Return to Session Directory

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Operations

Reducing NOx Emission in DP2 and DP3 Operations

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Abstract

DP capability and propulsion/thruster design for a DP2 vessel are based on maximum operational weather conditions and worst single failure. However, DP operations are often done in calm weather. Relevant requirements, e.g. Class requirements, states that the vessel must be fully redundant in such operations. This means that many thrusters and generators must be started during the DP operation. The power usage in calm weather will be so low that we are far below the ideal working conditions for the diesels and generators, and too low for the NOx catalyst to work.

This paper presents a thrust allocation method where the load is shared on the switchboards in order to bring generators above the catalyst limit without using extra thrust such as thruster biasing. The method leads to reduced emission of NOx.

Introduction

Environmental considerations have grown over the last years, and reducing emission of pollutants is an important goal. NOx is one of the pollutants that several governments have put an emission limit on. NOx acidifies soil and water, and is harmful for animals, humans and plants. Norway has committed to reduce the NOx emission with 30% of the estimated emission within 2010 (The 1999 Multi-effect (“Gothenburg”) protocol). The maritime industry is claimed to contribute to a significant part of the reduction.

There are two main modifications that can be done on vessels in order to reduce NOx:

- Engine modifications.
- Purification of the exhaust.

Purification of the exhaust gives the highest reduction of NOx, but is also the most expensive method [1]. Selective Catalytic Reduction (SCR) is the most common exhaust purification method. Urea or ammonia is added to the exhaust in order to convert NOx to N_2 and H_2O. A temperature between 270 and 500 °C is needed in order to obtain this chemical reaction. Many modern supply vessels have diesel-electric propulsion systems, and a standard generator for such vessels needs to have above 25-30% load in order to reach the exhaust temperature needed for SCR.

Class requirements states that DP Class 3 operations shall be done with separated power segments, and that a minimum of thrusters and generators must be connected on each power segment. Some oil companies also requires the same for DP Class 2 operations as well.

The Norwegian ship-owner Østensjø had recognized that most DP2 operations were done in weather situations that lead to too low load for SCR on each power segment. The separated power segments prohibited use of traditional power management system (PMS) functionality for asynchronous load on the generators. Østensjø therefore asked Kongsberg Maritime to develop a solution for this problem in the DP system.

Power production and power consumption

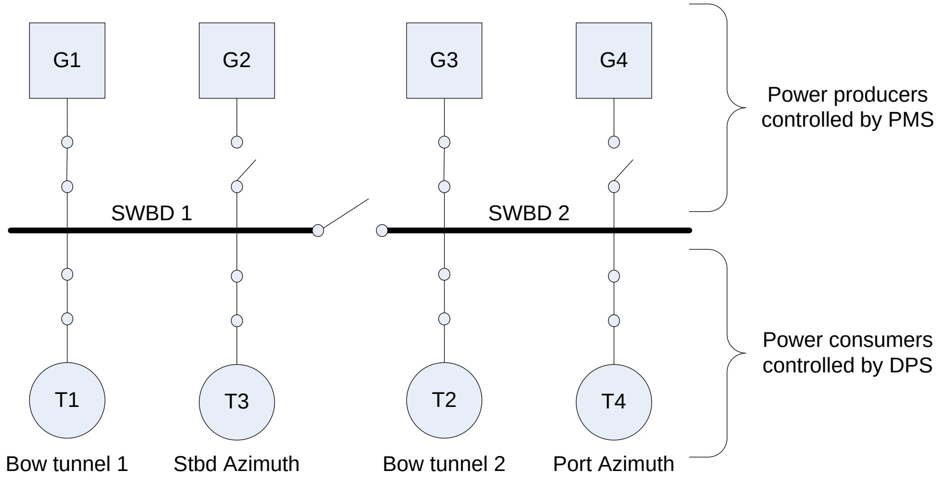

Figure 1: Typical power layout in DP2 operation.

Before we discuss strategies for the solution of the problem we shall take a look at the characteristics for the power producers and –consumers on a DP vessel. With consumers we mean thrusters and propellers, as they are the only one controllable from a DP system. Figure 1 show how the power distribution system is typically arranged in a DP2 operation. The vessel has one generator producing power on each power segment. Two thrusters are connected to each power segment.

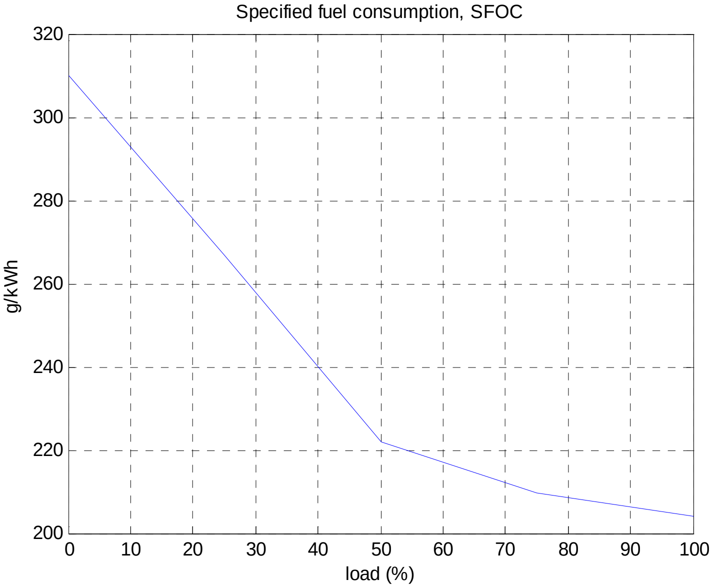

Figure 2: Specified fuel consumption measured on a typical generator for supply vessels.

A typical fuel consumption curve for a marine generator is shown in Figure 2. It shows us that the efficiency increases rapidly up to approximately 50% load, and is then flattening out. NOx cleaning can be done when the load is above 25-30%, but we see that increasing the load more will only give better working conditions.

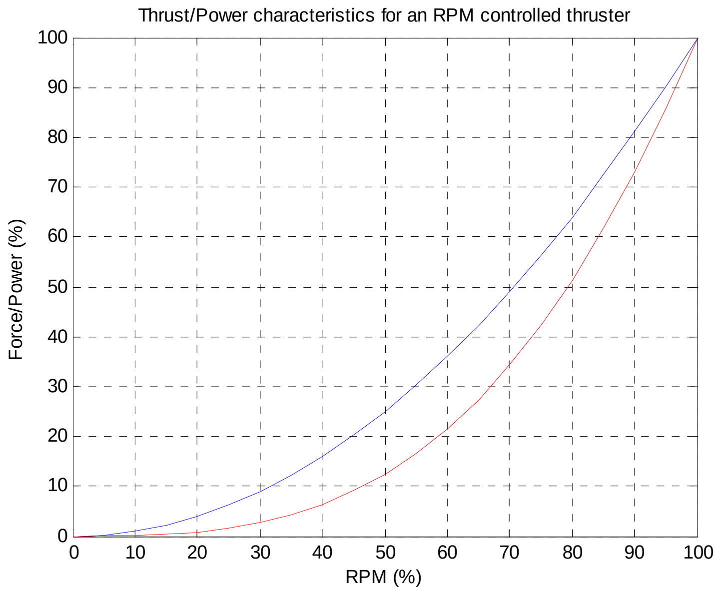

Figure 3: Standard thruster characteristics for an RPM controlled thruster. Thrust is blue color and power is red color.

We calculate with zero advance speed when a vessel is in station keeping mode. The standard formulas for thrust and power, see e.g. [2], can then be reduced to the following for an RPM controlled thruster;

$$T = T_0 \cdot n,^2$$

$$P = P_0 \cdot n,^3$$

where T_0 is the maximum available thrust, n is normalized RPM and P_0 is the maximum consumed power. The thruster characteristics are plotted in Figure 3. We notice that the power curve is very steep at high RPM.

Load share strategies

Thruster Force Bias

The most commonly used function to increase load is *Thruster Force Bias*. This function adds thrust on a group of thrusters in such a way that the resulting force vector is zero. This function is not suitable for the purpose of reducing emission, as it will lead to a significant increase in fuel consumption and emission of other pollutants than NOx.

Hibernating thrusters

The first strategy that was suggested was to allocate all thrust on the thrusters on one selected power segment, and let the other thrusters (on the other power segment(s)) be in a hibernate-mode. The hibernate-mode should be turned off if the power was insufficient on the selected power segment.

Some static simulations were performed to evaluate this strategy. The power situation was as shown in Figure 1. The thrust demand was equal to the demanded thrust in simulations with 12-14 m/s wind and 0.8 kts current for a typical supply vessel. This gave a demand of 12 tonnes to the bow thrusters and 7 tonnes to the stern thrusters. The hotel load (other consumers) was set to 100 kW on each power segment.

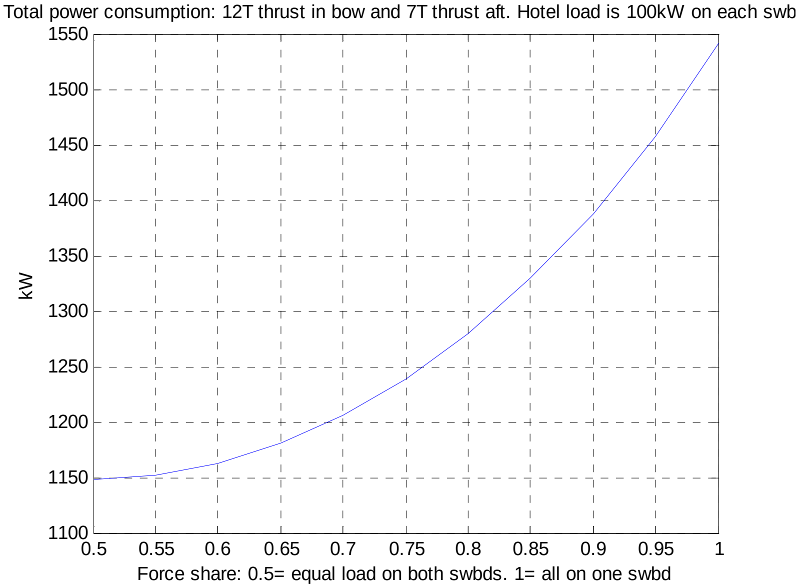

Figure 4: Power consumption when the demanded thrust is shifted from both swbds to only one swbd.

The total power consumption for the simulation is shown in Figure 4. The standard way to allocate thrust in a DP system will give a force share of approximately 0.5 between the two power segments. The figure shows that the power consumption will increase with 34% if the thrusters on one swbd are set to hibernation mode. An increase in power consumption was expected, because the standard thrust allocation will provide the minimum power solution for this vessel.

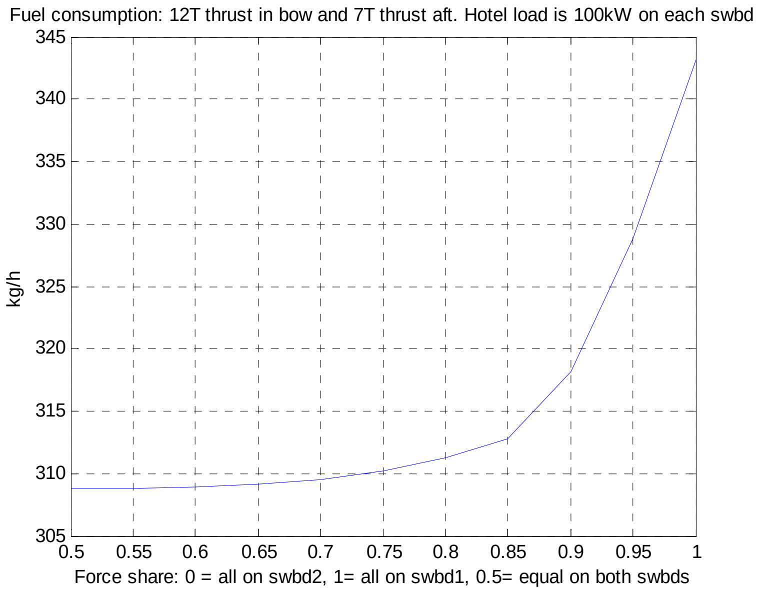

Figure 5: Fuel consumption when the demanded thrust is shifted from both swbds to only one swbd.

The total fuel consumption for the simulation is shown in Figure 5. It shows us that shifting the force totally to one power segment will give 11% increase in fuel consumption. This is not acceptable, and shows that the hibernate-method is not suitable as an environmentally friendly solution.

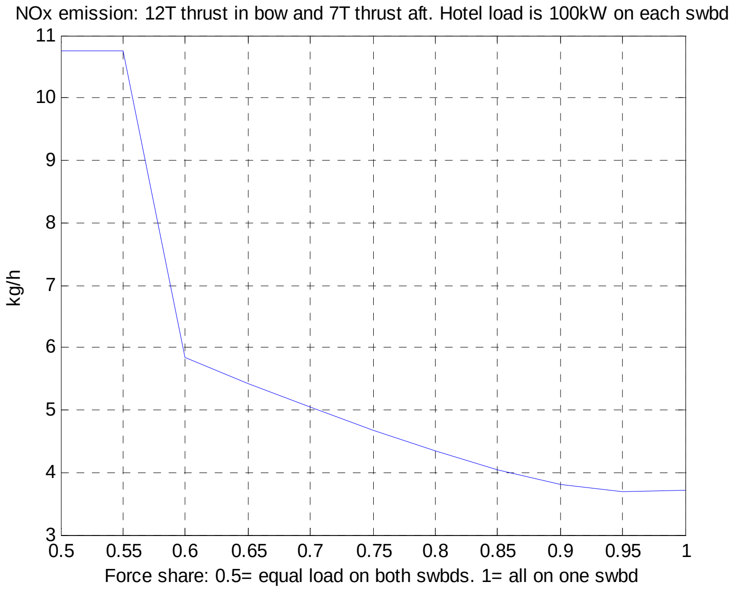

Figure 6: NOx emission when the demanded thrust is shifted from both swbds to only one swbd.

The NOx emission for the simulation is shown in Figure 6. We see that the effect of SCR is dramatic. The numbers used in the simulation is 8.5 kg NOx pr tonnes fuel with SCD and 35 kg NOx pr Tonnes fuel without SCR. We see that the hibernate method will give a NOx reduction of 66%.

Power Optimal Thrust Allocation

The simulations done for Hibernate mode showed that the fuel consumption was the problem with this strategy. But if swbd1 takes 60-85% of the force we get NOx cleaning and almost no increase in fuel consumption. This is shown in Figure 5 and Figure 6. These facts inspired us to try a new strategy were the power optimal thrust allocation [3] was extended to achieve the desired effect. The new power optimal thrust allocation function is called *increased swbd load*.

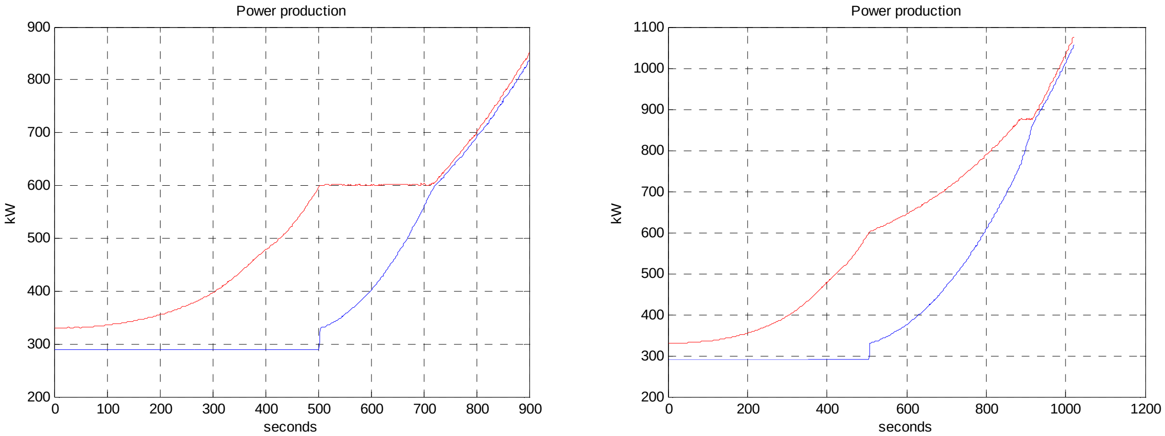

Figure 7: Power production on swbd1 (red) and swbd2 (blue) as the load increases. Swbd1 is selected to have increased load, and the desired minimum limit is set to 600kW.

The objective in the thrust allocation is normally to minimize the square thrust used.

$$g_0(t) = \frac{1}{2} \cdot \left(\sum_j w_j \cdot (t_j)^2 \right), \text{ where } t_j \text{ is the thrust of each thruster.}$$

The weights, w_j, are normally set to the inverse of the maximum thrust the thruster can provide. In this way we scale the variables so that the thrust will be uniformly with respect to the percentage of the maximum thrust. The *Increased swbd load* function will change the objective, and dynamically calculate the weights so that we obtain the desired power usage on one selected power segment. The calculation of the weights can be adjusted in order to obtain different ways to share the load at medium demands as shown in Figure 7. The figure shows how load is produced on the two power segments as the load demand increases. We will call the setup on the left side *setup1*. The setup on the right will be called *setup2*.

Simulations

Figure 8: "Edda Frende"

The power optimal thrust allocation has been tested with a vessel reference model (ship simulator). The simulator and the DP system was set up with the parameters for the Østensjø vessel "Edda Frende", Figure 8. This is a supply vessel with two bow tunnel thrusters (each rated to 1500 kW) and two stern Voith Schneider Propellers (each rated to 3500 kW). "Edda Frende" was the first vessel where *Increased swbd load* was implemented. The setup for the simulations was wind speed at 12 m/s (Harris spectra [4]) and sea current at 1 kts (fixed). The bus-bar was split in two with 100 kW hotel load on each side. One 2000 kW generator was connected on each side.

The results from the simulations are shown in Figure 9. Three cases have been tested. In the first case we let the vessel position with normal thrust allocation. In the second case we used *Increased swbd load* with setup1, and in the third case we used *Increased swbd load* with setup2. The limit for *Increased swbd load* was set to 30% for the simulations of setup1 and setup2. The simulations shows that normal thrust allocation will give too low load for SCR (must be above 25-30%), and that *Increased swbd load* makes it possible to engage SCR on one swbd. Calculations on the data from the simulations show that we will reduce NOx emission with 44% with both setup1 and setup2 compared to normal thrust allocation. Fuel consumption is increased with 3.5% for setup1 and 2.6% for setup2. The simulations show that setup1 gives a lot more dynamics on the swbd with low load than setup2.

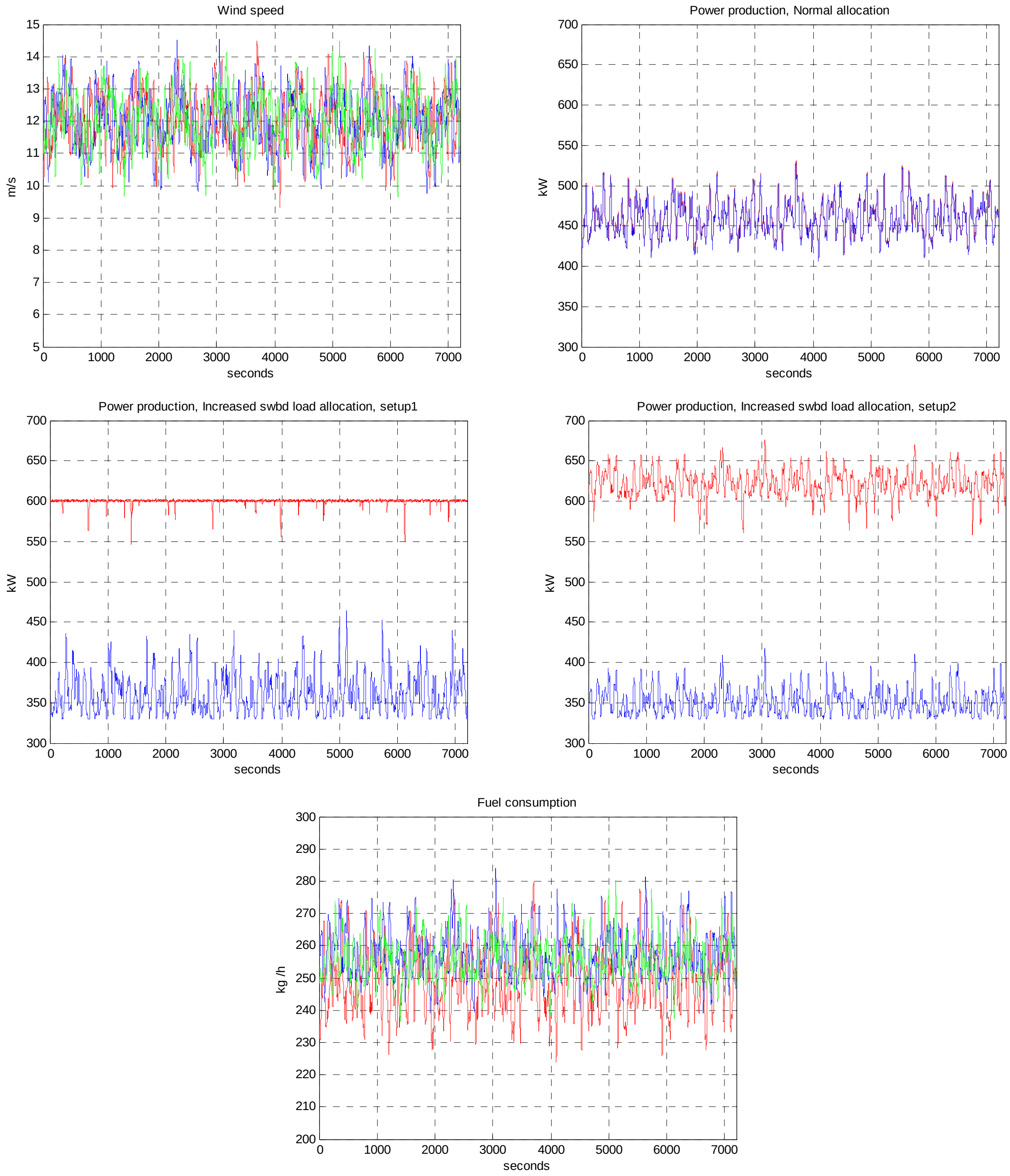

Figure 9: Simulation results. The following color code is used for 'Wind speed' and 'Fuel consumption': Blue: Normal thrust allocation. Green: Setup1. Red: Setup2.

Operations with closed bus-tie

Increased swbd load functionality is also possible with closed bus-tie (not ring-bus). This case demands a close interaction between the DPS and the PMS. The DPS will allocate thrust in order to achieve the desired consumed power on one specified power segment. The PMS must then control the load on the generators so that the current trough the bus-tie is zero, which is a common function in advanced power management systems.

Conclusion

Simulations for the hibernating thrusters method showed that reducing the number of active thrusters did not suit the purpose of reducing emission. Further simulations showed that the power optimal allocation function *Increased swbd load* gave a significant reduction of NOx with only a small increase of fuel consumption. The simulations showed that the objective used in *Increased swbd load* can be parameterized in different ways without significant changes of the emission.

The *Increased swbd load* function has been installed on the supply vessel “Edda Frende”. The feedback from the vessel is that the function works as desired.

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