Navigating the Mooring System Landscape

A White Paper
on the application of
multi-objective optimisation
techniques to mooring system design

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CHALLENGE

In the search for cost effective mooring system solutions, designers are often faced with many avenues that can be explored, as well as competing design requirements and aims. This can result in the need to carry out extensive numerical analyses of highly-coupled systems in order to optimise a design. The suitability of the design must then be verified across a broad range of environmental conditions associated with expansive farm array layouts e.g., floating offshore wind turbines (FOWTs). Furthermore, the analyses may have to be repeated if design changes are subsequently made. These issues are further compounded by the complexity associated with identifying practical mooring systems in challenging and diverse sites.

This white paper introduces multi-objective optimisation (MOO) techniques that can be used to efficiently explore parameter spaces. This enables the identification of cost effective mooring configurations that may otherwise remain undiscovered by conventional design approaches. Through automation of the design optimisation and down-select processes a set of potential candidates can be rapidly identified and verified.

BACKGROUND

There are several approaches which can be applied to the mooring system design process, which will be discussed in this section and are illustrated in Figure 1.

Iterative methods can be used to adjust a design until particular criteria are satisfied. The starting point for this approach might be a previous design combined with in-house expertise. However, with this approach it is either difficult to determine the effect of altering multiple parameters simultaneously or onerous to alter one parameter at a time. Considering the unique coupled behaviour of the floating system, this approach may result in a suboptimal mooring system in terms of its cost, function or serviceability. Furthermore, any subsequent changes made to the design necessitate re-running of the design load cases.

As the name implies, a brute force approach trials combinations of parameter values. It is therefore computationally demanding, e.g., if applied to a simple four-parameter system (such as component size, footprint radius, line length and pretension), each comprising N values, N^4 computations for each design load case would be required. The method is non-optimal because a large portion of the designs may simply be unfeasible and the search space between the N-dimension

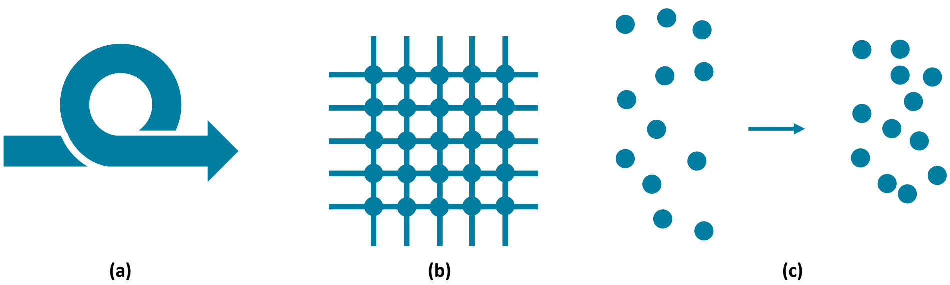

Figure 1: Search strategies for (a) iterative, (b) brute force and (c) evolutionary approaches (convergence over generations).

grid remains unexplored: optimum solutions may therefore be missed.

Heuristic search methods such as evolutionary algorithms are significantly more efficient than iterative or brute force methods because candidates with favourable characteristics are carried forward to the next generation in an effort to guide the population of solutions towards an optimal state. The end result is a set of solutions which are a compromise of the aims of the analysis (e.g., minimise system cost) and satisfy any constraints (e.g., component safety factors). Some manipulation is usually made to the population in order to preserve diversity across generations.

AN EFFICIENT APPROACH

Since 2018, TTI Marine Renewables Ltd has been developing a multi-objective optimisation tool to rapidly identify candidate mooring solutions for a set of parameters, objectives and constraints, with each candidate subjected to multiple design load cases. The algorithm works alongside mooring system software, Orcaflex, with the tool able to drive the set-up, execution of simulations and extraction of results. The tool is applicable to concept level, Front End Engineering Design (FEED) all the way through to detailed design. Referring to Figure 2, in the context of mooring and cable system design, optimisation parameters might include:

- **Variables** Component properties (including material type), line lengths, number of lines, footprint radii.
- **Objective functions** Minimise characteristic tensions, platform motions, CAPEX and maximise device performance.

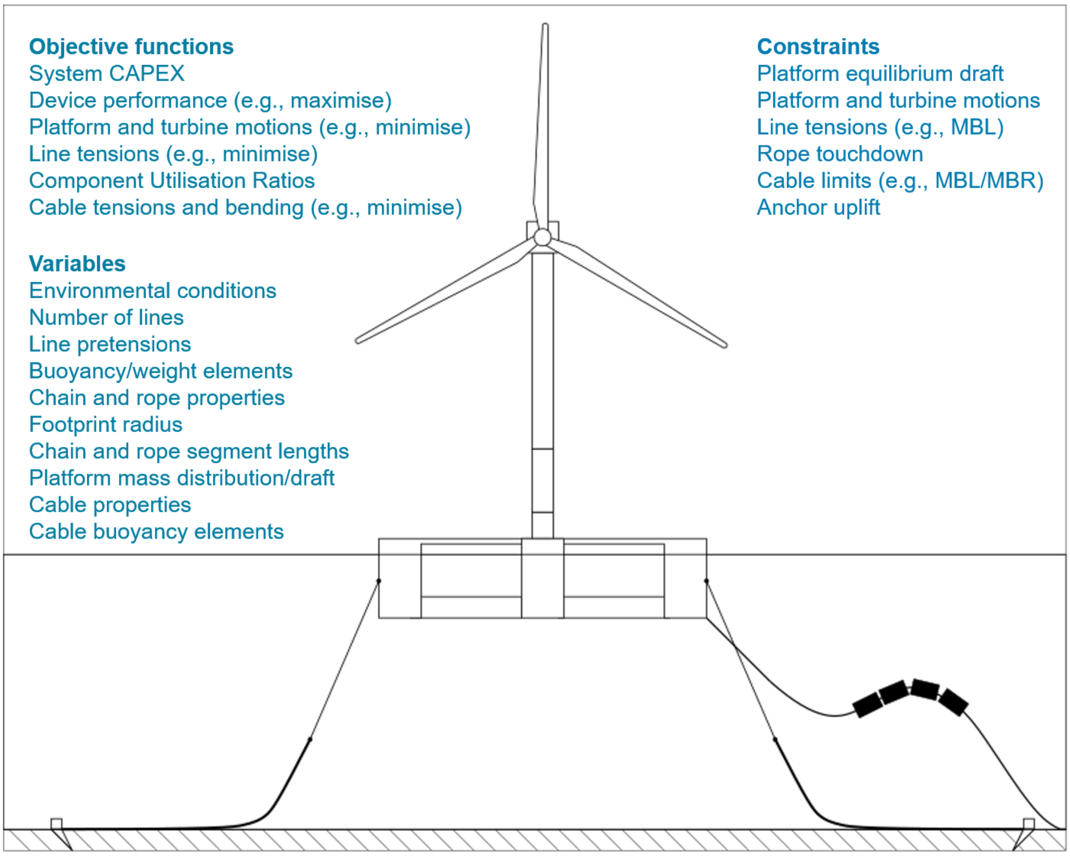

Figure 2: Example optimisation parameters that can be incorporated in the analyses.

- **Constraints** Component capacities, platform motion limits, anchor uplift or rope touchdown.
- **Design Load Cases** Operational and/or survival conditions.

Our approach has been to maximise the flexibility of the tool and hence any model object can be manipulated, e.g., for FOWTs this could include parameters related to the turbine, platform and export cables, associated hardware and more. The analyses can also be carried out for the purpose of site planning, e.g., multiple turbines could be modelled simultaneously for sites which have a range of water depths.

A mooring designer may, for example, be interested in minimising three competing objective functions (e.g., characteristic line tensions, platform excursions and CAPEX). In this case a compromise may exist between the objectives, e.g., in order to minimise platform excursions, higher characteristic tensions may need to be tolerated incurring higher CAPEX (as illustrated in Figure 3). Taking a farm-level view, these analyses can be used to determine the impact of mooring system design on the LCOE of the array, for example the influence of mooring system design conservatism on annual energy production (AEP).

Compared to iterative methods the end result of our approach is a pool of potential candidates which can be used to inform FEED activities. The down-selection process considers the relative merits of all candidates in the population, enabling a suite of optimum solutions to be quickly identified. Alternatively, it can be used to provide a high-level overview of the mooring system landscape for the supply chain to explore how their technologies can fit with emerging market opportunities.

Global analyses trends in both the input parameters and objectives can be explored, including how these have evolved through the generations e.g., there may be a trend towards a particular range of anchor footprint radii or component sizes etc.

The algorithm can also be instructed to allow the free-selection of input parameters, or to consider each value in a parameter set as a parallel optimisation task. The latter option has been used to study the impact of altering: i) the number of lines as well as ii) synthetic rope material on mooring system response.

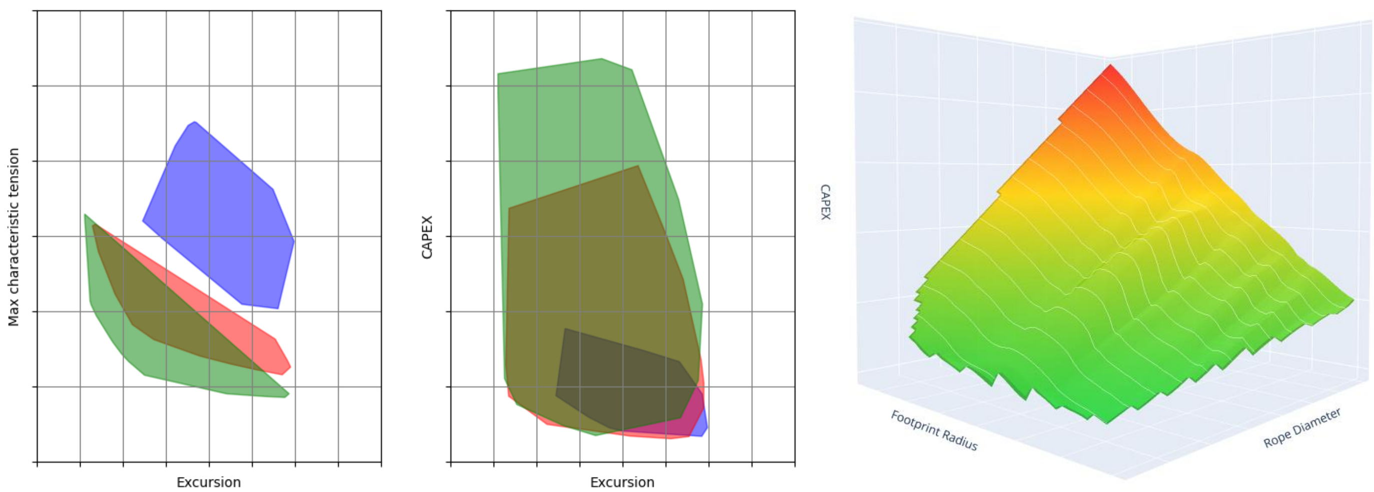

Figure 3: Example results for showing result regions for mooring systems with (*blue*) 3 line (*red*) 6 line and (*green*) 9 lines and the influence of input parameters on mooring system CAPEX.

Subroutines have been developed to provide further insight, e.g., CAPEX calculations, bill of materials generation and anchor design.

A variant of the tool has also been developed to ascertain and tune model parameters where system complexity is high and/or it is difficult to measure such parameters directly (e.g., identifying hydrodynamic coefficients from physical wave tank tests).

WORKING WITH YOUR BUSINESS

To date the approach has been successfully applied to a number of marine renewable energy and FOWT projects. It has provided developers and OEMs with an overview of the mooring system landscape as well as detailed mooring designs, some of which have been subsequently installed at sea (Figure 4).

Leveraging TTI Marine Renewables' high-end computational hardware, the time required to explore the parameter space is significantly reduced and confidence is increased that an optimal solution exists in the set of viable solutions.

If you are interested in using this approach for your next project, please get in touch.

ABOUT

TTI Marine Renewables Ltd is part of the TTI Ltd group which comprises a group of independent consultants who are experts in the design, development, procurement, installation and testing of mooring and anchoring systems for the offshore and renewables sectors including steel (e.g.

Figure 4: TODA Corporation ballasted spar near Goto Island, Japan.

chain and wire) and synthetic moorings. With a technology-neutral ethos, TTI consultants have led key mooring projects since the 1980s, with early work enabling the exploitation of very deep-water locations off Brazil using innovative mooring systems and materials. TTI has designed numerous components and systems to enhance mooring line life and examples of these can be found on some of the largest vessels and platforms in the world including several in the FOWT sector.

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