical strategy is to share the load evenly with all running generators so that the load relative to the maximum output of each generator is equal. While this might be the easiest method to share the load between generators, this is not optimal in terms of fuel consumption. Moreover, the power plant assets, such as diesel generators, change over time. The specific fuel oil consumption (SFOC) characteristic curve that describes the amount of fuel the diesel generator consumes to produce one unit of electrical energy with respect to the relative load of the engine, changes over time due to wear and tear of the components. Based on data from tens of ships over several years, fuel consumption in terms of SFOC can increase up to 3-6 % between overhaul periods. In order to run the generators optimally at all times, an adaptive solution is needed.

Another major aspect in power plant operation is that traditional solutions do not take into account the forthcoming operation profile in determining which assets should be run to produce the required power. In ship operation, the operation profile is typically known in advance due to the fact that the ship has a mission and the operation is planned so that the mission is executed. In addition, weather forecasts are available to predict the forthcoming operating conditions.

This paper describes the vertical integration concept for power plant optimisation where operation planning is automatically connected to a predictive optimisation solution to plan how the power plant should be run. In addition to planning power plan operation, a low-level power plant optimisation has been implemented to run the power plant optimally in real-time to take into account the planned operation as well as the ongoing real demand. The models used for optimisation are adapted using real data to ensure that the operation is optimal throughout the life cycle of the engines in order to enable continuous optimal operation.

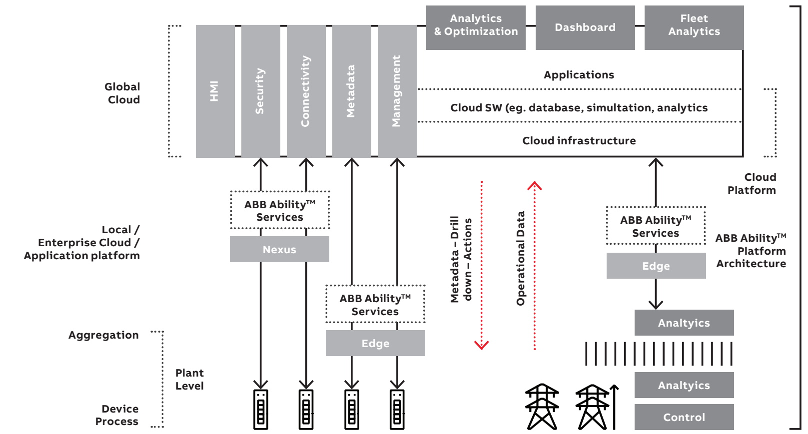

Figure 1: High-level architecture description of the ABB Ability™ platform

ABB Ability™ Platform

The ABB Ability™ platform is ABB's integrated industrial internet platform. It is the technology platform used to build and connect ABB Ability™ solutions, such as ABB Ability™ Marine Advisory System OCTOPUS software for marine operations management and optimisation. It comprises several digital-enabling technologies that can reside at the device, edge and cloud levels. It operates ABB's own technology and industrial software while leveraging Microsoft's enterprise-grade Azure cloud infrastructure, cyber security and services.

One such technology currently integrated in the Ability™ Platform is the Advanced Process Control & Analytics (APCA) suite, offering Analytics & Optimisation (A&O) services for monitoring, predictive diagnostics and closed-loop control. The APCA suite communicates its deployed advanced controllers and soft-sensors (i.e. analytics) with the ABB Ability Edge via OPC UA, an IoT enabled protocol, and can operate at the Edge, in a Distributed Control System, or at the ABB Ability™ Cloud.

In the ABB Ability™ Edge and Nexus, users can, among other options, filter, aggregate, analyse, process and store the data for redundancy and transmission between ABB Ability™ Cloud and the plant as illustrated in Figure 1.

Furthermore, in the ABB Ability™ platform, control and commissioning engineers can develop straightforward interfaces for tuning and configuring the parameters of deployed controllers as well as dashboards for data visualisation of key process variables.

ABB Ability™ OCTOPUS vertical integration concept

In typical ship operation, there are several types of planning and decision-making, typically performed by various people. There are several ways to define the levels of operation. In this paper, the decision-making and planning levels divide the operation into vertical levels, which are defined by the time constants of the operational dynamics typical to that level.

The highest level contains planning and management activities mostly taking place on shore, but also onboard the vessel, depending on the ship segment. The typical time constants in operation planning vary from hours up to months. Today, operation at this level is manual. The level below the planning and management is onboard operation. In this context the onboard operation consists of activities where a human is typically involved in decision-making or even in continuous control. The typical time constants in onboard operation vary from seconds to hours. The operation in this layer can be manual or automatic, depending on the case. The onboard operation layer commands the automation and control systems layer, which consists of several subsystems. The operation in this layer is fully automatic, except for backup functionalities that can be controlled manually. The typical time constants in this layer range from 1ms up to 1s. The lowest level of hierarchy consists of devices. The devices are individual devices or subsystems which are controlled by embedded control systems which concern only one system, such as propulsion motor and frequency converter, diesel generator, etc. Typical time constants in this layer range from microseconds to milliseconds. The operation in the device level is fully automatic, except for backup manual control functionalities.

In traditional operation of a ship, the information available in higher levels of hierarchies is not typically automatically utilised in the lower levels

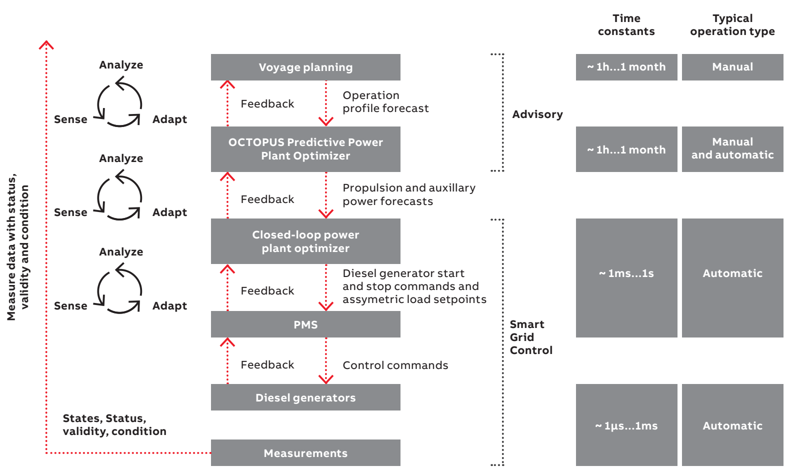

Figure 2: System hierarchies in voyage planning and optimal power plant operation

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 vertical integration concept enabled by ABB Ability™ applied to optimal power plant operation closes the loop from data to analytics and optimal control of the plant. In the highest level the operator onboard or onshore plans the voyage so that the mission of the ship can be executed as efficiently as possible given the operational constraints such as maximum speed and Required Time of Arrival (RTA). Voyage planning relies on knowledge of the ship model, predictions of forthcoming weather etc. Once the voyage plan has been done, the power demand during the voyage can be predicted in advance using the ship model, optimised speed profile and weather forecasts. In addition, the auxiliary power demand can be predicted based on ambient conditions, time of day, etc. By using the predictions of the forthcoming power demand, power plant operation can be planned in advance. This includes planning the charging and use of energy storage systems, figuring significantly in the operational efficiency in several operational situations.

The voyage plan and optimised operational plan for the power plant resources provide valuable information for the crew onboard when managing the daily operations. In addition, the optimised operation plan of the power plant can be fed to the lower level optimisation that runs in a second scale with prediction horizon of some minutes. The closed-loop optimisation integrated to the Power Management System (PMS) utilises the results of the higher level optimisation and the actual measured status and power demand of the power plant as well as accurate short term predictions in order to operate the power producers, such as diesel generators in optimal asymmetric setpoints and to start and stop the correct generators.

ABB Ability™ OCTOPUS Predictive power plant optimisation
The predictive power plant optimisation takes as input the predicted power demand over the whole voyage or voyage leg of the vessel, and minimises total fuel expenditure by determining the optimal load for each diesel generator for the duration of the voyage. The prediction horizon thus is expected to span tens of hours, and the sample time for optimisation is defined as one hour. The long-term optimisation utilises the model predictive control (MPC) paradigm to determine the optimal load distribution in the power plant over the voyage. In MPC, a process model is used to predict the plant state over a number of time samples (prediction horizon). An optimal control sequence for bringing the plant to a desired state is then determined for a shorter time span (optimisation horizon). This process is repeated at every sample time.

The prediction for the total power demand over the prediction horizon is delivered by OCTOPUS. Based on, or refined with operating data, various power demand models are included in OCTOPUS, which are able to deliver fairly accurate predictions. For example, the total propulsion power can be predicted based on the voyage plan, prevailing or forecasted weather conditions, and the time-variant vessel characteristics such as loading condition or the level of biofouling present on the hull. Similarly, the power demand of air conditioning on a cruise vessel can be predicted based on the number of passengers and the weather conditions.

OCTOPUS also monitors the specific fuel oil consumption (SFOC) of each diesel generator over the practical load range. Due to wear of the diesel engine, the resulting maintenance actions, and variations in fuel type or quality, the SFOC curve

can vary considerably over time. The impact on the optimal load distribution in the power plant is significant. Naturally in the absence of SFOC, monitoring the SFOC curve specified by the diesel engine manufacturer may be used as input to the power plant optimisation, but this should not be the default case.

The fuel consumption of the power plant is modelled as a nonlinear function of the diesel generator loads and online statuses. The optimisation takes into account the monitored SFOC curves of each diesel generator (DG), as well as any user defined constraints. Such constraints may be limits on the load of individual DGs, a requirement that some DGs are assigned equal load, or the exclusion of one or more DGs from optimisation altogether. In the last case, the power produced by the DGs excluded from optimisation is taken account as a feedforward variable when determining the optimal load for the other power producers.

The outputs from the optimisation are the loads of each diesel generator over the whole optimisation horizon, as well as the online statuses of the DGs. There are costs defined for manipulating these variables, which the optimisation takes into account. In particular, a suitably high cost may be assigned for switching a diesel generator on or off during the optimisation horizon. Frequent switching of the online status of a DG can thus be avoided.

Closing the loop with intelligent Power Management System
Power Management System (PMS) provides functions to remotely control power generation, and system topology. PMS also handles the state monitoring, and collecting information from various control locations. An illustration of the ABB Marine PMS user interface is shown in Figure 3.

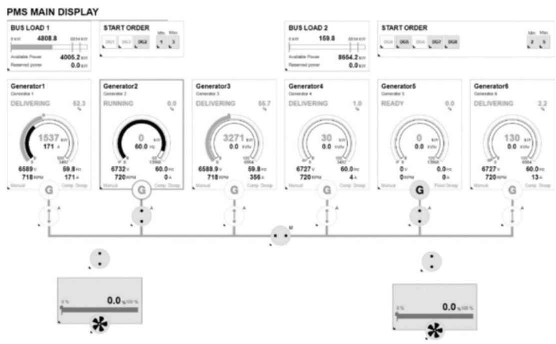

Figure 3: A user interface of the ABB Marine PMS

In order to operate the power plant optimally, the PMS has been modified to provide an additional interface for closing the loop from analytics to optimal control. The PMS takes care of standardising the interface between power management and an optimiser layer, so that the interface to the power plant hardware can be modified according to the actual specification and the optimiser interface can be left without modifications.

The interface between PMS and optimiser is simplified in order to provide required feedback and command signals for the optimiser, but so that PMS still retains overall responsibility over the power plant control, and can take over the control from optimiser if needed. This is important to make sure that the operational hierarchy and safety is ensured.

The closed-loop power plant optimiser running on top of PMS is able to request available engines for control, and choose which generator to use as a swing engine, to account for load shifts. Controls per engine are limited to starting, stopping, and a reference for desired working point. The power management system then provides, per engine, the signals for indicating the availability for optimising, current working point, maximum capability, and a running indication.

The optimiser utilises adaptive SFOC curves equally as in the OCTOPUS Predictive Power Plant Optimiser. The estimated SFOC will be used for sharing the load between the currently operating diesel generators to minimise actual fuel consumption. The minimisation is carried out using optimisation employing a short time prediction of the required power. The prediction horizon covers the start-up time for a diesel generator. The optimiser also has the ability to start a new diesel generator when needed and to stop a diesel generator when beneficial. With this function, the least fuel consuming combination of diesel generators will always be used. It is important to note that this solution may suggest a non-equal sharing of the load between the different diesel generators. The closed-loop power plant optimiser function runs in System 800xA as native code and is therefore fully integrated to the PMS.