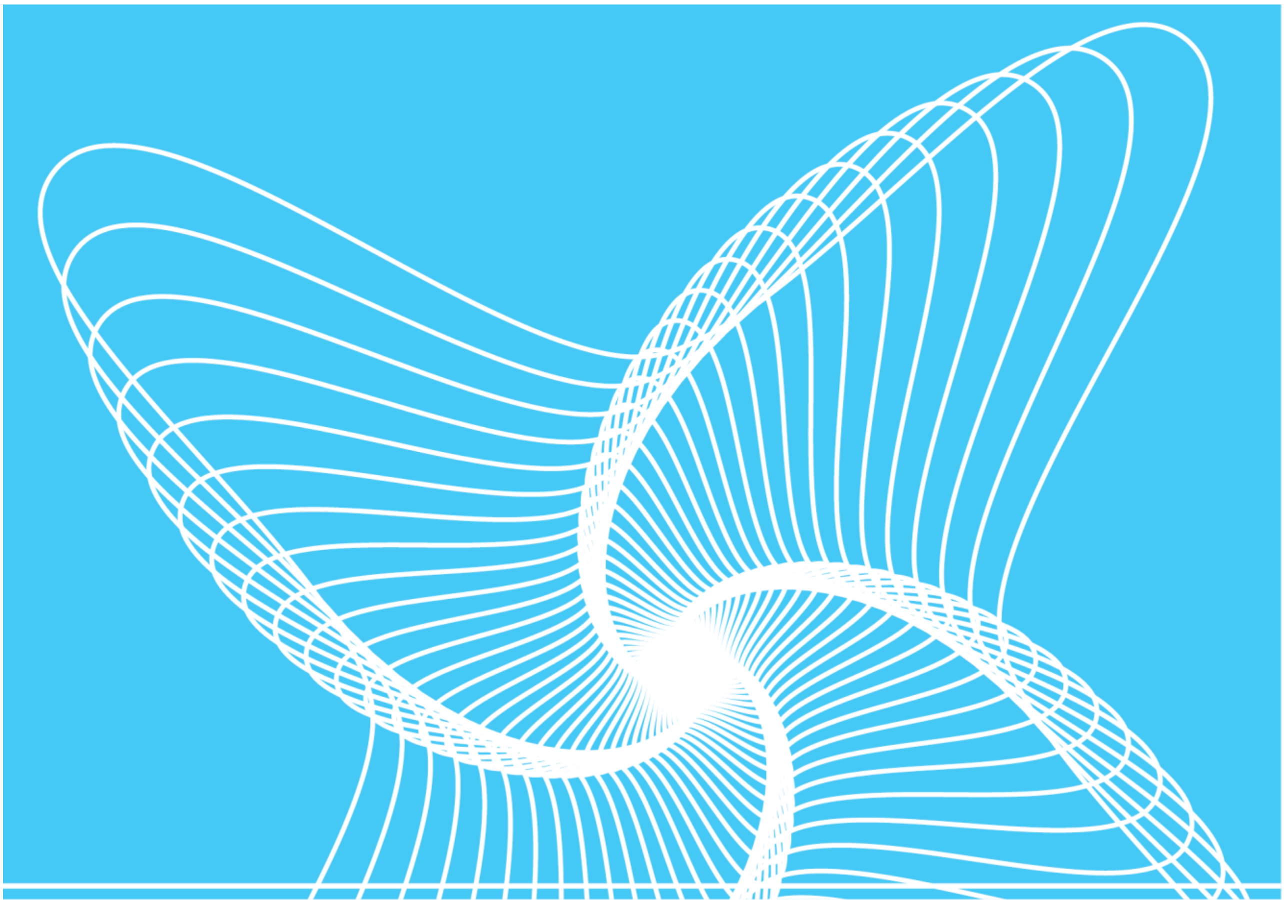
DNV·GL

WHITEPAPER

INTEGRATED ANALYSIS OF FLOATING WIND TURBINES



Reference to part of this report which may lead to misinterpretation is not permissible.

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1.0	2016-05-13	First issue	Chuang, Jenny Zhenju	Berg-Jensen, Jan Henrik	Berg-Jensen, Jan Henrik
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1 EXECUTIVE SUMMARY

Offshore wind is a young technology and experiencing fast development. As the industry evolves, offshore wind farms are being built further from the coast and in deeper waters to achieve a steadier and stronger wind resource, leading to a big potential for the floating wind turbine market.

Engineers are facing great challenges to ensure successful numerical modelling and analysis, among which the most critical part is to have the integrated system simulated in one numerical tool, taking into account the coupling effects between different objects, such as wind turbine, floating support structure, mooring and cables, and obtaining reliable results.

Sesam's module Sima (including Simo and Riflex) overcomes this difficulty, providing our users with a reliable and efficient solution(1).

Why choose Sesam?

- Complete floating wind turbine system could be simulated in one model, including blades, nacelle, tower line, and floater and mooring system, etc.
- Coupling effects between aerodynamic, hydrodynamic and structural response could be considered, which ensures more realistic analysis compared to other tools.
- It is straightforward to combine a variety of environmental loads, such as wind, wind wave, swell wave and current.
- Efficient time domain algorithm saves a large number of engineering hours.
- Engineers can easily post-process results based on the powerful in-built post-processor. This avoids the need to interface with another program.
- The user-friendly interface ensures good visualization, easy modelling and error check.

In this paper, you will find all the necessary information about how to model and analyse a floating wind turbine in Sesam.

2 INTRODUCTION

The offshore wind turbine industry only began doing research in the mid-1990s. It remains a hot topic around the world. According to a report by the European Wind Energy Association(2), wind will be the least-cost option for building excess electricity capacity almost universally by 2025.

Compared with onshore wind, offshore wind has many advantages:

- Large areas available at a low price
- No noise and visual impacts
- Higher wind velocities, less turbulent wind
- Feasible transportation and installation

These advantages are the real engines to drive offshore wind turbine development.

Different types of sub-floaters are chosen depending on the water depth. In general, if the water depth is more than 50 meters, it is preferred to use floating wind turbines(2).

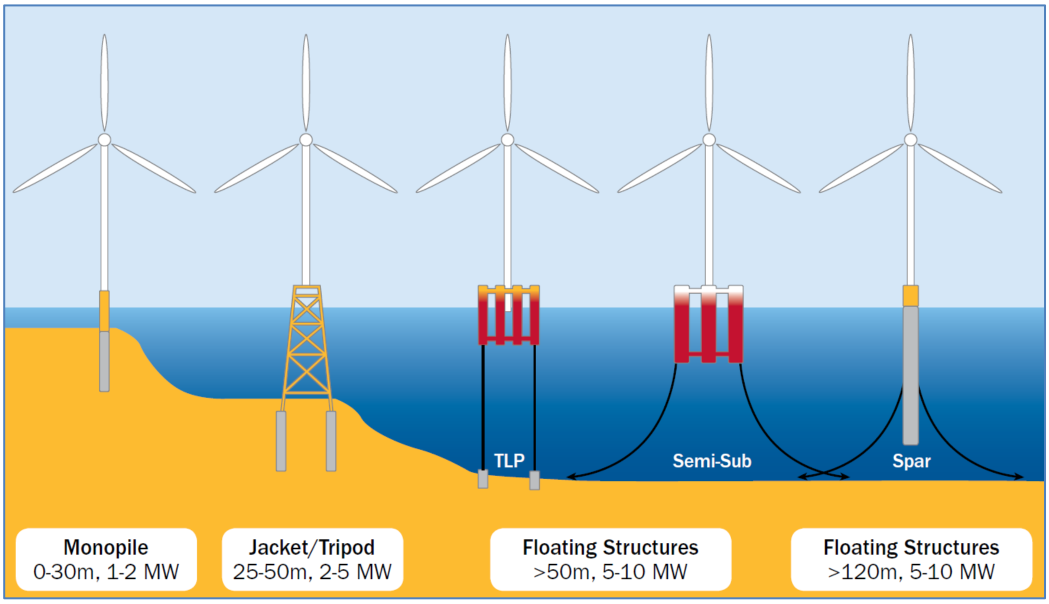

Fig. 2.1 Offshore wind floaters

Currently, three main kinds of floaters are adopted by the industry:

- Spar buoy: A very large cylindrical buoy stabilizes the wind turbine using ballast. The centre of gravity is much lower in the water than the centre of buoyancy. This provides good righting behaviour when the structure is heeling.

In 2009, Statoil installed the world's first large scale grid-connected floating wind turbine by using this kind of floater, Hywind from Norway, with a 2.3 MW Siemens turbine.

A pilot park will be established with five 6MW Hywind turbines on the coast of Scotland. This will be the world's largest floating wind farm, also owned by Statoil.

- Tension leg platform: A very buoyant structure is semi-submerged. Tensioned mooring lines are connecting the platform with anchors on the seabed to add buoyancy and stability.

- Semi-submersible: Combining the main principles of the two previous designs, a semi-submerged structure is designed to reach the necessary stability.

One of the successful designs is WindFloat from Portugal. There are three primary advantages to the WindFloat foundation: Firstly, it has good stability performance. Secondly, the assembly of the whole system is done on shore to avoid dynamic weather influence. Lastly, its shallow draft ensures convenient transportation.

This document aims at providing the best practice to guide our users on:

- Modelling a floating wind turbine
- Assigning locations and environmental conditions, necessary hydrodynamic properties
- Carrying out a real-time domain coupling dynamic analysis
- Post-processing the result data and making a comprehensive report

Three modules in Sesam, including GeniE, HydroD and Sima, are used with seamless interfaces.

GeniE is used to model the geometry of the floater for the hydrodynamic analysis with potential theory. FEM file including wet surface meshes is used for this purpose. Sima is using the geometric files (OBJ, GDF, FEM) for visualization.

HydroD calculates the hydrodynamics of the shell hull to get coefficients such as added mass, damping, wave force transfer function and motion transfer function, etc. These hydrodynamic data will be imported into Sima.

Sima will take the input from GeniE and HydroD. The wind turbine and mooring system will be created inside Sima. Both static and dynamic analyses will be done in Sima.

The following two figures illustrate a spar buoy floating wind turbine and a semi-submersible type floating wind turbine model in Sima.

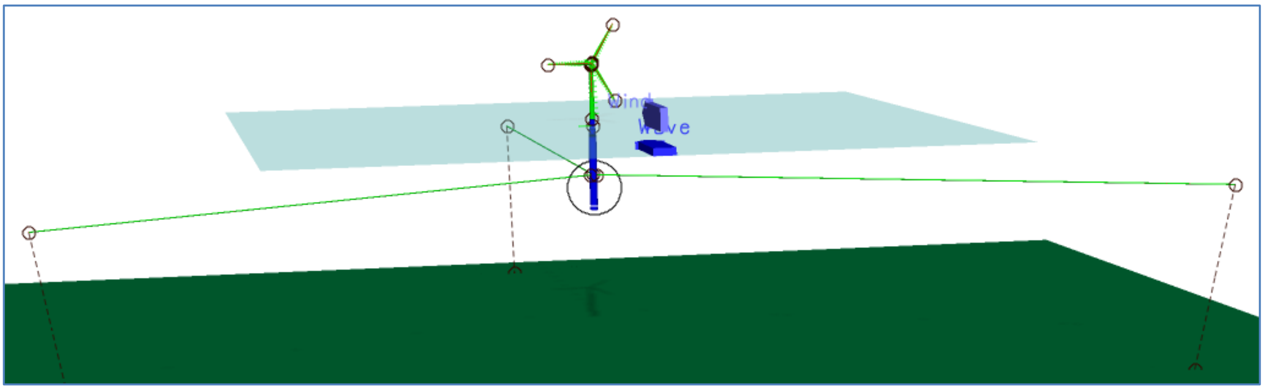

Fig. 2.2 Spar buoy type floating wind turbine in Sima

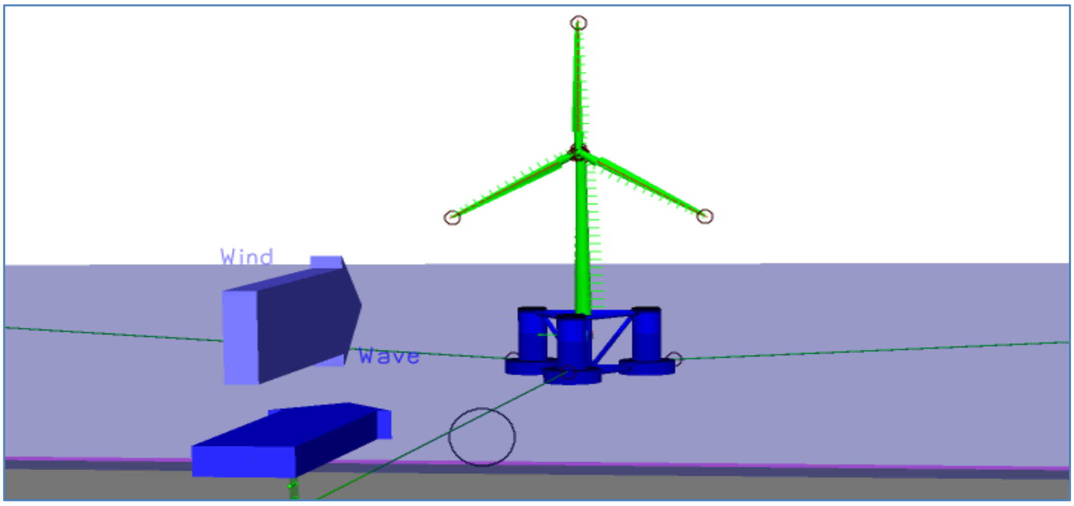

Fig. 2.3 Semi-submersible type floating wind turbine in Sima

3 MODELLING IN SIMA

A complete floating wind turbine system can be modelled inside Sima. In general, it consists of three major parts: locations and environment conditions, body and slender system. Details for each element will be explained as following.

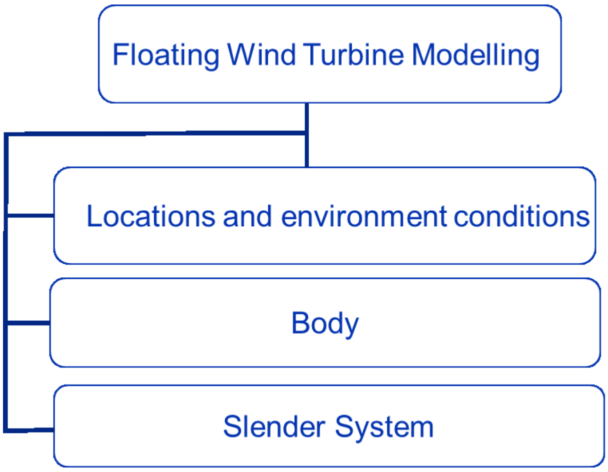

Fig. 3.1 Elements for modelling

3.1 Locations and environment conditions

Location includes the general information about physical properties for an actual location. Acceleration of gravity, water density, air density, water depth, etc. can be defined there. Position, size and colour for sea surface and flat bottom can also be defined for visualization.

Sea environment setting is quite straightforward. Wave, swell, current and wind can all be included together from the user interface. Both regular and sea spectrum can be defined in Sima with any combination of frequency, heading and wave height.

Sima also provides numerical wave generation. Users can create their own wave spectrum with any combination of frequencies and headings.

Multiple options for wind spectrum are available, as shown in Fig. 3.2.

Current profile and velocity will vary with different levels relevant to sea surface and propagating direction.

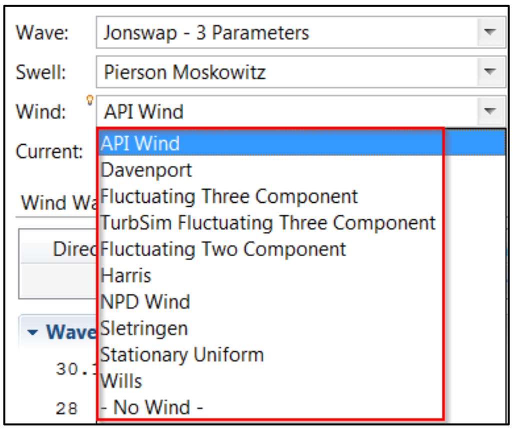

Fig. 3.2 Wind spectrum in Sima

3.2 Body

Different types of bodies can be defined in Sima. Body can be large volume type with 6 or 3 degrees of freedom, small volume body with 3 translational degrees of freedom, or prescribed motion type.

In this example, three large volume bodies are created, which are spar, hubmass and nacelle. Each body has a slender system connection.

Spar is a slender, cylinder-type floater submerged into water. See from the highlighted part in Fig. 3.3. As a large volume body its 6-DOF motions are simulated in time domain.

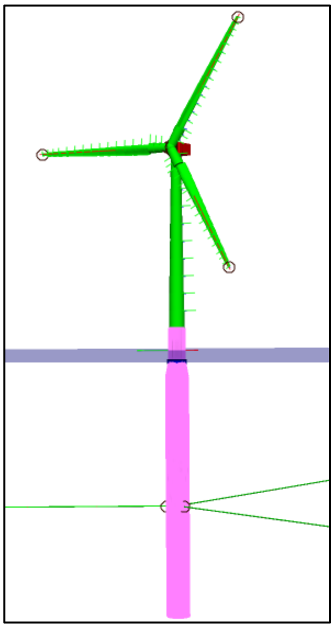

Fig. 3.3 Spar type floater

Hydrodynamic data regarding kinetics and radiation data (as shown in Fig. 3.4) can be imported by reading Sesam interface files from HydroD/Wadam, which can be modified (editing the values, add or delete) after importing into Sima.

Sima also provides the option to include drag force from viscous effect. This is done by creating slender elements attached to the body. Linear drag and quadratic drag coefficients can be specified.

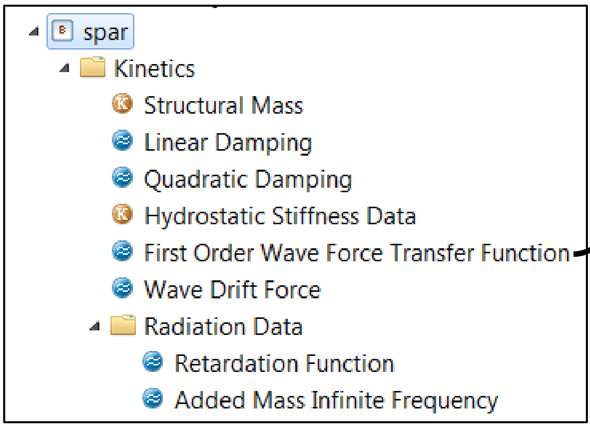

Fig.3.4 Hydrodynamic data for Spar

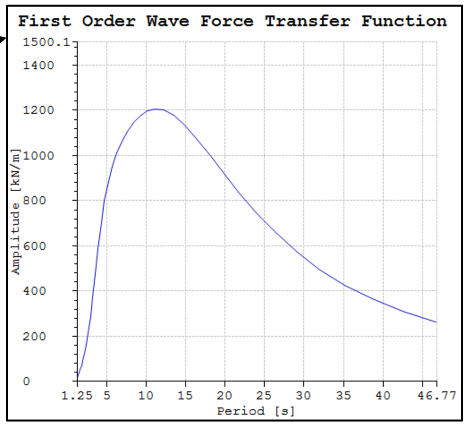

Fig.3.5 First order transfer function for spar

Hubmass is an important component for wind turbine. It connects the shaft line, tower line and blades. Correct mass information is important for rotation purpose of the wind turbine.

Nacelle is located right behind the hub. Since nacelle is above sea surface, only mass information and wind coefficient are relevant.

Relative positions of hubmass and nacelle are shown in Fig. 3.6.

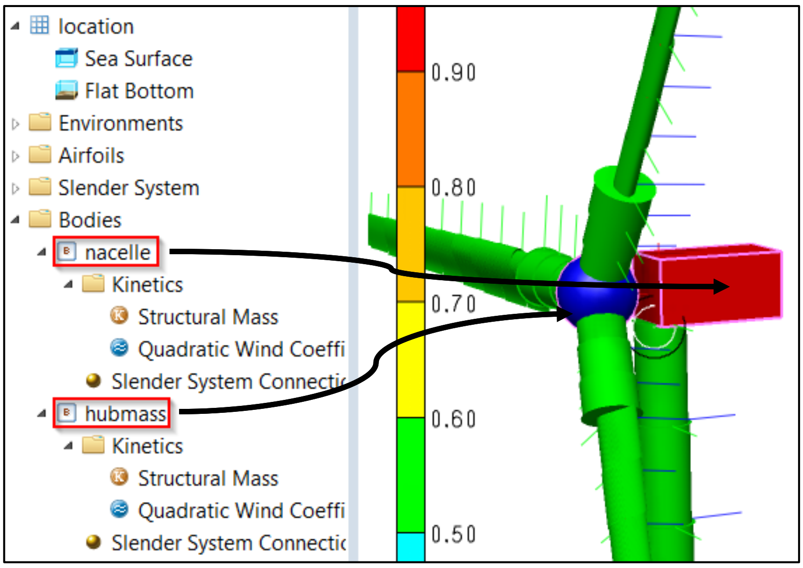

Fig. 3.6 Nacelle and hubmass modelling

3.3 Slender system

Modelling of the slender system should start from supernode, element, segment and line. At last, the whole wind turbine is created by combining these components. Fig. 3.7 shows the basic topology of the slender system.

- SUPERNODE: Branching points or nodes with specified boundary conditions.
- LINE: Suspended structure between two supernodes.
- SEGMENT: (Part of) line with uniform cross-section properties and element length.
- ELEMENT: Finite element unit.

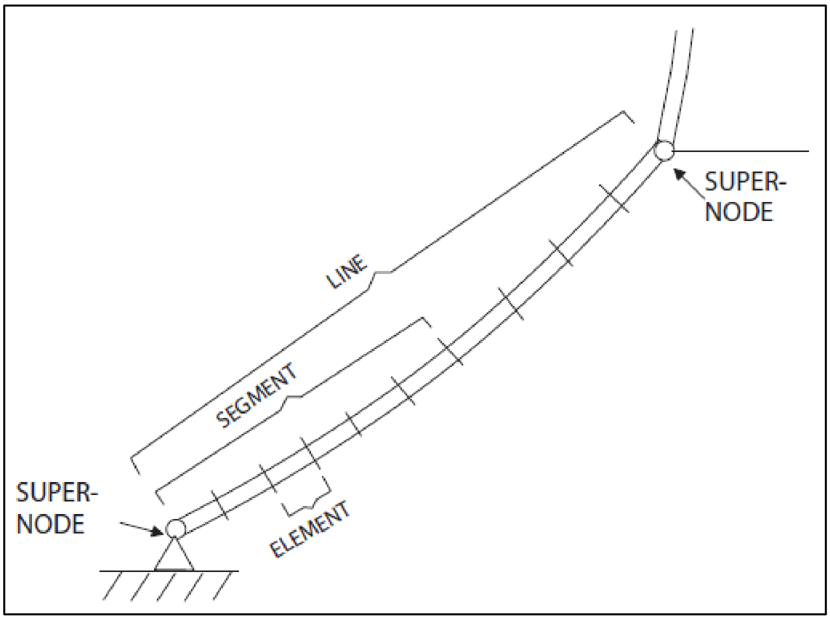

Fig. 3.7 Slender system terms

Slender system takes a large part of the floating wind turbine model. Blades of the turbine, electrical lines, shaft lines and mooring lines should all be modelled with slender system. Fig. 3.8 shows the whole system.

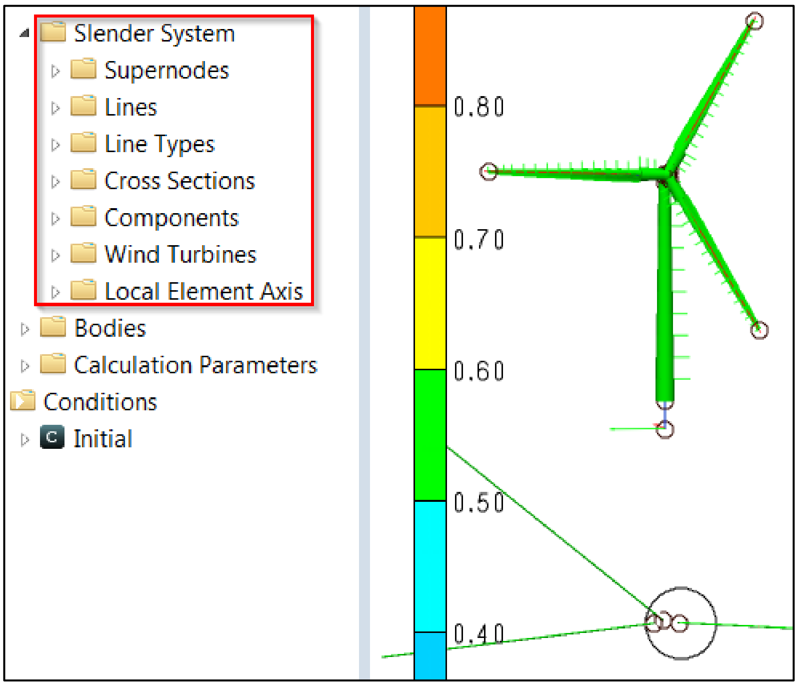

Fig. 3.8 Slender system

3.3.1 Supernode

We have a certain amount of supernodes in our example. Two main cards should be set up for supernodes: position and boundary condition. There are four types of boundary conditions: free, fixed or prescribed, slaved, fixed relative to orientation. Any of six DOF including translation and rotation can be set up with free or fixed.

Setting up correct boundary condition for all supernodes is challenging work. Please see Fig. 3.9 for the detailed boundary information on all the supernodes.

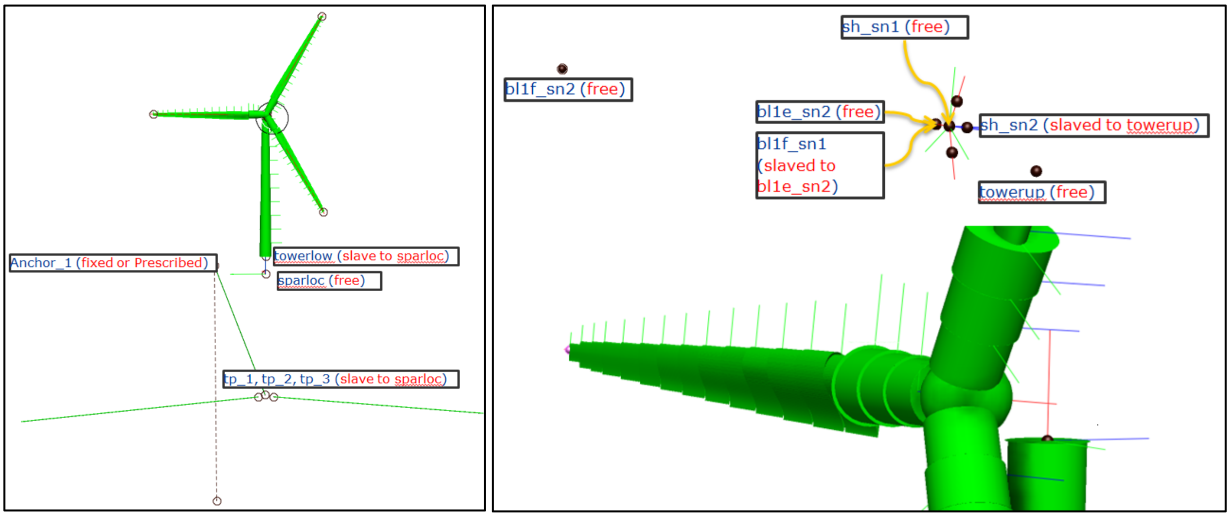

Fig. 3.9 Supernode boundary condition

3.3.2 Lines

Lines are created by connecting two supernodes. There are in total 12 lines covering mooring lines, blade lines, electrical lines, tower line and shaft line. See line table in Fig. 3.10.

Lines in ExampleFloatingWindTurbine

Name	Line Type	End1	End2	Length	Distance
shaft	shaft_lt	sh_sn1	sh_sn2	1.0	0.99997
bl1ecc	bl_ecc	sh_sn1	bl1e_sn2	1.5002	1.5
bl1foil	bl_foil	bl1f_sn1	bl1f_sn2	61.5	61.5
bl2ecc	bl_ecc	sh_sn1	bl2e_sn2	1.5002	1.5
bl2foil	bl_foil	bl2f_sn1	bl2f_sn2	61.5	61.5
bl3ecc	bl_ecc	sh_sn1	bl3e_sn2	1.5002	1.5
bl3foil	bl_foil	bl3f_sn1	bl3f_sn2	61.5	61.5
moor_1	m_line	tp_1	anchor_1	902.2	902.2
moor_2	m_line	tp_2	anchor_2	902.2	902.2
moor_3	m_line	tp_3	anchor_3	902.2	902.2
sparart	spardum	sparloc	towerlow	10.0	10.0
tower	tower_lt	towerlow	towerup	77.6	77.6

Fig. 3.10 Table of Lines

The process of creating lines in Sima is quite clear and easy to follow.

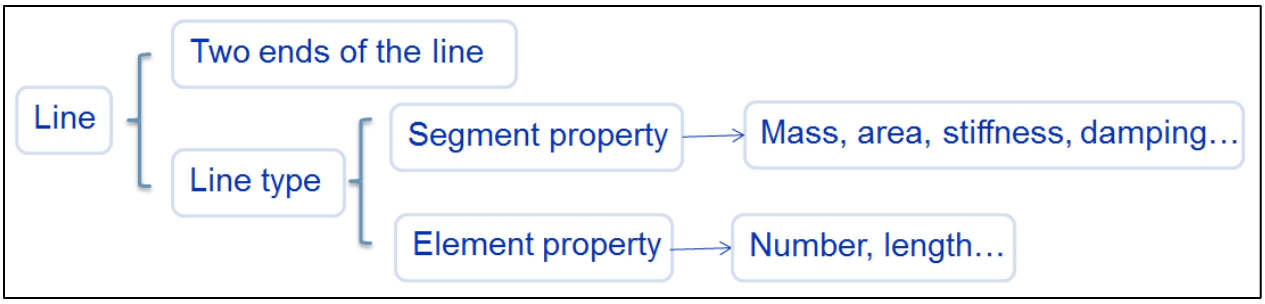

Fig. 3.11 Properties for Line

Cross section: 'Generic axisymmetric pipe' and 'double symmetric cross section' cross sections have been used here. Details including cross section property, stiffness property, axial stiffness, bending stiffness, torsion stiffness, hydrodynamic force coefficients and aerodynamic force coefficients, etc. can all be specified here.

Cross section of the blades has air foil shape. Different air foil shapes can be assigned to different cross sections from the tip to the base. Sima provides elaborated user interface for detailed design. Air foil geometry is given by X and Y coordinates in two dimensions. Air foil characteristic is defined by assigning drag coefficient, lift coefficient and moment coefficient at different attack angles for different Reynolds numbers.

One line can be divided into any number of segments; each segment can have its own cross section property and number of elements. An element can be clearly seen from the user interface if you zoom in close enough. This is good for modelling work and checking the quality of element length.

The component represents the elementary description of the mechanical properties. A flex joint has been applied in our example at one end of the shaft line. This is for flexible connection between shaft and tower line.

Wind turbine: The wind turbine can be created by composing body, shaft line, tower line, wind load option and blades together. The controller is used to set up the data for engine and control the rotational speed of the blades. Fig. 3.12 and Fig. 3.13 show more details.

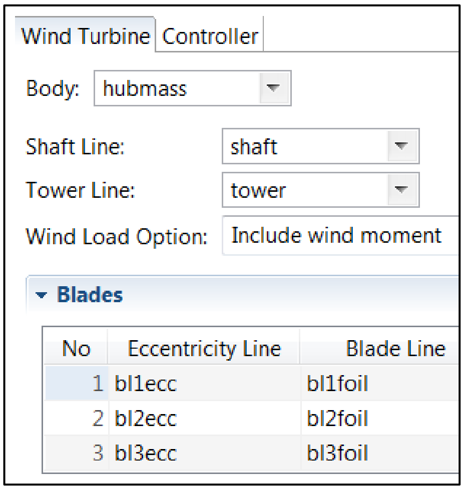

Fig. 3.12 Wind turbine components

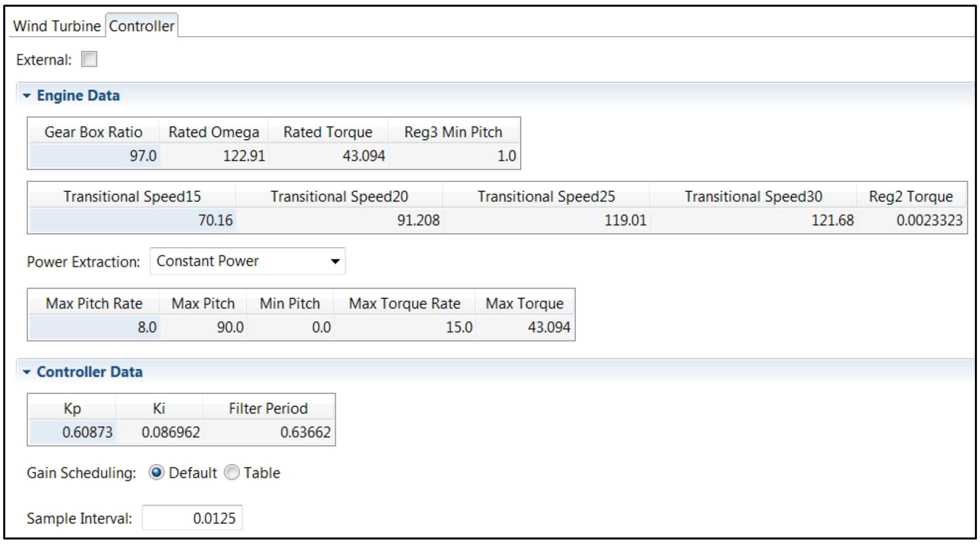

Fig. 3.13 Controller data

4 CALCULATION PARAMETERS

4.1 Static analysis

Static configuration is the starting point for time domain dynamic calculation Five loading sequences are included in static analysis.

Volume forces: Presents weight and buoyancy of the slender system.

Boundary change: Identification of supernode for boundary change

Specified displacement: supernode with specified rotation will be rotated to static equilibrium position and line ends will be moved from stress free position to static equilibrium position.

Body force: Force from floater

Current forces: Forces from the current

Number of load steps, max iterations and accuracy for iterations can be defined for each load sequence.

Static configuration after static analysis can be seen from Fig. 4.1.

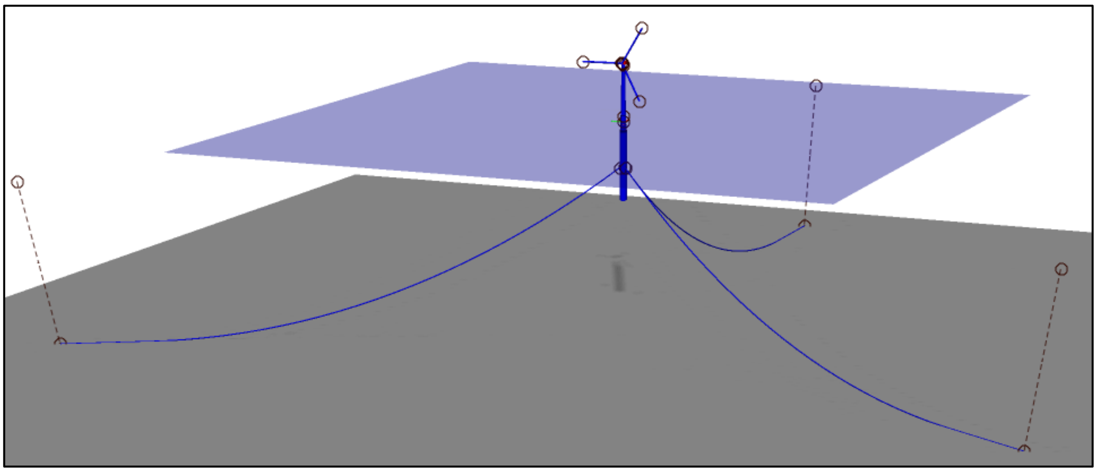

Fig. 4.1 Static configuration

4.2 Dynamic calculation

The dynamic responses of floating wind turbine in designed environmental load condition are of the main interests, including the nonlinear coupling effects between the floater and slender system.

Simulation length and time step should be setup carefully, especially considering the high frequency wind loads on the turbines. Multiple options for storage of results are also provided to avoid too large database with unconcerned signals. Time history of displacement, force response, acceleration, curvature and wave kinematics etc. can be stored for different bodies, lines, segments or nodes, for post-processing.

Fig. 4.2 shows how to set up the displacements storage for upper node for tower line. It is easy to add or delete any parts of the slender system for storage purpose.

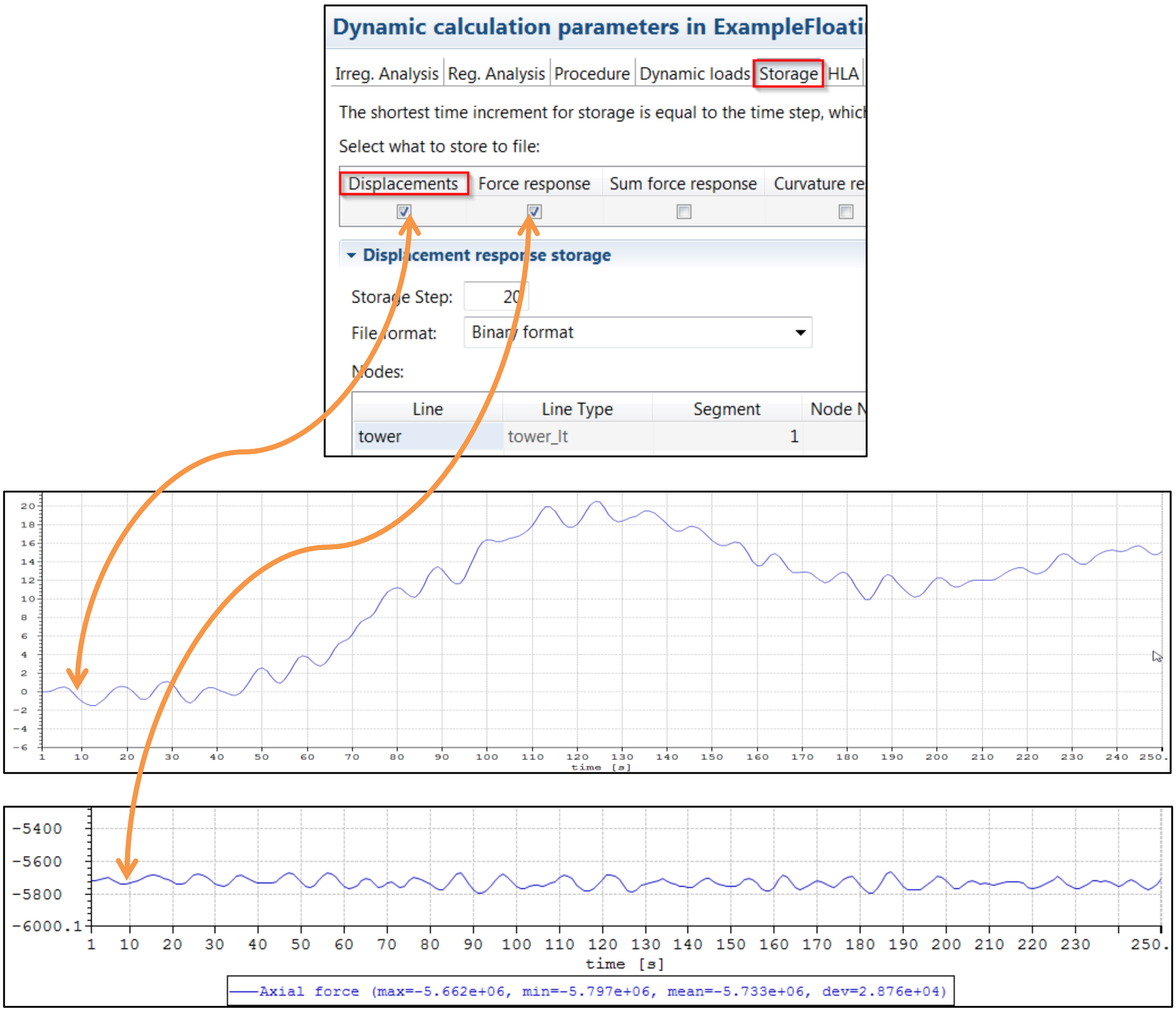

Fig. 4.2 Displacement and Force storage for tower line

5 DISPLAY AND POST-PROCESSING RESULTS

Any of the stored results can be used for post-processing. Sima has powerful post-processing abilities, as shown below some examples:

- Direct simulation results to plots or file output
- Filtering of results
- Arithmetic operations
- Spectral analyses
- Statistical operations, distributions etc.
- Code check
- Fatigue analysis
- Others

An easy example is demonstrated here to capture the local peaks for the signals in Fig. 5.1 and Fig. 5.2.

Clearly information for all these local peak responses will be very easy to observe and understand how the system is behaving under oscillating environmental loads. This is useful to predict and prevent excessive response happens.

A flowchart needs to be created in the post-processor as shown in Fig. 5.1. Then, by double-clicking the 'plot' icon, results will be shown in Fig. 5.2.

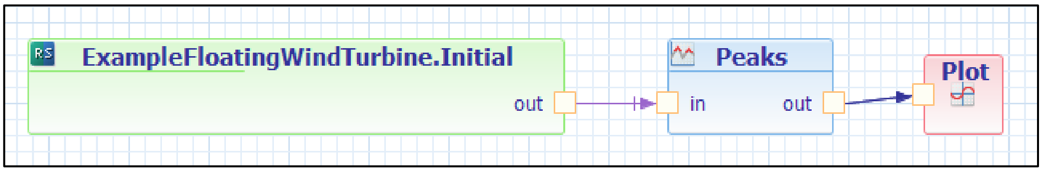

Fig. 5.1 Flowchart for capturing maximum points for signals

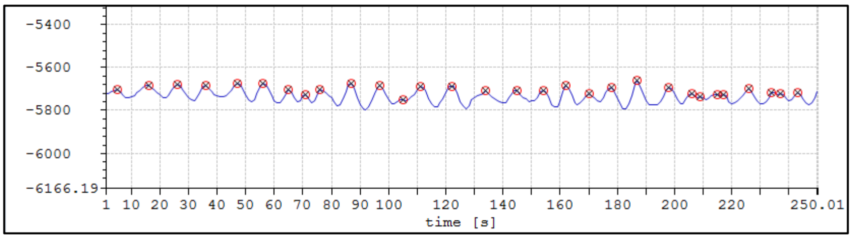

Fig. 5.2 Capturing local maximum points for force at upper node of tower

Another example below is aimed at showing more possibilities in Postprocessing. Axial forces of top segments of three mooring lines can be plotted (Fig. 5.3.1). Damaged fatigue is also calculated with defined SN curve (Fig. 5.3.2). Moreover, Rayleigh distribution with peaks can also be done to obtain extremes of each top segments with probability of non-exceedance (Fig. 5.3.3).

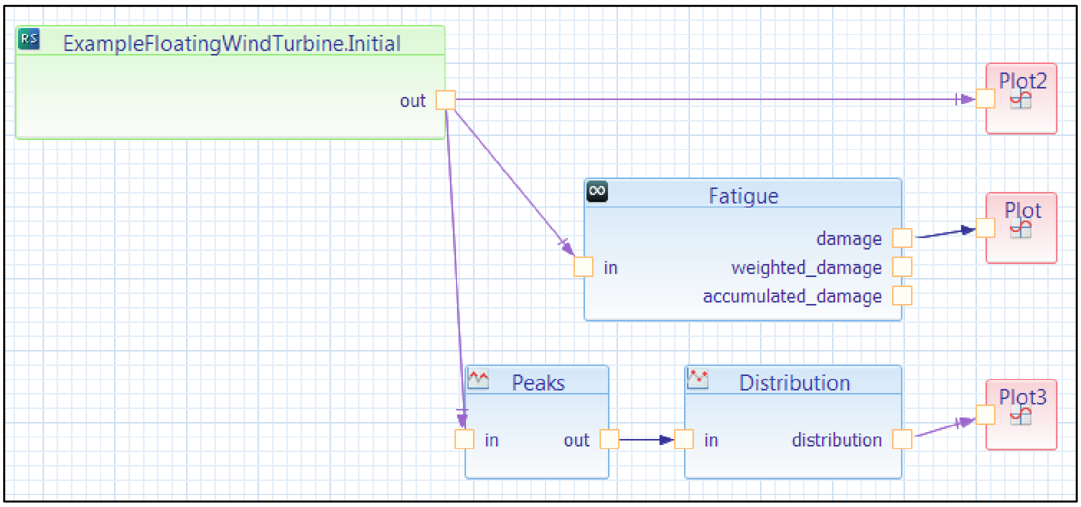

Fig. 5.3 Postprocessing of axial forces of top segments of three mooring lines

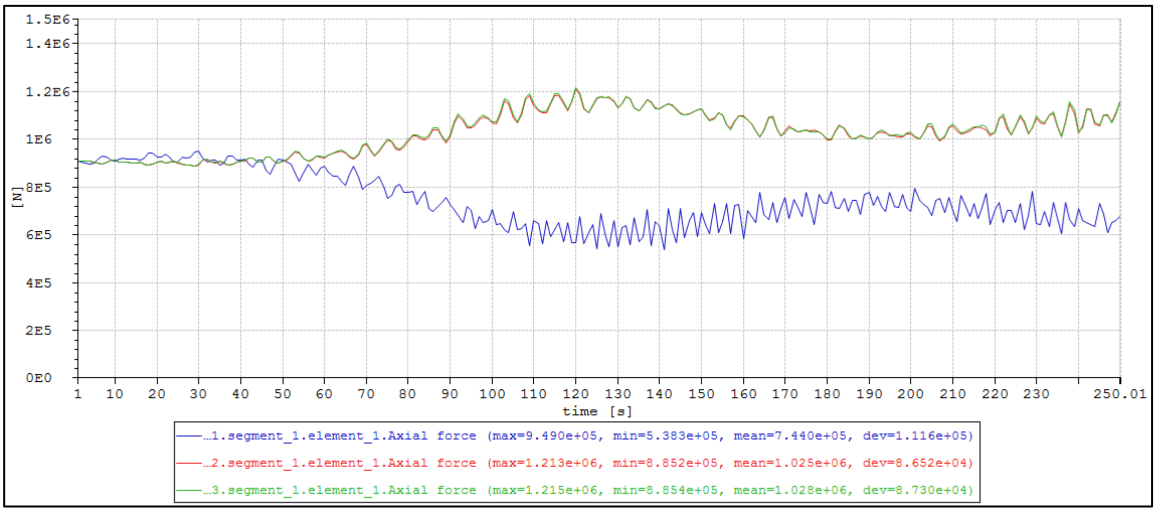

Fig. 5.3.1 Axial force of top segments of three mooring lines

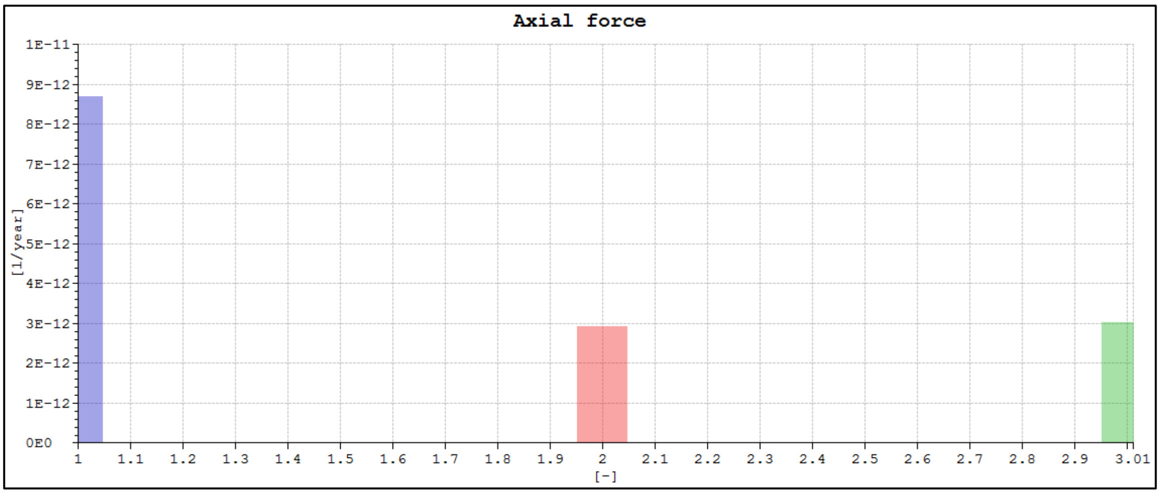

Fig. 5.3.2 Damaged fatigue for top segments for three mooring lines

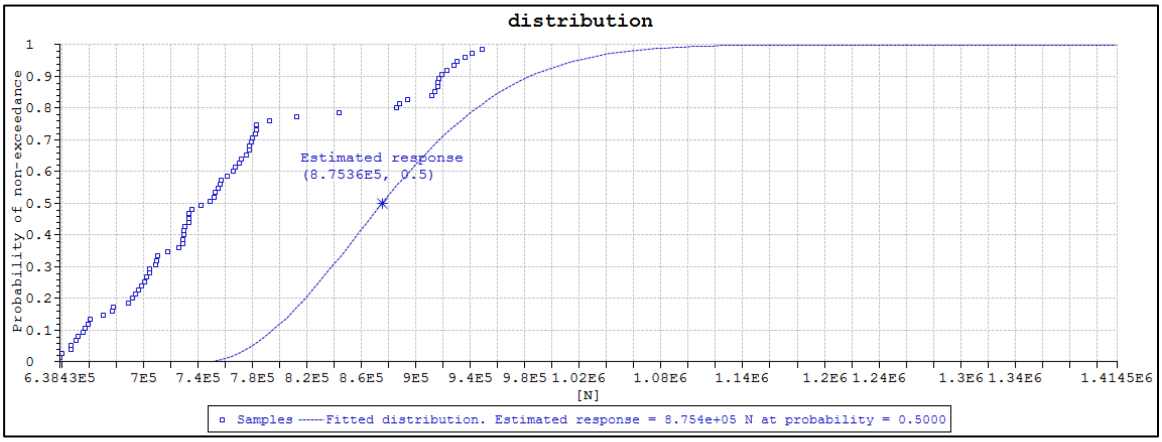

Fig. 5.3.3 Rayleigh distribution of peak responses for mooring line 1

6 REPORT

A report can be generated from Sima using multiple kinds of data both inside Sima and from external resources. Users have a full control of the report organization and content by defining sections and inserting data resources such as text, image, plot, tables, formula and so on.

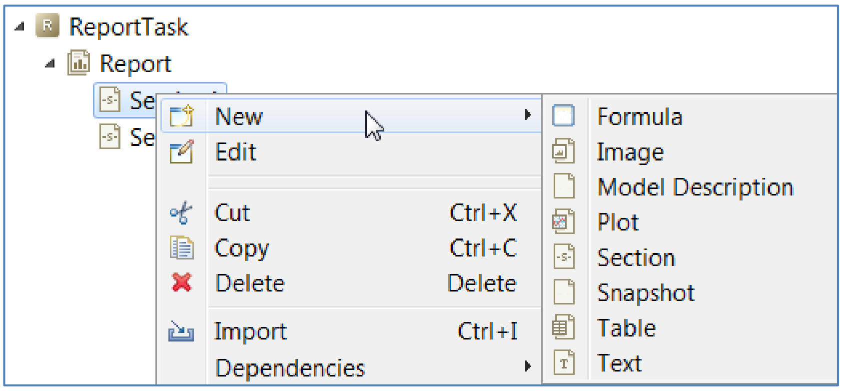

Fig. 6.1 Report generator in Sima

Fig 6.2 shows an example of report template. Three sections are created. Section 1 includes a model description and an image of floating wind turbine. Section 2 contains a plot of floater wave drift force, a table of spar structure mass and a snap short of static configuration. Section 3 aims at showing axial forces for three mooring lines. After editing the structure and content of the report, a Word document will be easily generated by clicking the icon 'Generate report'.

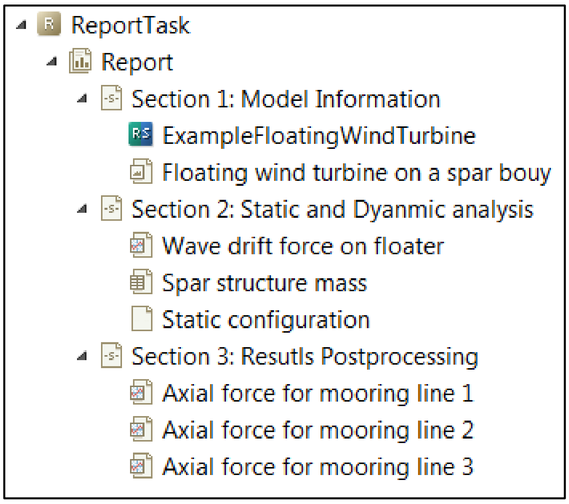

Fig. 6.2 An example of report template

7 SUMMARY

Sima has the capability to take the whole system of the floating wind turbine into account and running coupling analysis in a reliable and efficient way.

If readers want to learn the best practice from this whitepaper, please kindly contact our support team via software.support@dnvgl.com.

8 REFERENCES

/1/ Zhang, F. FLOATOVER ANALYSIS. Whitepaper from DNV GL Software, 2015.

/2/ Arapogianni, A; Genachte, A; et.al. Deep Water-The next step for offshore wind energy. A report by the European Wind Energy Association - July 2013