Course Project: Integrated Dynamic Analysis of Wind Turbines
Fall 2022

Contents

1 Introduction

This project will be carried out in groups of 3-5 students, where each group will be assigned a floating or fixed wind turbine for study. Most of the substructures support the DTU 10MW wind turbine [1]. The offshore wind turbines under consideration are summarized in Table 1; additional details regarding the models are provided in the listed references.

It is strongly recommended that you read through the entire document before beginning the project.

Group	Platform/Support structure	Water depth (m)	Reference material
1	10MW spar #1	320	[1-3]
2	10MW spar #2	320	[1, 3]
3	10MW TLP	150	[1, 4]
4	OOStar 10MW	130	[1, 5]
5	CSC 10MW	200	[1, 6]
6	10MW monopile	30	[1, 7]
7	INO-WINDMOOR 12MW semi	150	[8]
8	UMaine VolturnUS-S 15MW semi	200	[9, 10]

Table 1: Floating wind turbine platforms for each group.

2 Provided models, input files, and codes

Each group will receive a SIMA (RIFLEX Coupled) global analysis model of their concept in the form of an stask file. Note that in order to carry out the required analyses, the models will need to be modified. Some models require supplemental files for control or have particular features that need to be accounted for, see the relevant appendices.

Wind input files from TurbSim are also provided: see section 3.3.1. Matlab and python codes that can help in post-processing the results from SIMA are also provided, additional details are provided in an appendix (Section 6).

3 Required analyses

Each group will be required to perform and report upon 5 sets of analyses. First, (1) constant wind tests will be carried out with both a stationary rotor and the full system. Next, (2) decay tests, (3) constant wind tests, (4) a fatigue study with turbulent wind and irregular waves, and (5) blade pitch fault simulations will be carried out with the full system. The decay and constant wind tests are identification tests in order to gain some understanding of the models, while the fatigue study requires more extensive calculation and analysis. The blade pitch fault simulations are included in order to examine the structural response to wind turbine faults.

The work should be reported in 3 phases, as defined in Table 2. The reporting consists of filling in the indicated slides in the presentation template (and presenting the work at the end). In the case of 5-person groups, there are additional tasks required. These are indicated in italic text in the appropriate sections.

Analyses	Assigned	Due
Constant wind (3.1)	Sept. 13th	Oct. 6th 23:59
Decay tests (3.2)	Sept. 27th	Oct. 20th 23:59
Complete fatigue analysis (3.3) + fault conditions (0)	Oct. 11th	Nov. 17th 23:59

Table 2: Project timeline and deadlines

3.1 Constant wind tests

Constant uniform wind tests will be performed in order to check the wind turbine performance, including the controller. These tests should be performed first for the simple model with a fixed rotor and then for the complete model including substructure. Each student should perform constant uniform wind tests for 8 m/s, rated (11.4 m/s for the 10 MW turbine, 10.6 m/s for the 12 MW turbine and 15 MW turbine), and 18 m/s mean wind speed. In addition, simulations for wind speeds 4m/s, 6 m/s, 10 m/s, 12 m/s, 14 m/s, 16 m/s, 20 m/s, 22 m/s, and 24 m/s should be carried out for each group.

The results to be presented for constant wind analysis with fixed rotor are:

- Mean rotor speed
- Mean thrust
- Mean torque
- Mean power
- Mean blade pitch

(as a function of wind speed). Note that statistics should be taken after the turbine reaches its steady-state condition. The turbine start-up takes longer for low wind speeds. It is possible to obtain these results either through separate simulations for each wind speed, or by generating an input file with step wind. Additional guidance for using the step wind is provide in the appendix (section 6).

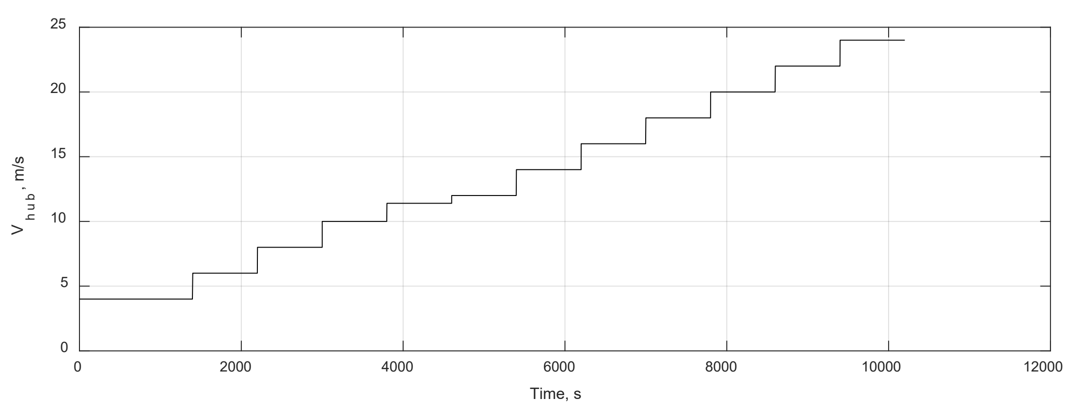


Figure 1: Example of a step wind file covering the required wind speeds for the 10 MW turbine.

For the wind speeds 8m/s, rated, and 18 m/s, examine the time series of the thrust force. Discuss the shape and source of any oscillations which you may see. Discuss any differences between the fixed rotor and the complete model.

The results to be presented for constant wind analysis with floating platform are:

- Mean offset in platform surge
- Mean offset in platform roll
- Mean offset in platform pitch
- Mean rotor speed
- Mean thrust

- Mean torque
- Mean power
- Mean blade pitch

(as a function of wind speed). These results should be compared to the previous results with the fixed rotor. How do the platform motions affect the mean loads and performance? Note that statistics should be taken after the turbine and platform have reached an approximately steady-state position. Some slow transients in surge may be expected.

Additional tasks for 5-person groups: Include one figure that shows a time series of the bending moments at the root of the blade (bending moments around local y and z axes) for a few rotations at 11.4 m/s for your platform. (Alternative: show the bending moments as a function of the azimuth angle). Describe the effects that you see.

Simulation length	at least 800 s (depends on transients)
Simulation time step (Time Step in SIMA)	0.005 s
Wave/body response time step (Time Increment in SIMA)	0.1 s
Turbine condition	Operational
Wind input	Constant
Wave conditions	Hs = 0.001 m, Tp = 20 s

Table 3: Simulation parameters for constant wind tests.

The 10MW wind turbine performance as a function of wind speed can be compared to given performance curves in Figure 2 and the provided table (FAST_10MWsteadyState.xlsx). Note that the tabulated values are from FAST v7, which does not include any blade torsion deformation, and has a slightly different implementation of the aerodynamic loads. The 12 MW and 15 MW wind turbine performance curves, based on OpenFAST v3.0.0, are shown in Figure 3 and Figure 4, and tabulated in spreadsheets WM12MW_OpenFAST.xlsx and IEA15MW_OpenFAST.xlsx, respectively. Note that there may be differences in the control inputs for the fixed rotor and floating turbine.

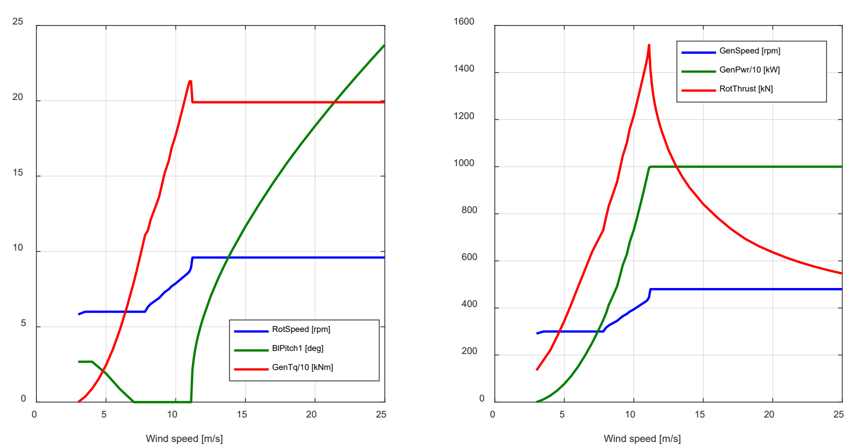


Figure 2: 10MW wind turbine performance curves.

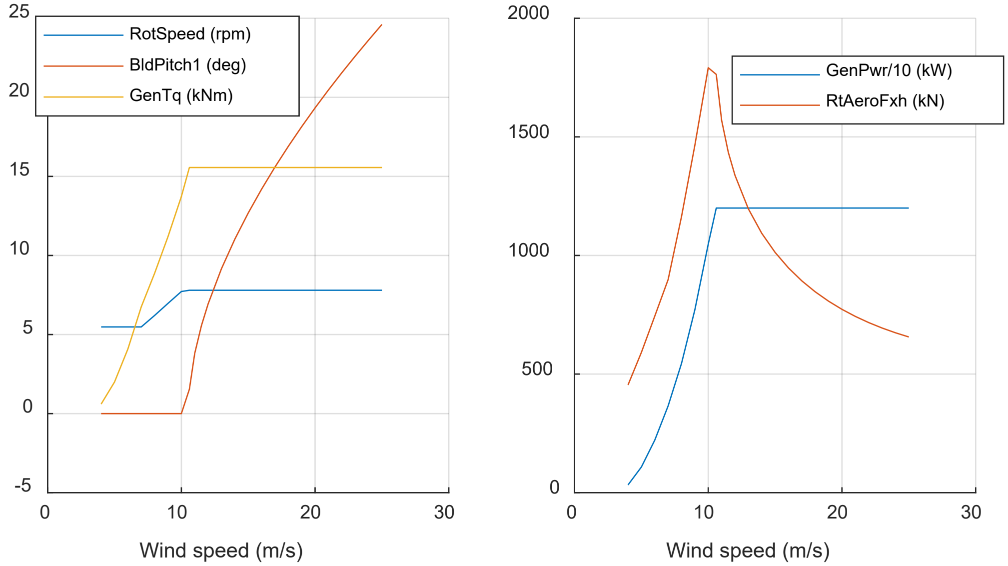


Figure 3: 12MW wind turbine performance curves.

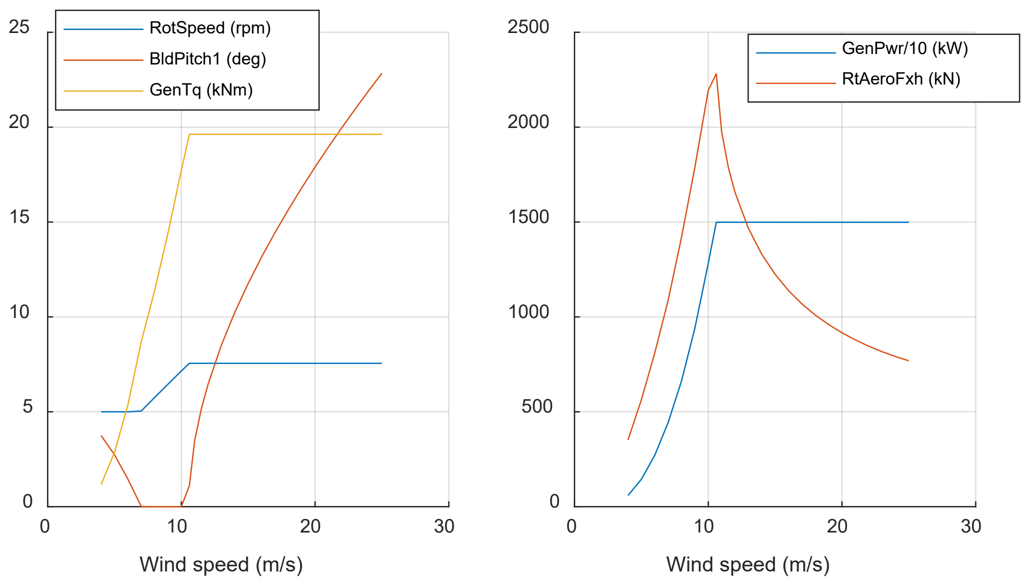


Figure 4: 15MW wind turbine performance curves (without peak shaving).

3.2 Decay tests

Decay test analyses are performed in order to document the system natural periods and damping. Only surge, heave, pitch and yaw need to be considered for the decay tests for the floating platforms. The first fore-aft and side-side side modes are considered for the bottom-fixed concepts. For this project, the initial displacement will be achieved by applying a ramp force, followed by a constant force, which will then be released (Figure 5). Some suggested forces and moments to be applied are given in Table 4. If the initial displacement is too large, or if the duration of the ramp is found to be insufficient, you may modify these values as needed. In SIMA, you should use the SPECIFIED FORCE or SPECIFIED MOMENT.

The specified forces can be applied to the nacelle for the monopile (note that the location of application should be in the body local coordinate system, but the table is given in the global coordinate system).

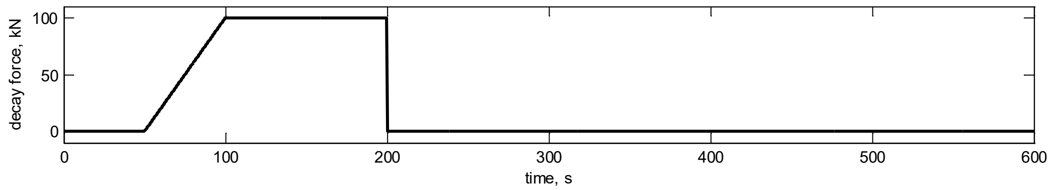


Figure 5: Example of decay force with ramp duration 50s, starting from t=50s, and constant force duration 100s.

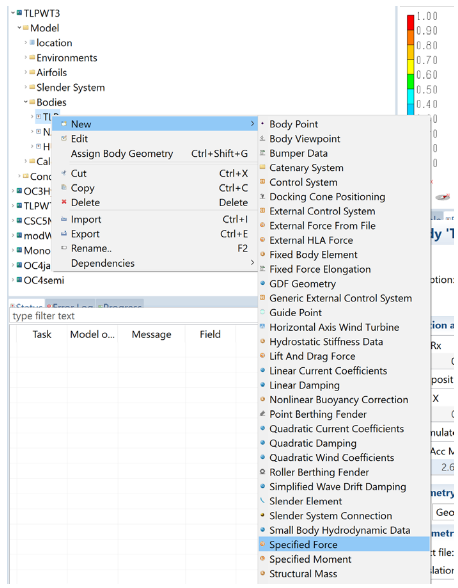


Figure 6: Specified force input in SIMA.

The group's final results for the natural periods for rigid body motion and PQ analysis should be included in the presentation. For a TLPWT, two pitch (actually, pitch/bending) natural periods should be reported. The combination of multiple frequencies makes it rather difficult to carry out the PQ analysis for pitch/bending for a TLPWT, and the PQ analysis does not need to be shown. For a monopile, the only decay tests will be fore-aft and side-side.

For the floating wind turbines, the time series of the tower base bending moment during the pitch decay should be studied in addition to the motion time series. You should try to identify the first tower fore-aft bending natural period based on the initial part of the decay. You should also try to compare the corresponding natural frequency with the 1p and 3p rotor frequencies.

Platform	Motion	Force/Moment	Simulation Length (s)	Point of application for decay force	ramp duration (s)	constant force duration (s)
10 MW spar #1	Surge	1000 kN	1200	(0,0,-77.2)	100s	200s
	Heave	3000 kN	800		50s	100s
	Pitch	180000 kNm	800		50s	100s
	Yaw	17000 kNm	400		50s	100s
10 MW spar #2	Surge	1000 kN	1200	(0,0,-56.3)	100s	200s
	Heave	3000 kN	800		50s	100s
	Pitch	180000 kNm	800		50s	100s
	Yaw	17000 kNm	400		50s	100s
10 MW TLP	Surge	1000 kN	1000	(0,0,0)	50s	100s
	Heave	20000 kN	400		50s	50s
	Pitch	180000 kNm	400		50s	50s
	Yaw	17000 kNm	600		50s	100s
OOStar 10 MW	Surge	1000 kN	1200	(0,0,-12)	100s	200s
	Heave	10000 kN	400		50s	100s
	Pitch	180000 kNm	400		50s	100s
	Yaw	17000 kNm	800		50s	100s
CSC 10 MW	Surge	1000 kN	1200	(0,0,-5.7)	100s	200s
	Heave	10000 kN	800		50s	100s
	Pitch	180000 kNm	800		50s	100s
	Yaw	17000 kNm	800		50s	100s
10 MW monopile	Fore-Aft	1500 kN	600	(0,0,115)	50s	50s
	Side-Side	1500 kN	600		50s	50s
INO-WINDMOOR 12 MW	Surge	1700 kN	1400	(0,0,0)	100s	200s
	Heave	10000 kN	600		50s	100s
	Pitch	220000 kNm	800		100s	100s
	Yaw	10000 kNm	1200		100s	100s
UMaine VolturnUS-S 15 MW	Surge	2250 kN	1200	(0,0,0)	100s	100s
	Heave	10000 kN	800		100s	100s
	Pitch	530000 kNm	800		100s	100s
	Yaw	10000 kNm	1200		100s	100s

Table 4: Simulation parameters for the decay tests (for each platform).

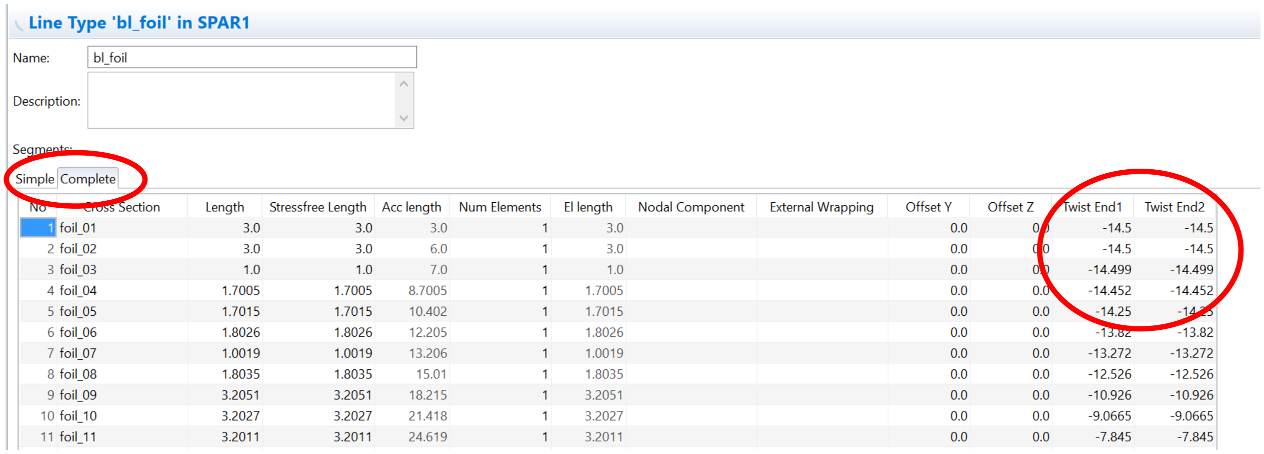
A summary of the simulation parameters for the decay tests is given in Table 5.

Simulation time step (Time Step in SIMA)	0.01 s
Wave/body response time step (Time Increment in SIMA)	Spar or semi: 0.1 s TLPWT in pitch or heave: 0.01 s TLPWT in surge or yaw: 0.1s Monopile: 0.01 s
Turbine status	**Parked**, **blades feathered**
Wave conditions	Hs = 0.01 m, Tp = 20 s
Wind input	0.01 m/s constant wind

Table 5: Simulation parameters for decay tests.

The BEM method is not really suited for the parked turbine. You should turn off the induction calculation for the parked cases. To turn off the induction calculation and park the turbine, there are three modifications:

1) Add a master-slave connection such that sh_sn1 is a slave to towerup (then the turbine cannot spin)
2) Change the twist angle of the blades to feather them. This means adding negative 90 degrees to the twist angle. This is done under "line type" blfoil, you have to expand the table to see the twist angle at each end of each segment. You might want to make this a variable so that it is easy to change it back!



No	Cross Section	Length	Stressfree Length	Acc length	Num Elements	El length	Nodal Component	External Wrapping	Offset Y	Offset Z	Twist End1	Twist End2
1	foil_01	3.0	3.0	3.0	1	3.0			0.0	0.0	-14.5	-14.5
2	foil_02	3.0	3.0	6.0	1	3.0			0.0	0.0	-14.5	-14.5
3	foil_03	1.0	1.0	7.0	1	1.0			0.0	0.0	-14.499	-14.499
4	foil_04	1.7005	1.7005	8.7005	1	1.7005			0.0	0.0	-14.452	-14.452
5	foil_05	1.7015	1.7015	10.402	1	1.7015			0.0	0.0	-14.25	-14.25
6	foil_06	1.8026	1.8026	12.205	1	1.8026			0.0	0.0	-13.82	-13.82
7	foil_07	1.0019	1.0019	13.206	1	1.0019			0.0	0.0	-13.272	-13.272
8	foil_08	1.8035	1.8035	15.01	1	1.8035			0.0	0.0	-12.526	-12.526
9	foil_09	3.2051	3.2051	18.215	1	3.2051			0.0	0.0	-10.926	-10.926
10	foil_10	3.2027	3.2027	21.418	1	3.2027			0.0	0.0	-9.0665	-9.0665
11	foil_11	3.2011	3.2011	24.619	1	3.2011			0.0	0.0	-7.845	-7.845

Figure 7: Blade foil line type, showing the twist angle

3) Turn off the induction calculation in the aerodynamics.

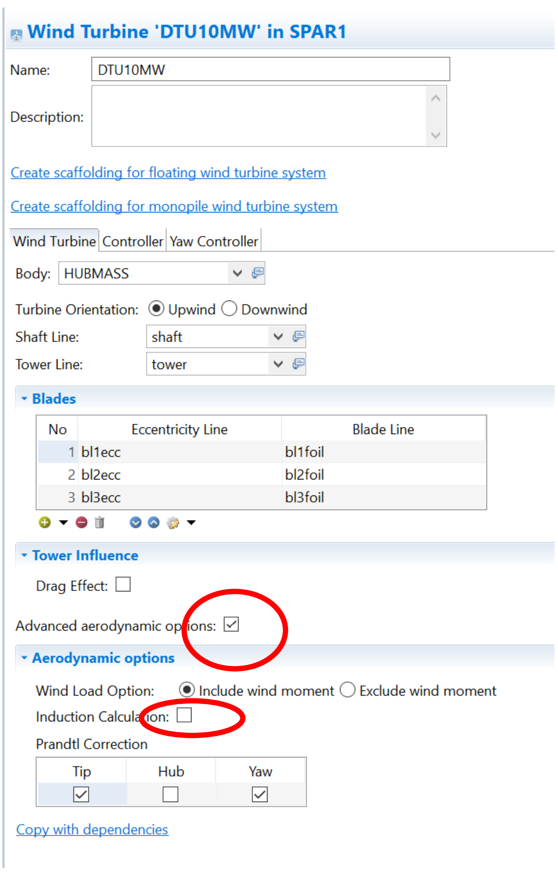


Figure 8: Turning off the induction calculation.

Additional tasks for 5-person groups: Carry out decay tests in sway and roll (use the same load levels/duration as for surge and pitch, respectively). Note and explain any differences that you see.

3.3 Response and fatigue study

The bulk of the simulation time will be devoted to a response and fatigue study, where the objective is to evaluate the performance of each floating concept at an idealized hypothetical location.

3.3.1 Environmental data

Binned environmental data are provided for the idealized installation location, as shown in Table 6. The wind and waves are both assumed to always travel in the positive x direction. The turbine is assumed to have 95% availability, which is reflected in the listed probabilities. We will assume that there is no power production and no fatigue damage during the other 5% of the time. The same conditions are assumed for all platforms, regardless of the variation in water depth and hub height.

Condition Number	Hs (m)	Tp (s)	U at 115m (m/s)	Turbulence Intensity (%)	Probability	Number of Seeds	Wave seed 1	Wave seed 2	Additional wave seeds
1	1.25	4	4	30.1	0.0973	2	101	102	
2	1.5	6	6	23.6	0.0730	2	103	104	
3	2.5	8	4	30.1	0.0412	2	105	106	
4	3	8	6	23.6	0.0291	2	107	108	
5	2.5	8	8	20.3	0.0986	6	109	110	201, 202, 203, 204
6	3.5	10	8	20.3	0.0237	2	111	112	
7	2.5	12	10	18.3	0.0818	2	113	114	
8	2.5	10	12	17	0.0716	2	115	116	
9	4	9	10	18.3	0.0402	2	117	118	
10	4	12	12	17	0.0356	2	119	120	
11	2.75	10	14	16.1	0.1405	2	121	122	
12	2.5	8	18	14.9	0.0343	2	123	124	
13	4	10	18	14.9	0.0782	2	125	126	
14	6	12	18	14.9	0.0217	2	127	128	
15	5.5	10	20	14.4	0.0833	2	129	130	

Table 6: Binned environmental conditions for the idealized location, 10 MW wind turbine

For each condition, two one-hour simulations (after transients) should be carried out (2x4000s total simulation time). The wave seeds to be applied in the analysis are provided in Table 6. The wind input files are provided for each condition. In the given files, the normal turbulence model (NTM) [11, 12] is applied for Class B turbines. Wind input boxes are provided for each of the turbines. The naming convention for the wind files is: IEA_ws**X**_NTM_**Y**, where X is the mean wind speed and Y is the seed number.

Simulation length	4000 s
Simulation time step (Time Step in SIMA)	0.005 s
Wave/body response time step (Time Increment in SIMA)	0.1 s
Turbine condition	operational
Wind input	IEA_wsX_NTM_Y, where X is the mean wind speed and Y is the seed number

Table 7: Simulation parameters for response and fatigue study simulations.

Note: it is expected that all group members will contribute to carrying out the simulations from Table 6.

Wind input files for the 10MW turbine: https://studntnu-my.sharepoint.com/:f:/g/personal/bachynsk_ntnu_no/Ei3lSq0X9S9IiatUOugjxmoBE8-JbXMpuDB9Mf2LgqjMpA?e=a4kFEM

Wind input files for the 12MW turbine: https://studntnu-my.sharepoint.com/:f:/g/personal/bachynsk_ntnu_no/Eu7LfDc7ZwxOpWnrjZak8oYBPBLr7x1QBhKXvkSwATExHw?e=LLUKYB

Wind input files for the 15MW turbine: https://studntnu-my.sharepoint.com/:f:/g/personal/bachynsk_ntnu_no/Eje4yElYBVpPuSv-CbCS3UsBKPKjZ8i-d1zmRDZciAQEPg?e=rt9xOL

3.3.2 Fatigue damage calculation

Short-term (1-hour) fatigue damage at the tower base due to axial stress should be calculated for each environmental condition. Some useful information for computing the fatigue damage is given here. The shear stress may be neglected in this study. The tower base geometry is given in Table 8.

	10MW spar #1	10MW spar #2	10MW TLP	OOStar 10MW	CSC 10MW	10MW monopile	INO-WINDMOOR 12MW semi	UMaine/VolturnUS-S 15MW
Outer diameter (m)	8.3	8.3	8.3	11.4	8.3	9.34	9.90	10
Thickness (mm)	38	57	38	75	38	67	90	82.95
Vertical location above SWL (m)	10	10	10	11	10	0	15.5	15.0

Table 8: Tower base structural properties.

Axial and shear forces, as well as bending moments, are output from RIFLEX in the local RIFLEX coordinate system. For the tower, all models can use the same transformations to the calculation coordinate system (Figure 9):

Nx = DOF 1 Axial force from RIFLEX
My = -1 * (DOF 3 Mom. about local y-axis, end 1 from RIFLEX)
Mz = DOF 5 Mom. about local z-axis, end 1 from RIFLEX

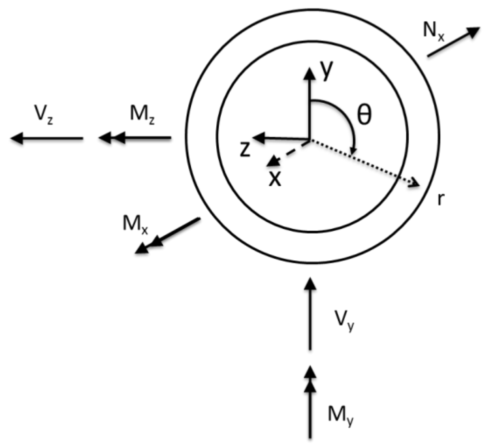


Figure 9: Coordinate systems for tower base fatigue damage calculation

The axial stress (σ) can then be computed as in Eq. (1) for a location (r, θ) on the cross section.

$$\sigma = \frac{N_x}{A} + \frac{M_y}{I_y} r \sin\theta + \frac{M_z}{I_z} r \cos\theta \tag{1}$$

In general, one should consider all locations on the cross section for the calculation of fatigue damage. In this case, with aligned wind and waves, it is permissible to only consider a **point on the outer radius and $\boldsymbol{\theta = 270°}$.** At this point, it is worthwhile to note that the outputs from RIFLEX are in kN (or kNm) and that the stress should be computed in MPa (in order to be consistent with the SN curve).

After computing the time history of stress at the given point, one must compute the number of stress cycles. In MATLAB, rainflow counting can be done with help of the WAFO routines *dat2tp* and *tp2rfc*:

```
x = [time stressSx];
[tp, ind] = dat2tp(x);
def.res = 'CS';
def.asymmetric = 0;
def.time = 0;
[RFC,RFC1,res,def] = tp2rfc(tp,def);
```

The documentation from WAFO should be examined in order to apply these codes correctly.

In python, rainflow counting can be done with the help of the rainflow package and the provided fatigue damage calculation script. The code is called as:

```
FatigueDamage(stress_history,thk,thk_ref,k,K1,beta1,stress_lim=0,K2=0,b
eta2=0)
```

In order to compute the damage, one must then apply the correct SN-curve. For the tower base, we will use S-N curve D from Table 2-1 in DNV-RP-C203 [13].

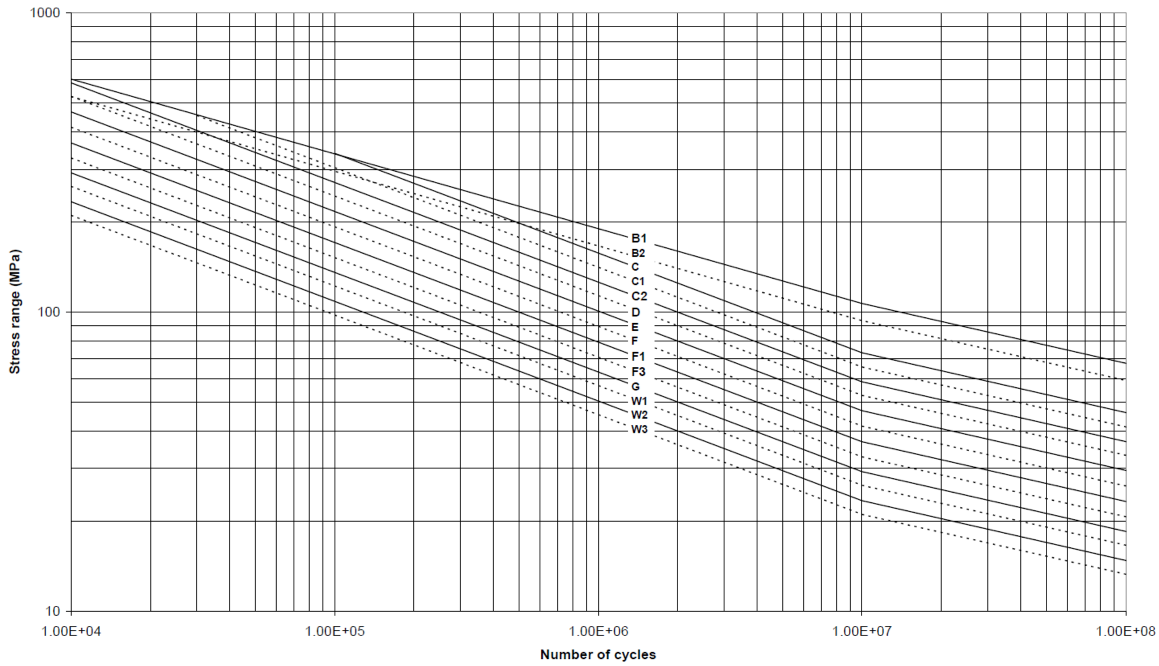


Figure 10: SN curves in air (copied from [13])

The DNV S-N curve is defined as in Eq. (2) , where *N* is the number of cycles, *t* is the thickness, and $\Delta\sigma$ is the stress range. The parameters for the fatigue curve are as given in Table 9. For simplicity, we will assume a stress concentration factor of 1.

$$\log N = \log \bar{a} - m \log\left(\Delta\sigma\left(\frac{t}{t_{ref}}\right)^{k}\right) \quad (2)$$

N≤10^7 cycles		N>10^7 cycles		Fatigue limit at 10^7 cycles	k	t_{ref} (for the given cross section)
m	$\log \bar{a}$	m	$\log \bar{a}$			
3.0	12.164	5.0	15.606	52.63 MPa	0.20	25 mm

Table 9: SN-curve for the tower base.

The additional matlab code *cc2dam_2slope* (provided) can be used to compute the fatigue damage based on a two-part SN curve. Note that β is a vector with 2 values that is equivalent to *m* from Table 9, and $K = \frac{1}{10^{\log \bar{a}}}$. This code is modified from the WAFO routine *cc2dam*, which accounts for SN curves with a single slope. The code is also modified to account for the difference in definition between the DNV SN curve and WAFO: the DNV curve is based on stress ranges, while WAFO is based on amplitudes. An additional factor $2^{\beta}$is therefore included in the *cc2dam_2slope* routine.

```
DRFC_sx = cc2dam_2slope(RFC,beta,K,stresslim,thk,tref,k);
```

In python, the provided code accounts for the stress limits. The inputs are as similar as possible to WAFO, so $K = \frac{1}{10^{\log \bar{a}}}$.

3.3.3 Results to be included in the presentation

The following results should be presented for each condition:

- mean offsets of all motions
- standard deviation of all motions
- mean and standard deviation of rotor speed
- mean and standard deviation of tower base bending moments (FA and SS)
- estimated 1-hour fatigue damage at the base of the tower (for a point lying on the global x-axis)

Furthermore, **spectral analysis of the platform motions and the tower base bending moment** should be presented **for conditions 5 and 15**. You may choose to show one or more seeds, or you may average the spectra for a given condition.

In order to test the hypothesis that two seeds are sufficient to get a reasonable estimate of the fatigue damage, **four additional simulations should be carried out for condition 5.** The variation in the estimated fatigue damage for condition 5 based on the number of simulations should be discussed separately from the total fatigue damage calculation.

The average power production and estimated 20-year fatigue damage due to axial stress at the tower base should be presented. It is expected that the discussions will explain which conditions contribute the most to fatigue/power production and why.

Additional tasks for 5-person groups: Before running the simulations, make sure to add storage of the force output at two additional locations along the tower (approximately 15 m above the tower base and approximately 50 m above the tower base). Find the diameter and thickness of the tower section where you output results. Estimate the fatigue damage at these locations as well (and present the same results as shown for the tower base).

3.4 Blade pitch fault simulations

In addition to operational load cases, the design load conditions for offshore wind turbines include conditions with fault. In this project, such load conditions will not be included in the fatigue analysis, but will be considered separately. Only blade pitch seize faults will be considered, but two types of responses will be studied: blade pitch seize without corrective action, and blade pitch seize followed by emergency shutdown. The conditions for simulation are summarized in Table 10.

Condition Number	Hs (m)	Tp (m)	U at 115m (m/s)	Turbulence Intensity (%)	t_F (s)	Shutdown?	Blade pitch rate (deg/s)	Wave seed	Corresponding fault-free simulation
F1	2.5	10	12	17	1000	None	8	115	8
F2	6	12	18	14.9	1000	None	8	127	14
F3	2.5	10	12	17	1000	0.1	8	115	8
F4	6	12	18	14.9	1000	0.1	8	127	14

Table 10: Blade pitch fault simulations

The definition of blade pitch seize faults for our purposes is that the pitch actuator of **blade 2** is blocked at time t_F, and we consider both cases without shutdown (F1 and F2) and cases with shutdown (F3 and F4). When shutdown occurs, it is assumed to start 0.1 seconds after the fault, with total loss of generator torque and without mechanical brake. All of the conditions include above-rated wind speed, so that the blade pitch controller may be important. The fault simulations should be carried out for at least 2000s. A single seed may be used for each condition.

3.4.1 Simulating faults in SIMA

The occurrence of fault is simulated directly in SIMA under “Dynamic Calculation Parameters”> “Dynamic Loads” > “Wind turbine faults”.

In order to simulate blade pitch fault without shutdown, only the “Blade pitch” tab should be considered. Here, the time of fault occurrence and the RIFLEX line which is to be subjected to fault should be filled in (Figure 11).

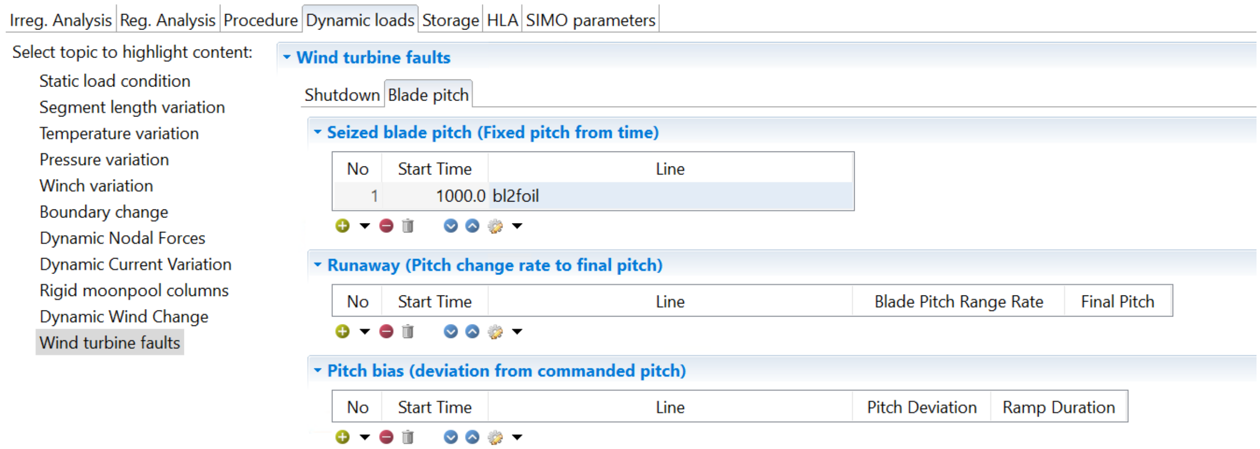


Figure 11: Blade pitch seize fault definition in SIMA.

If the blade pitch fault is followed by shutdown, the "shutdown" tab should be used as well. Note that blade pitch faults override the shutdown inputs, so only the non-faulty blades will contribute to shutdown. An example of the inputs is given in Figure 12.

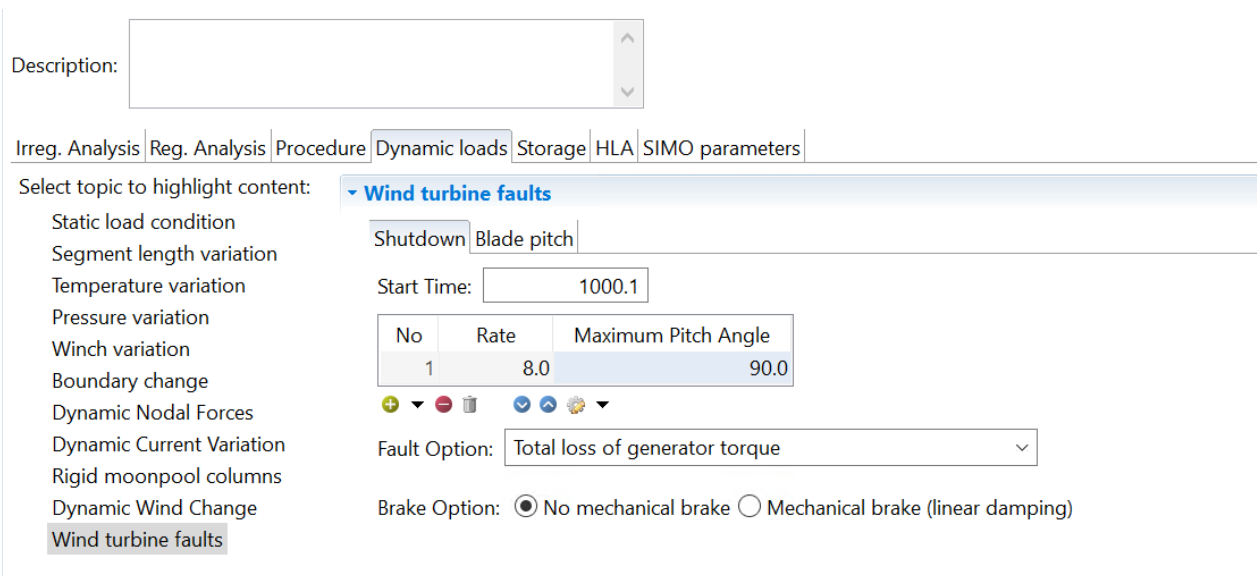


Figure 12: Shutdown definition in SIMA.

3.4.2 Results to be presented

In addition to the previously mentioned results, the presentation should include **results and discussions** of the blade pitch seize fault study in irregular waves and turbulent wind.
The following results should be presented for each condition:

- Pitch, roll, and yaw motions (time series)
- Maximum (absolute values) of bending moments at the base and top of the tower (both directions), as well as time of occurrence

For the conditions with shutdown, the amount of time until the turbine is “stopped” (rotational speed less than 5% of rated) should also be reported.

These results should be compared to the corresponding values for the fault-free simulations.
For the given (limited) number of cases for your platform, is it helpful to shut down the turbine?

4 Phase 3 presentation

At the end of phase 3, each group is expected to prepare a single presentation including results from phase 1, phase 2, and phase 3. The **20-minute presentation** should discuss the most interesting results. (In other words, you can skip over some slides even though you include them for completeness in the file). The template does not include the extra tasks for 5-person groups! You need to submit the presentation electronically in Blackboard in addition to giving the presentation.

5 References

1. Bak, C., et al., *Description of the DTU 10MW Reference Turbine*. 2013, DTU Wind Energy.
2. Xue, W., *Design, numerical modelling and analysis of a spar floater supporting the DTU 10MW wind turbine*, in *Department of Marine Technology*. 2016, Norwegian University of Science and Technology: Trondheim, Norway.
3. Hegseth, J.M. and E.E. Bachynski, *A semi-analytical frequency domain model for efficient design evaluation of spar floating wind turbines.* Marine Structures, 2019. **64**: p. 186-210.
4. Tian, X., *Design, Numerical Modelling and Analysis of TLP Floater Supporting the DTU 10MW Wind Turbine*, in *Department of Marine Technology*. 2016, Norwegian University of Science and Technology.
5. Yu, W., K. Müller, and F. Lemmer, *Deliverable D4.2 Public Definition of the Two LIFES50+ 10MW Floater Concepts*, in *Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m*. 2018.
6. Wang, Q., *Design of a Steel Pontoon-type Semi-submersible Floater Supporting the DTU 10MW Reference Turbine*. 2014, Norwegian University of Science and Technology, Delft University of Technology.
7. Velarde, J.B., Erin E. , *Design and fatigue analysis of monopile foundations to support the DTU 10 MW offshore wind turbine.* Energy Procedia, 2017. **137**: p. 3-13.
8. Souza, C.E.S.d., et al., *Definition of the INO WINDMOOR 12 MW base case floating wind turbine*. 2021, SINTEF Ocean.
9. Allen, C., et al., *Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine*. 2020, National Renewable Energy Laboratory: Golden, CO.
10. Gaertner, E., et al., *Definition of the IEA 15-Megawatt Offshore Reference Wind*. 2020, National Renewable Energy Laboratory: Golden, CO.
11. International Electrotechnical Commission, *Wind turbines: Part 1: Design Requirements*. 2005.
12. International Electrotechnical Commission, *Wind turbines: Part 3: Design requirements for offshore wind turbines*. 2009.
13. Det Norske Veritas, *Fatigue Design of Offshore Steel Structures*. 2010.

6 Appendix: Matlab and Python code for analysis

Some Matlab/Python code is provided as a starting point for examining the analysis results. It is, of course, possible to write your own routines in the programming language of your choice.

6.1 Step wind file generation

For those who wish to use the step wind option, the codes genStepWind.m and genStepWind.py are provided. You may need to update file paths and durations to suit your needs. When using a step wind file in SIMA, you need to choose the "fluctuating two-component wind" option in the description of the environment in SIMA.

6.2 Decay test analysis

A code for PQ analysis (PQanalysis.m or PQanalysis.py) is provided. This code can be combined with ReadTimeDomainResults (see Section 6.3). Note, however, that the code assumes that any mean offset has already been removed, and that only the free decay part of the time series is given as input. It is important to examine the peaks and troughs in each decay test and ensure that the code has managed to identify appropriate points. You may need to make some modifications!

In matlab: note that *dat2tp* (which also calls additional routines) from the WAFO package is needed in order to use this code.
In python: numpy and matplotlib are the only dependencies for this code.

6.3 Reading of results

A script called *readTimeDomainResults.m* (or *readTimeSeriesResults.py*) is provided in order to read in the various text files. Since different codes in the coupling write results at different rates and possibly at different points in the timestep, one must pay attention to which results are associated with which "time" vectors. The time series that are available in the workspace after running this script are shown in Table 11.

Time variable	**Result variable**	**size**	**units**	**Description**
time_SIMO (mx1)	PlatMotions	(mx6)	m,m,m,deg,deg,deg	Platform position/rotation in global coordinates
	wave	(mx1)	m	Wave elevation at the origin
time_WT (nx1)	Bl1Pitch	(nx1)	deg	Blade 1 pitch angle
	Bl2Pitch	(nx1)	deg	Blade 2 pitch angle
	Bl3Pitch	(nx1)	deg	Blade 3 pitch angle
	genPwr	(nx1)	kW	generator power (not corrected for efficiency)
	genTq	(nx1)	kNm	generator torque (low speed shaft side)
	AeroForceX	(nx1)	kN	thrust (aero. force along shaft)
	AeroMomX	(nx1)	kNm	aero torque (aero moment about shaft) – rotor inertia is not included
	HubWindX	(nx1)	m/s	wind speed at hub along shaft axis
	HubWindY	(nx1)	m/s	wind speed at hub horizontal perpendicular to shaft axis
	HubWindZ	(nx1)	m/s	wind speed at hub vertical perpendicular to shaft axis

	omega	(nx1)	rad/s	rotor speed
time_RIFLEX (jx1)	TowerBaseAxial	(jx1)	kN	(DOF1) Axial force at tower base
	TowerBaseBMY	(jx1)	kNm	(DOF3) Bending mom. Y at tow base
	TowerBaseBMZ	(jx1)	kNm	(DOF5) Bending mom. Z at tow base
	TowerBaseShearY	(jx1)	kN	(DOF7) Shear force Y at tow base
	TowerBaseShearZ	(jx1)	kN	(DOF9) Shear force Z at tow base
	TowerBaseTors	(jx1)	kNm	(DOF2) Torsional moment tow base
time_RIFLEX (jx1)	TowerTopAxial	(jx1)	kN	(DOF1) Axial force at tower top
	TowerTopBMY	(jx1)	kNm	(DOF3) Bending mom. Y at tower top
	TowerTopBMZ	(jx1)	kNm	(DOF5) Bending mom. Z at tower top
	TowerTopShearY	(jx1)	kN	(DOF7) Shear force Y at tow top
	TowerTopShearZ	(jx1)	kN	(DOF9) Shear force Z at tow top
	TowerTopTors	(jx1)	kNm	(DOF2) Torsional moment tow top
time_RIFLEX (jx1)	bl1Axial	(jx1)	kN	(DOF1) Axial force at blade 1 root
	bl1Tors	(jx1)	kNm	(DOF3) Bending mom. Y blade 1 root
	bl1BMY	(jx1)	kNm	(DOF5) Bending mom. Z blade 1 root
	bl1BMZ	(jx1)	kN	(DOF7) Shear force Y blade 1 root
	bl1ShearY	(jx1)	kN	(DOF9) Shear force Z blade 1 root
	bl1ShearZ	(jx1)	kNm	(DOF2) Torsional moment blade 1 root
time_RIFLEX (jx1)	bl2Axial	(jx1)	kN	(DOF1) Axial force at blade 2 root
	bl2Tors	(jx1)	kNm	(DOF3) Bending mom. Y blade 2 root
	bl2BMY	(jx1)	kNm	(DOF5) Bending mom. Z blade 2 root
	bl2BMZ	(jx1)	kN	(DOF7) Shear force Y blade 2 root
	bl2ShearY	(jx1)	kN	(DOF9) Shear force Z blade 2 root
	bl2ShearZ	(jx1)	kNm	(DOF2) Torsional moment blade 2 root

Table 11: Workspace variables from *readTimeDomainResults.m*.

No plotting or statistical analysis is carried out in the provided code. The time series in the workspace include transients, which should be removed before plotting.

6.4 Spectral analysis

Prior to computing the power spectral density, it is recommended to subtract the mean value from the time signal.

In matlab, the WAFO utility *dat2spec* in matlab may be useful – but caution is advised regarding smoothing. The smoothing is controlled by the input *L*, and a larger *L* gives less smoothing. A value around 16000 can be a good starting point.

In python, the function scipy.signal.welch with Hanning windows is recommended. The choice of nperseg and noverlap can greatly affect the smoothing. Values 16384 and 8192, respectively, can be a good starting point.

6.5 Fatigue calculation

6.5.1 Matlab

dat2tp
tp2rfc
An additional routine, *cc2dam_2slope* is also provided (see Section 3.3.2). Note that the calculation of stress from the internal load time history is not included in the provided code.

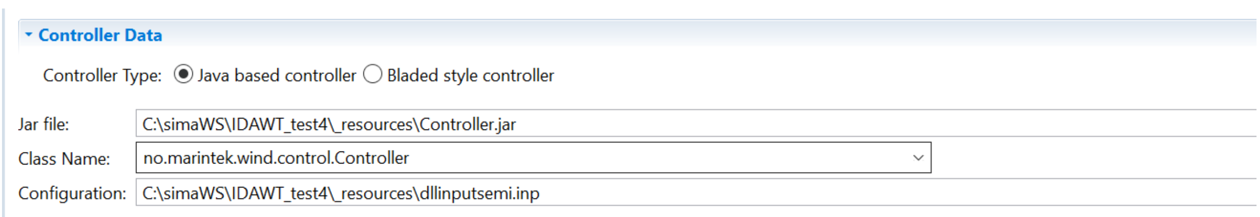
6.5.2 Python

See Section 3.3.2.

7 Appendix: Controller for the OO-Star 10 MW Platform

The OO-Star 10 MW semi-submersible is modelled with the updated control system developed in the LIFES50+ project. This is a Bladed-style DLL which is called by a java file, rather than a direct implementation in java. When you import the .stask file, the .jar file and configuration file will show up in the “resources folder”. However, we need to also refer to the “SimaControllerforDistribution”.

To set this up, start by looking at the controller data for the turbine. You should see the path to the .jar file and to the dllinputsemi.inp filer:



You should then open the dllinputsemi.inp file (in a text editor) and modify lines 2, 7, and 9 to point to the correct corresponding locations on your computer (this depends where you download and extract the “SimaControllerForDistribution” folder).

8 Appendix: INO-WINDMOOR 12 MW semi-submersible

The INO-WINDMOOR 12 MW semi-submersible is modelled in a coordinate system which more closely resembles the Ocean Basin, so the wind and wave direction for our purposes will be **180 degrees rather than 0 degrees**.

9 Appendix: UMaine VolturnUS-S 15 MW semi-submersible control system

The 15 MW wind turbine model makes use of a Fortran DLL via the Bladed-style interface. One change needs to be made to the DISCON.IN file in order to correctly reference the performance file (needed for the wind speed estimator). You should update the full path to the Cp_Ct_Cq.IEA15MW.txt file in line 79 of the DISCON.IN file to match your own setup.

10 Appendix: Running simulations in part 3 in a condition set

A convenient way to set up the simulations in part 3 would be to define appropriate variables for the environmental conditions such that all of the conditions can be defined in a table. For example, one could define variables for Hs, Tp, wave seed, and wind file name.

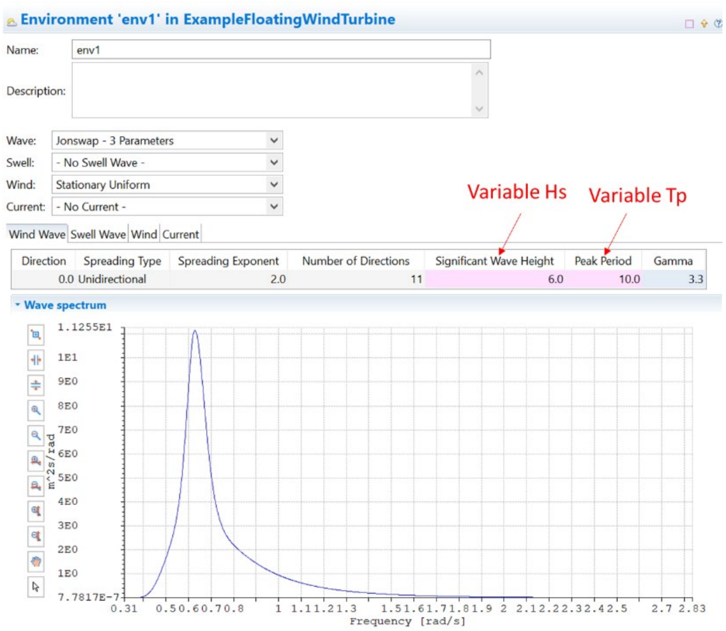


Figure 13: Variables for Hs and Tp (under environment)

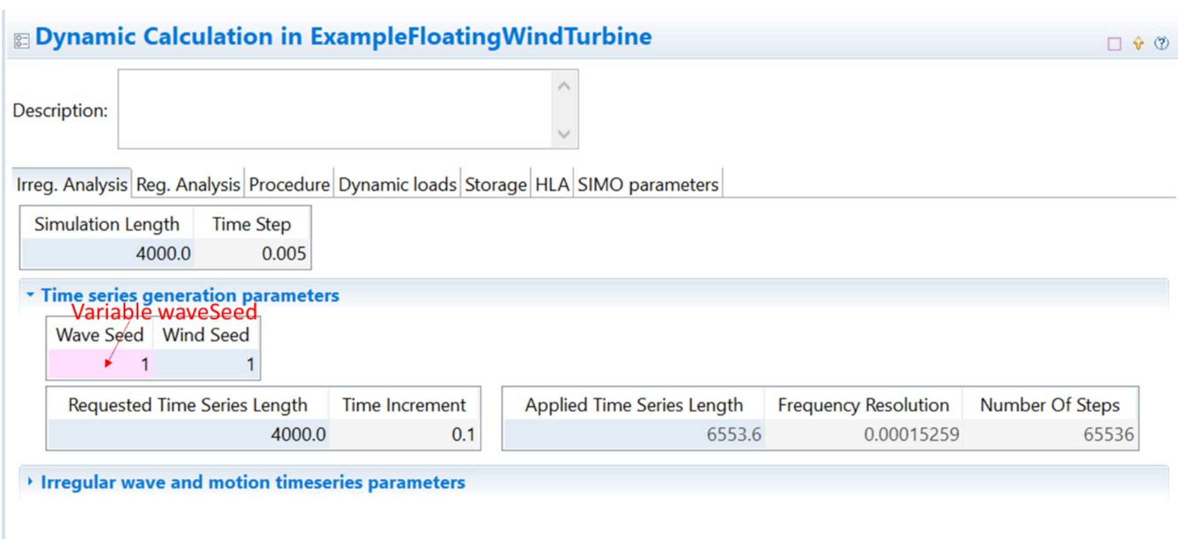


Figure 14: Variable wave seed

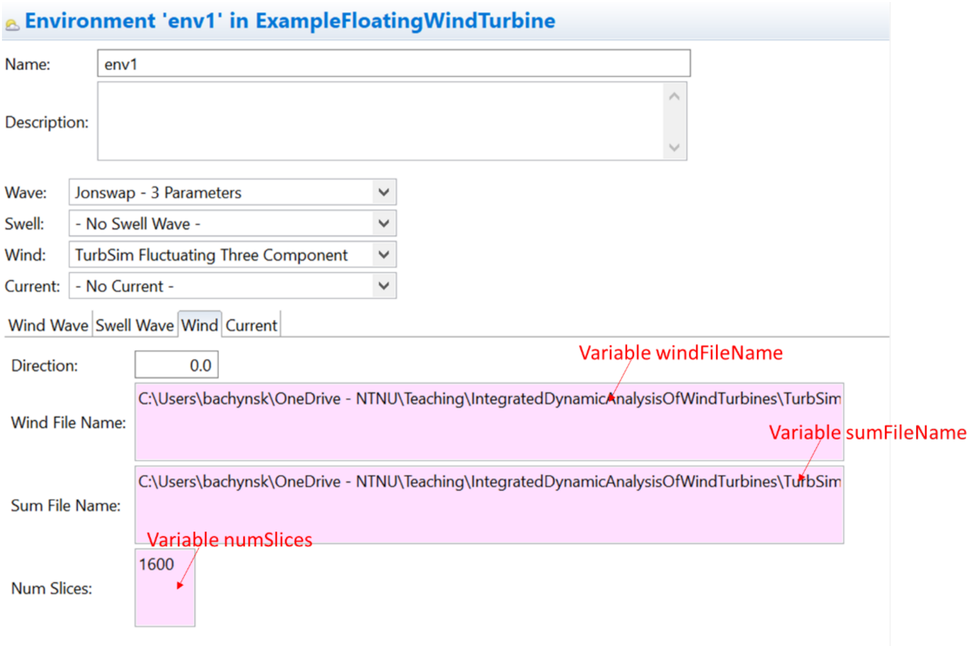


Figure 15: Variables for the wind file and number of slices (note that you may need to increase this number compared to the default!)

Once all of the variables are defined, you can create a condition set with each of the conditions you want to run. (Nonsense input is given below just to show an example of four simulations).

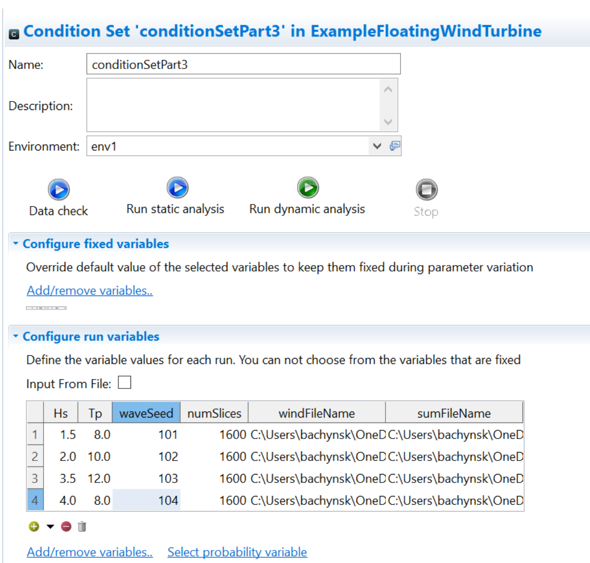


Figure 16: Condition set with four conditions (note that this input is not in accordance with the project, it's just an example).

When you run the dynamic analysis in the condition set, all of the conditions will run. SIMA will run the number that you allow it to run simultaneously, the others will start (in turn) when previous simulations are finished). To control the number of simultaneous simulations, you can look in the preferences.

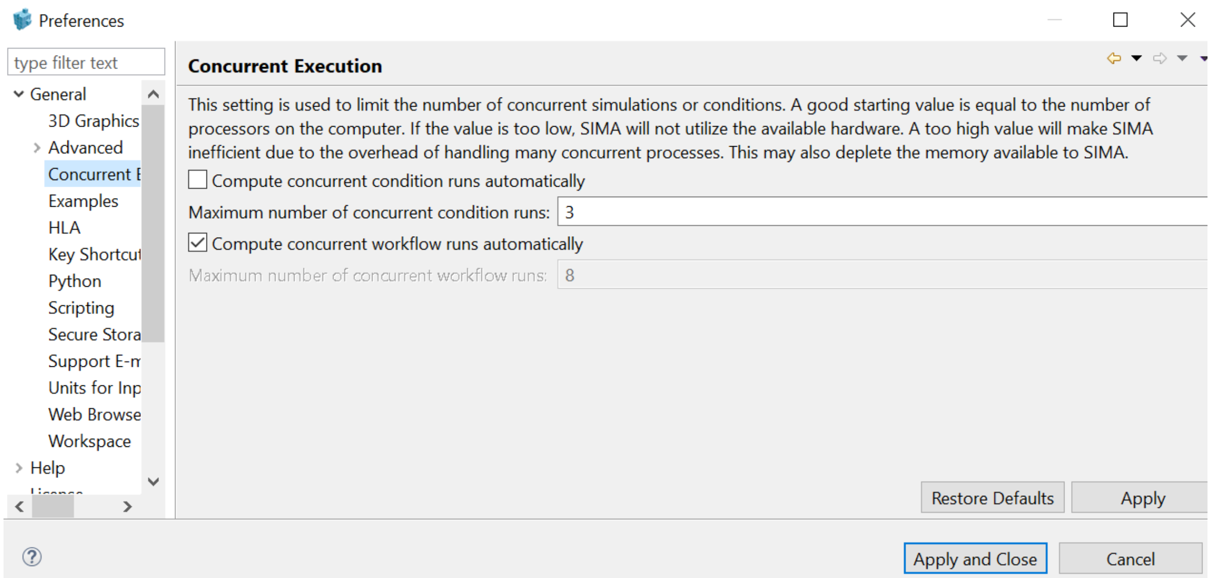


Figure 17: Preferences menu showing that 3 runs will carried out simultaneously