DYNAMIC POSITIONING CONFERENCE
October 17 – 18, 2000

DESIGN

Optimizing and Evaluating the Performance of Power and Thruster Plant in DP Vessels with an Integrated Vessel Simulator

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Abstract

ABB has developed a unique Integrated Vessel Simulator (IVS) integrating vessel motion simulation and power system simulation for vessels with electric propulsion. The simulation tool is ideal for design, optimization and evaluation of diesel-electric propulsion system. Time domain simulation, dynamic positioning capability analysis, estimated short circuit level, and estimated harmonic distortion level are some of the features included in the simulator. An example of capability plot is shown. The power system simulator has been verified with full-scale measurements from sea-trials of the semi-submersible drilling rig West Venture, owned by Smedvig, where ABB delivered total integrated automation, positioning and power system. The performance of the simulator is excellent, with good correspondence with measured results.

1 Introduction

The marine offshore market consists of vessels and rigs for oil exploration, drilling, production, loading, pipeline laying, and supply. Typically, these operations demand high power, expensive installations for energy production, and safe and reliable equipment and operational management. Together with the production, drilling, utilities, positioning and hotel loads, the installed power may typically be in the magnitude of 25-50 MW [1,2]. ABB offer integrated diesel-electric solutions including power, automation, and positioning systems. Since all the power demanding loads like positioning thrusters/propulsion, drilling, and automation processes are connected via the common power system, there is a huge potential for energy and gas emissions reduction and operational safety increase by exploiting the integration even further. In the Integrated Vessel Simulator (IVS) the performance of an all-electric vessel may be investigated, during different weather situations while operating in DP mode or in transit. New functionality may be investigated for optimization of fuel consumption. Designing power plant configuration and thruster configuration are easy to handle using the capability and time domain simulation tool. Other purposes of the simulator are to integrate system knowledge of each subsystem to yield a more safe, reliable, and optimal overall performance without reducing safety margins. It is also proven to be a valuable tool for pre-tuning of control parameters, reducing time for commissioning and sea trial [3].

2 Simulator description

The IVS simulator is built as a user-friendly tool with easy configurable systems. Several years of expertise and research experience has been absorbed in the development of the simulator, yielding high accuracy dynamic performance of all components represented in the simulation tool. The simulator is developed in Matlab-Simulink, and a power library including all main components for electric propulsion system, are included utilizing simple drag and drop methods to configure new system. Lot of attention has been made to simplify the configuration of the system, yielding reliable input and fast investigations of how different configurations may affect the vessel performance.
Figure 1 shows the single line configuration for a typical semi-submersible drilling rig with a four-split switchboard system and eight thrusters. Figure 2 shows the simulation window where environmental conditions are set and vessel parameters are selected and with simulation and analysis tools.

The time domain simulation incorporates vessel dynamics with vessel motion controllers as Dynamic Positioning (DP), Manual Thruster Control (MTC) and Autosail controllers. These controllers provide the RPM references for the thruster drive controllers. The power system part of the simulator calculates power flow and fuel consumption, and includes dynamic models of variable speed thruster drives, distribution network and diesel generators. A load flow algorithm calculates the load flow and voltages in the power system network. The breaker status is easily changed, and the effects of different weather conditions on the power system performance and fuel consumption are clearly noticed and vice-versa, by

Figure 1: Single line diagram configuration for the power system part of the simulator.

Figure 2: Simulation window for environmental condition settings, simulation and analysis tools and vessel parameter setup.
breakers power system operational effects on vessel motion may easily be investigated.

2.1 Short circuit analysis

The short circuit analysis function calculates the three-phase fault levels for the main switchboards in the system. In figure 1, this corresponds to the 11 kV and the 690V switchboards. The calculation takes into account the breaker status in the high voltage system. The intention of the simulator is not to work as a full-scale calculation tool, but to give a close estimate.

The basis for the calculation is IEC 909. The simulator calculates the initial symmetrical short-circuit current I\(n\), which is the basis for power system ratings. Contributions from the generators and the direct online motors (if any) are included. Frequency converters are assumed not to contribute to the fault current. The cable impedances are not included, but this is considered to be negligible for fault current assessment in this type of network.

The calculations give a good approximations of the maximum prospective short-circuit currents that can arise in the network.

2.2 Harmonic analysis

The harmonic distortion level estimation is based an extensive simulation program where the propulsion drives have been simulated for different values of generator reactance and transformer impedance. A time domain simulation tool (KREAN) has been used for this purpose. The results are stored in tables. In the IVS the harmonic distortion level of the switchboard voltages are estimated based on these tables and the configuration of the power system defined by the breaker statuses in the single line drawings. The estimation is carried out for 100% and 50% thruster loads. Given a certain single line drawing the number of generators and thrusters connected to the switchboards and the splitting configuration will influence the harmonic distortion levels.
2.3 Capability analysis
An example of a capability plot is shown in Figure 3. A certain weather is specified and by using the capability analysis tool, the vessel's capability to stay in position is visualized by the plot of the most loaded thruster, at all angles for the total environment. By using this tool a study of different configurations, weather specifications may influence the positioning capabilities of the vessel. The capability analysis uses information about the power system configuration. Breaker statuses are detected in order to get which components that are connected to the power system. The thrusters will influence by the applied thrust force to the vessel. The connected generators and the other loads will influence the available power for thruster propulsion. This means that if several generators are disconnected and the available power for propulsion is limited, this will influence the capability, such that each thruster is not allowed to consume more power than the available power to prevent overloads and blackouts.

3 Verification plots, time domain simulations
The power system simulator has been verified with full-scale measurements from the sea-trials with Smedvig’s West Venture (Figure 4) in Japan and Norway. Several sequences have been logged during different weather conditions and different tests.

Figures 6-10 shows the verification plots, for a selected logging sequence. During this logging the rig was operating in DP, with harsh weather environment in the North Sea. As Figure 11 shows, the wind was 20-25 m/s, with a positioning accuracy of +/- 6 m. The thruster RPM references are taken from the DP controller output and set as inputs to the RPM controllers in the simulator. The measurements contain data for thruster RPM and power, active and reactive power at the switchboards and generators, frequency and voltage at the main switchboards and fuel consumption at the diesel engines. During logging all the data are collected through a serial link which contains a varying time delay from the actual time of the log and when it is collected in the logger. This time delay explains some of the horizontal deviations between the measured curves and the simulated curves.
The verification presented in the following figures, are thruster RPM for thruster no. 3, total power from all switchboards, voltage and frequency for switchboard no. 1 and total fuel consumption for switchboard no. 1. The verification results are very good and shows that the performance of the simulator is excellent with respect to capture the main dynamics of electric propulsion systems.

Besides thruster loads, other loads are specified as aggregate loads with a fixed active and reactive power demand, with disturbances added. Also detailed drilling loads may be included in the power system model.

### 4 Concluding remarks

The ABB integrated vessel simulator is presented. Dynamic positioning capability analysis and time domain simulations are tools provided by this simulator to back up configuration design and
to show how a vessel may perform in different weather conditions. Vessel motion, dynamic positioning algorithms, and power system performance and their cross-influence are integrated in the simulator.

The IVS proves to be a valuable tool for such design and analysis of dynamically positioned vessels. The IVS is used for:

- Optimizing the installation with respect to investments, operational costs, and safety margin improvements to fit the requirements in early design phase.
- Documenting the performance.
- Pre-tuning of controllers during project phase for faster commissioning and sea trial.

The simulator has been verified with measurements from the DP sea trials of the semi-submersible drilling rig West Venture, where ABB delivered total integrated automation, positioning and power system. This verification showed an excellent coincidence with measured station keeping capability and performance and power system behavior.
5 Concluding remarks

ABB wish to acknowledge participants in the Marintronics™ project, Smedvig, Rolls Royce Ship Technology, Marintek, and Norsk Hydro for valuable input and support for evaluating and verifying the IVS, and Norges Forskningsråd for partial funding of the project.

6 References

