DYNAMIC POSITIONING CONFERENCE
September 18-19, 2001

POWER PLANT SESSION

A New Concept for Fuel Tight DP Control

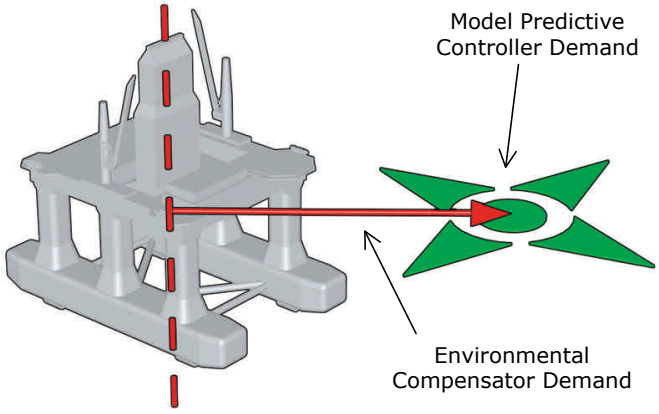
Ole Gunnar Hvamb, *Kongsberg Simrad*

Introduction

Compared to existing DP systems, the new concept named **GreenDP** ® is designed with focus on reducing fuel consumption. DPs have traditionally been designed to obtain a “bulls eye” station keeping performance in a changing environment. The new design emphasizes keeping the vessel within its operational boundaries. In deep-water operations, e.g. drilling, quite large operational areas may be permissible.

This new controller design consists of two main parts:
– *Environment Compensator*
– *Predictive Controller*

The *Environment Compensator* is designed to give a slowly varying thruster demand compensating for the average environmental forces. Conceptually the thrust generated is similar to the traditional DP-controller, but with much slower and smoother response. This demand will maintain the wanted position under average conditions, but reacts very leisurely to a changing environment. Thus, keeping the power consumption more stable and reduce the thruster usage.



The two components: *Environment Compensator* and *Model Predictive Controller*

The *Predictive Controller* brings our experience of motion prediction one step further by using a forecast of the vessel movement as an input for the controller. The *Predictive Controller* demand is taking action during more hefty changes in the external forces. The prediction is considered in conjunction with pre-set position boundaries. When the prediction indicates that the boundaries will be broken the controller reacts swiftly; assuring that the vessel will stay within the operational area.

Forcasted Fuel Reductions

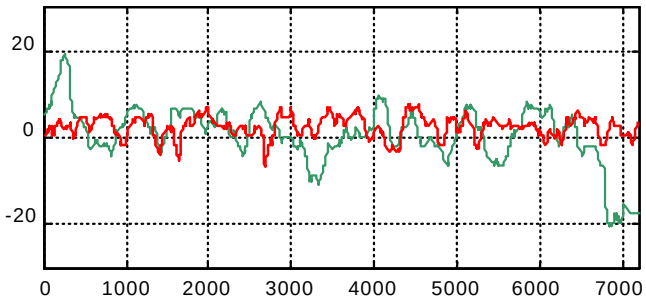
The new control strategy has been verified through detailed dynamic simulations representing weather conditions from the North Sea (typical conditions for a one-year operation). The fuel reduction is found to be approximately 20% over the year. Similarly, CO_2, NO_x and other gasses emitted to the atmosphere are reduced with about the same amount.

In addition to fuel reduction, the variation of the power consumption is reduced tremendously. The standard deviation in power variations has shown to drop by more than 50%, and in bad weather conditions up to as much as 80%. This will have several effects:

- Reduced wear and tear
- More optimal operation of diesels
- Lower maintenance cost
- Increased operational reliability

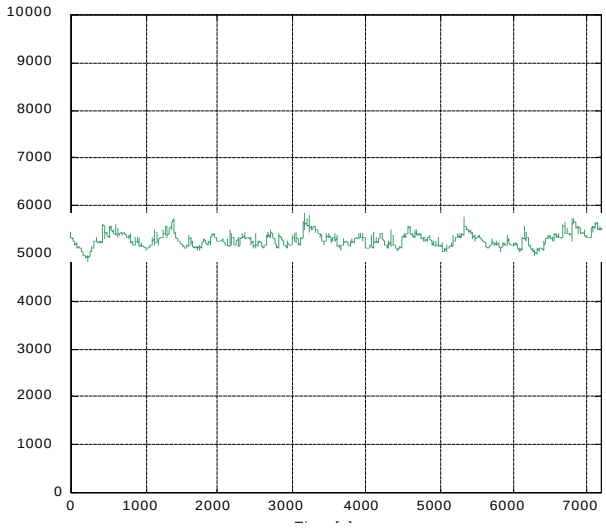
An example is shown in the next two figures. The upper graph shows positioning in North direction (m) for Normal DP and **GreenDP** ® as function of time (sec) for exactly the same wind, wave and current (typical for North Sea bad weather winter conditions). The graph below shows the corresponding electric power consumption (kW) of the thrusters. Since the power variations are much smaller the number of running generators may be reduced. Hence the diesel engines may operate more optimal and significant fuel saving may be obtained.

Positioning (m)



Red curve: Normal DP
Green curve: **GreenDP** *Ò*

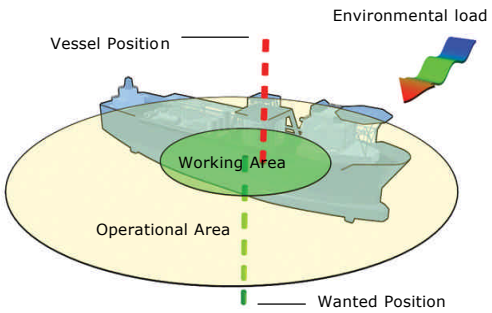
Power consumption (kW)



Red curve: Normal DP
Green curve: **GreenDP** *Ò*

How is *GreenDP* ® Working?

The concept utilizes new control technology with advanced modeling and real time optimization techniques to get best possible vessel performance within user defined operational constraints

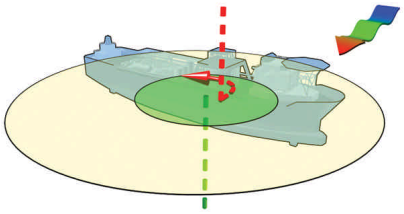


- Operational area, elliptic or rectangular in two levels as shown in the figure to the right,
  - The full *Operational Area* and
  - The *Working Area*
- Maximum dynamic thrust to be used

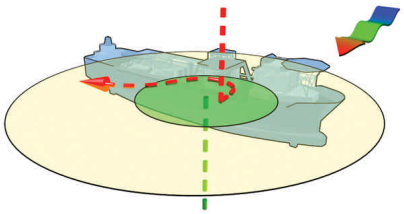
The vessel is free to move about in the *Working Area*. The user may influence the control through his setting of operational constraints. By limiting the amount of dynamic thrust to be applied, early actions will be taken preventing overstepping the boundaries.

Control actions are optimized according to predicted future vessel motion as shown in the three cases below, not only its present movements as normally done in DP systems. The arrows indicate predicted trajectories and the dot the present position of the vessel.

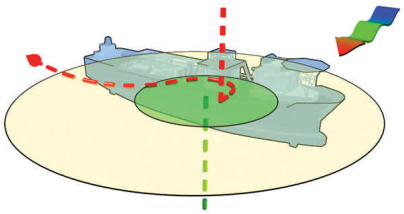
Vessel predicted to stay inside *Working Area*
- Compensate the average environmental load only
- No additional dynamic thrust needed



Vessel predicted to violated *Working Area*
- Compensate the average environmental load
- Find additional dynamic thrust reducing the predicted overshoot as a best compromise between overshoot and thrust usage
- “Cost tags” are associated with thruster use and overshoot



Vessel predicted to violated *Operational Area*
- Compensate the average environmental load
- Find additional dynamic thrust bringing the forecasted vessel position inside the *Operational Area* and as close to the *Working Area* as possible as a best compromise between overshoot and thrust usage. A maximum permissible dynamic thrust is used if necessary
- “Cost tags” are associated with thruster use and overshoot



Control Methodology

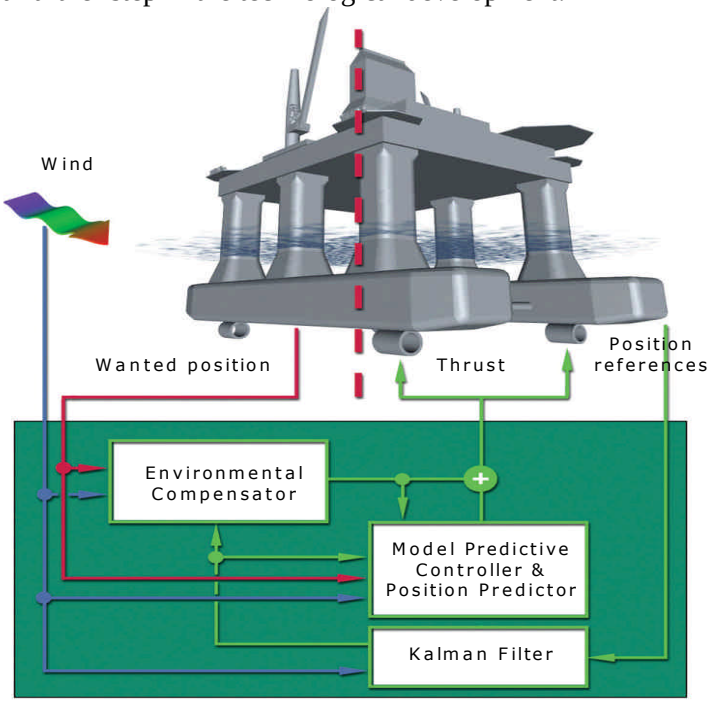
GreenDP ® is a result of a large R&D project carried out in Kongsberg Simrad since 1997 as part of the Norwegian Research Counsel's program "KLIMATEK" (climate technology - aiming at reducing outlet of climate gasses). The program is a co-operation between Norwegian government, Oil Companies and the offshore equipment industry. Kongsberg Simrad has worked together with SINTEF (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) in developing this new control methodology. Shell, Norwegian Petroleum Directorate and Saipem have also been engaged.

The control consists of three major components:

- *Environment Compensator*,
- *Model Predictive Controller*
- *Position Predictor*

While the *Environment Compensator* is based on the mature theory of Optimal Control used in DP systems for a long period of time, the *Model Predictive Controller* is based on a modern theory called **Non-linear Model Predictive Control** (NMPC). As the name indicates the NMPC has a predictive behavior. By continuously solving an accurate non-linear dynamic mathematical model of the vessel, the future vessel behavior is forecasted. This is the task of the *Position Predictor*. Since the mathematical model of a DP vessel is non-linear, non-linear theory must be applied.

Earlier Model Predictive Controller (MPC) has been applied to industrial plants. The non-linear version represents a further step in the technological development.



The **GreenDP** *Ò Controller*

The *Environment Compensator* is designed to give a slowly varying thruster demand compensating the average environmental forces. Conceptually the demand generated is similar to the traditional DP-controller, but with much slower and smoother response. The input to the *Environmental Compensator* is the measured wind and estimated current calculated by the DP *Kalman Filter*, and a forecast of how the vessel is going to move, the *Wanted Position* or *Reference Trajectory*.
The trajectory represents the desired behavior of the vessel when doing a change of position or following a desired track path. The unknown forces from waves and currents are all parts of the estimated current velocity.

Due to its nature the system will not instantaneously react to a wind gust unless the *Position Predictor* detects that actions must be taken immediately. Hence unnecessary sudden thrusting is avoided.

The *Model Predictive Control* algorithm is much more complex and time-consuming in computing than the traditional controller designs generally used for DP.

The NMPC algorithm has three computational demanding steps:

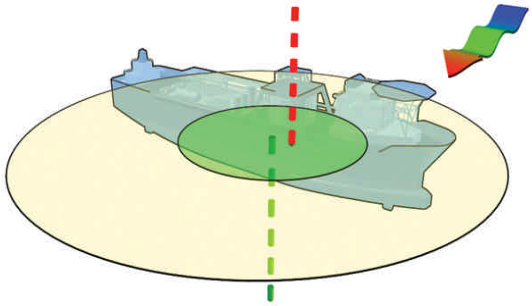
- Prediction of movement from the non-linear vessel model
- Finding the step response mapping
- Defining and solving the optimization task of calculating the “best possible” thrust to be applied.

In order to handle these increased computational requirements, Kongsberg Simrad has developed a new and more powerful control computer, the SBC500.
The *Position Prediction* is made by taking advantage of the mathematical model of the vessel used in the *Kalman filter* of the DP. The forecasted position and heading are found step by step for the whole prediction horizon. This is used as a basis for the step response mapping that describes how the predicted trajectory will change with changing thruster demands.

The optimization is formulated as a quadratic programming problem with linear inequality constraints associated with the physical thruster limitations. One of the great benefits of the NMPC is the way of incorporating constraints on the predicted-, measured-, and estimated variables. The predicted position trajectory is constrained by inserting position boundaries given by the physics of the marine operation itself. Additionally restrictions may be put on the vessel velocity or rate of change in thrust demand.

There are two different constraints in the optimizing algorithm:

- “soft limits” (which are weighted quadratic in the optimization) typically the *Working Area* boundary
- “hard limits” (weighted linearly) typically the *Operational Area* boundary



Operational limits (Working Area - "soft" inner boundary and Operational Area - "hard" outer limit)

These constraints have a very different behavior when optimizing. A quadratic weighted constraint is adding smooth demand when predicting overstep, while a linear constraint will allocate as much demand as necessary (or allowed) to keep the vessel within the constraint.

In the traditional DP controller there are no outer operational limits. This controller is designed to keep a "bulls eye" performance and give a proportional demand like a rubber band being tied to the wanted position and the center of the vessel. There is also a damping keeping the velocity as close to zero as possible.
With the new controller the demand is, as mentioned above, split in two parts: the demand from the *Environmental Compensator* and the demand from the *Model Predictive Controller*.
The "cost function" in the NMPC optimization is configured to minimize only the variables that overshoot the constraints. In contrast to the continuos restoring force demand generated between the vessel and its wanted position in the traditional controller, a repulsive force is generated between the vessel and its boundaries by the NMPC controller.

Thus, in the new controller design, the *Environment Compensator*, generates a leisurely attractive force towards the wanted position whilst the *Model Predictive Controller* adds a more swift demand repulsive to the predicted overshoot of the limits.

The *Environmental Compensator* will always provide a thrust demand making the vessel maintain its position in average and secures zero steady state position deviation. But since it reacts very leisurely larger deviation from the wanted position may be experienced when the external forces change.
During normal operation, without great changes in the external environment, the demands allocated to the thrusters come exclusively from the *Environmental Compensator*. Only during more dramatically changing external forces the demand from the *Model Predictive Controller* is added as a result of predicted overstepping pre-set limits for the *Working*- or *Operational Area*.

Since the *Environmental Compensator* is designed to give a smooth and slowly varying demand, the change in power usage is also much more relaxed. There are less peaks of high consumption and the power level is very steady. The average force needed to stay on positioned is the same as for the traditional DP since the new controller design does not change the physics.

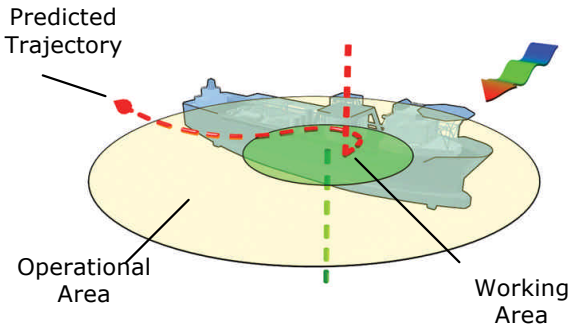
Therefore, the power level needed over time is lower and the number of generators running can be kept lower. Since the rate of change in power consumption also is significantly reduced, generators do not need to pick up load as quickly.

Optimization

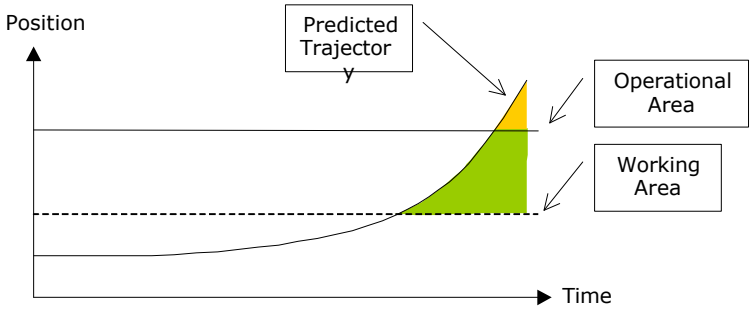
The operational constraints are the clue to the optimization, and can be set to cover station keeping, position moves as well as track operations.

The objective of the optimization is to find the smallest thrust vector which will bring the predicted vessel trajectory inside (or as close to the *Working Area* as possible) taking into account the "cost" of thruster usage and overstepping the different boundaries:

- Thrust (fixed "high" quadratic cost)
- *Working Area* ("moderate" quadratic cost outside boundary)
- *Operational Area* ("very high" linear cost outside boundary)

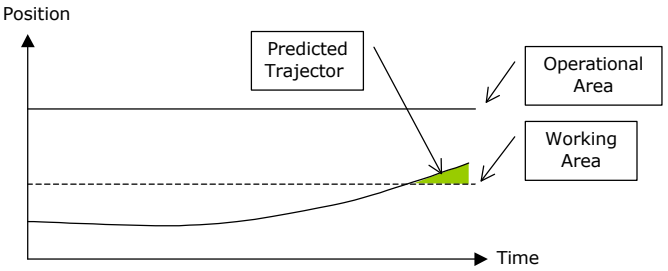


In order to solve this optimization, the *Position Predictor* is used to find the anticipated future vessel motion, the *Predicted Trajectory* within our prediction horizon assuming that only the thrust provided by the *Environmental Compensator* is applied. See figure below.



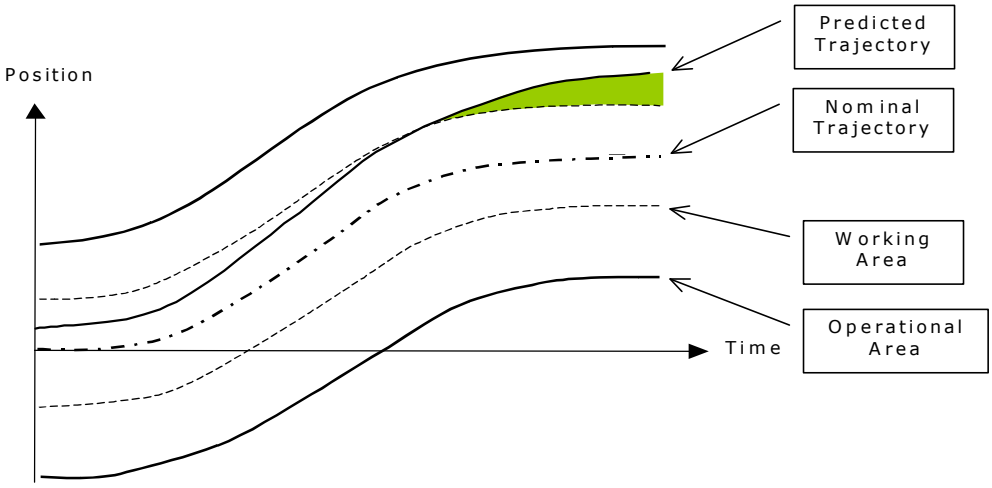
In the figure the *Predicted Trajectory* oversteps both boundaries. The optimizer will then find the optimal dynamic thrust keeping the new *Predicted Trajectory* as close to the *Working Area* as possible. Note that the new *Predicted Trajectory* will always overshoot the *Working Area* boundary because there is a "cost" associated with the use of thrusters and no "cost" of staying inside the *Working Area* boundary.
On the other hand it is not necessarily true that the vessel really will move that far because the prediction horizon is long and the environment may improve during this period.

The optimization is solved as a *Dynamic Quadratic Programming* problem where the step response mapping gives the relationship between applied thrust and vessel trajectory. The result is indicated in the figure below.



After the optimization is completed, the sum of the thruster demands from the *Environmental Compensator* and the *Model Predictive Controller* are treated by the *Thruster Allocation* and applied to the thrusters.

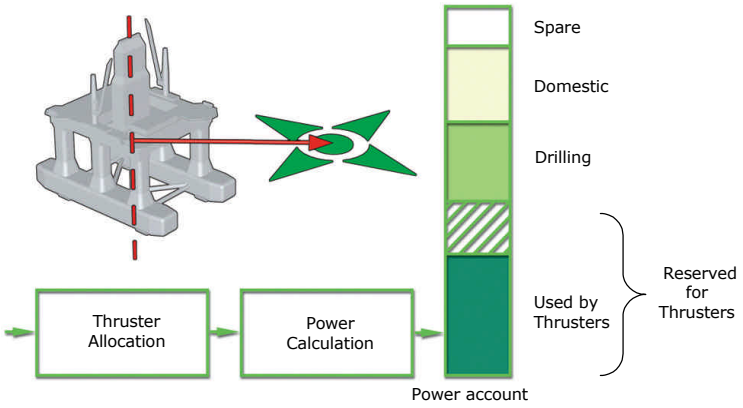
The boundary conditions described in this example are typical for pure station keeping. When doing a position change the boundaries will be time dependent following a *Nominal Trajectory*, the most desirable vessel path. See figure below.



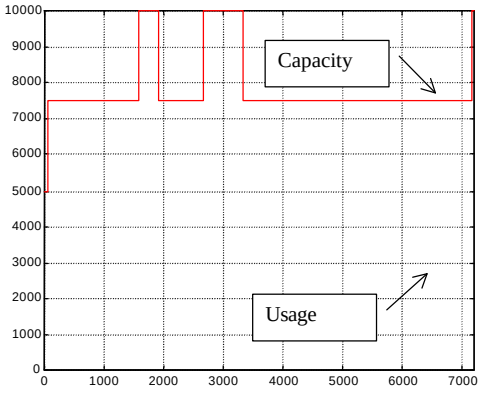
In this case the *Environmental Compensator* also provides necessary acceleration and deceleration forces in order to for the vessel to follow the *Nominal Trajectory*.

Power Management System

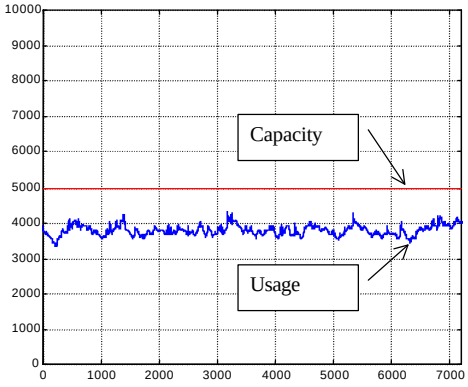
Since the new control concept requires very little dynamic thrust to keep the vessel on location, the dynamic thrust range can be restricted. Due to the controller's predictive nature, it may start reacting early with a low dynamic thrust in stead of late with a quite bigger one.
As a consequence the Power Management System may reserve a certain amount of power for the thrusters, and the DP will stay within this limit.
The control system is based on the average needs to compensate the environment and the worst case dynamic allowance, can calculate the amount of power to be reserved. This is illustrated in the figure below.



This also implies that automatic start and stop of generators performed by the Power Management System can be made more intelligent, with significant smaller margins which will give an additional effect on the fuel saving.
This is illustrated in the next two figures showing power consumption and running capacity (kW) using normal DP and **GreenDP** ® respectively as a function of time.



Normal DP



GreenDP ®

Normally automatic stop is not used in DP operations. With a much smoother power demand, however, the main reasons for increased power needs are changes in the environment.
Since the environment is generally not changing very quickly (except for e.g. loop current in the Golf of Mexico) and the system is estimating its own power demands to be reserved by the Power Management System automatic stop may be feasible.