FLOATGEN

Requirements for the floating structure (Demo 1)

Deliverable nº: 2.3

SEVENTH FRAMEWORK PROGRAMME

EC-GA nº 295977
Project full title: Demonstration of two floating wind turbine systems for power generation in mediterranean deep waters

Deliverable Nº 2.3

Requirements for the floating structure (Demo 1)

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Brief Summary

This document outlines the codes and standards the design has to follow and provides the basic input data and design philosophy to be used while developing the concept.

General guidance is provided herein for the overall floater. Additional design brief and specification documents specific to the components and sub-systems will be developed based on the present document.

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1. EXECUTIVE SUMMARY

1.1 PROJECT OVERVIEW

The objective of the FLOATGEN project is to demonstrate the technical and economic feasibility of two different multi-megawatt integrated floating-wind turbine systems in deep waters, never applied before to Mediterranean Sea conditions, in order to extend deep offshore wind resources and demonstrate decrease of costs for electricity generation down to competitive level.

The project will also assess, compare and obtain conclusions about performance of such two different combinations of wind turbine and floating structure technologies to get the knowledge to improve performance of the future replication projects of these technologies.

To reach such objectives, the project will join a 10 partnership European consortium, industry led by two global wind turbine manufacturers and wind farm operators, GAMESA and ACCIONA WIND, in cooperation with the floating systems developers IDEOL and NAVANTIA, the contribution of ACCIONA ENERGIA, OLAV OLSEN and STUTTGART UNIVERSITY for structural design, and supported for monitoring, environmental and dissemination activities by FRAUNHOFER-IWES, RSK GROUP and GREENOVATE.

Demonstrator 1 will be a 2MW demonstrator that will use a 2MW Gamesa wind turbine mounted on an IDEOL ring-shaped surface floating platform. Its novel hydrodynamic properties make its performance exceptional compared to other surface floating platforms. Its patented moonpool acts as a damper to wave motion thanks to the oscillation of the entrapped water mass. These oscillations compensate for wave excitation loads and thus reduce the motion induced on the turbine.

1.2 SCOPE OF DOCUMENT

The scope of this document is to list the basic requirements that will apply to the floating foundation.

This document outlines the codes and standards the design has to follow and provides the basic input data and design philosophy to be used while developing the concept.

General guidance is provided herein for the overall floater. Additional design brief and specification documents specific to the components and sub-systems will be developed based on the present document.

Other documents pertaining to the wind turbine, interface piece and regulatory framework collects the data necessary for the design of these specific tasks.

2. ACRONYMS AND REFERENCES

2.1 ABBREVIATIONS, SYMBOLS AND DEFINITIONS

ACI	American Concrete Institute
API	American Petroleum Institute
ASL	Above Sea Level
ASME	American Society of Mechanical Engineers
AWL	Above Water Line
BV	Bureau Veritas
DNV	Det Norske Veritas
GL	Germanischer Lloyd
H_s	Significant wave height
IACS	International Association of Classification Societies
ILLC	International Load Lines Conventions
ILO	International Labour Organisation
IMO	International Maritime Organisation
ISO	International Standardisation Organisation
LAT	Lowest astronomical tide
LR	Lloyd’s register
MW	Megawatt (1’000’000 Watt)
MWe	Electrical Megawatt (electrical power delivered by a generator)
nm	Nautical Mile
Shall	Denotes a mandatory requirement
Should	Denotes a preferred configuration
t	Metric tonne
T_p	Wave spectrum peak period
T_z	Wave zero up-crossing period
UTM	Universal Transverse Mercator

2.2 REFERENCES

2.2.1 PROJECT DOCUMENTS

[P01] Consortium document Floatgen project contract Annex 1 “Description of Work”

[P02] Gamesa document GD0xxxxx-en “RD WTG FLOATGEN” Rev 0

[P03] Ideol document G02-SP-MEC-2523-00 “Transition Piece design requirements” (To be issued)

[P04] Ideol document G02-DW-INT-0200-00 “Floatgen Interface Drawing”

2.2.2 RULES AND STANDARDS

[R01] ISO 19901-1 ”Metocean design and operating considerations”

[R02] ISO 19901-5 “Weight control during engineering and construction”

[R03] ISO 19901-7 “Stationkeeping systems for floating offshore structures and mobile offshore units”

[R04] IEC 61400-1 “Wind turbines: design requirements”

[R05] IEC 61400-3 “Wind turbines: design requirements for offshore wind turbines”

[R06] “Code for construction and equipment of mobile offshore drilling units” 2001 IMO MODU code

[R07] “International load lines convention” IMO ILLC 1966 as amended

[R08] International ship and port facility security code” IMO ISPS code 2003 as amended

[R09] BV NI-572-DT-R00-E “Classification and certification of floating offshore wind turbines” – November 2010

[R10] DNV OS-E301 “Position mooring”

[R11] DNV classification note 30.5 “Environmental loads and environmental conditions”

[R12] API RP 2SK “Design and analysis of station-keeping systems for floating structures” October 2005 and addendum 2008

[R13] API RP 2A “Recommended practice for planning, designing and constructing fixed offshore platforms—Working stress design”, 21st edition 2000 and supplements 2002, 2005

[R14] “Actions and action effects” NORSOK Standard N-003, 2007

3. PROJECT DATA

3.1 SYSTEM DESCRIPTION

As a general rule, the arrangement of the design accounts for:

- No part of the platform interferes with the operation of the turbine,
- Means of access and escape to / from the platform shall be safe for both the personnel and the equipment under conditions similar to fixed offshore foundations,
- Remediation to single point failures as identified in 4.1.2,
- Interference between mooring lines, umbilical, and access areas are prevented,
- Maintenance of equipment is possible by the platform's own equipment and outfitting.

The arrangement developed today is a ring-shaped floater with its mooring lines grouped in three clusters of lines, each spurring at 120° from each other.

The main dimensions of the floater for a 5MW wind turbine are approximately 40m in side, 9m in depth for an operation draught of 6m to 7m. The span of skirts is around 2.5m. All these dimensions will be updated for the 2MW wind turbine and specific site conditions. The picture below shows the arrangement of the platform:

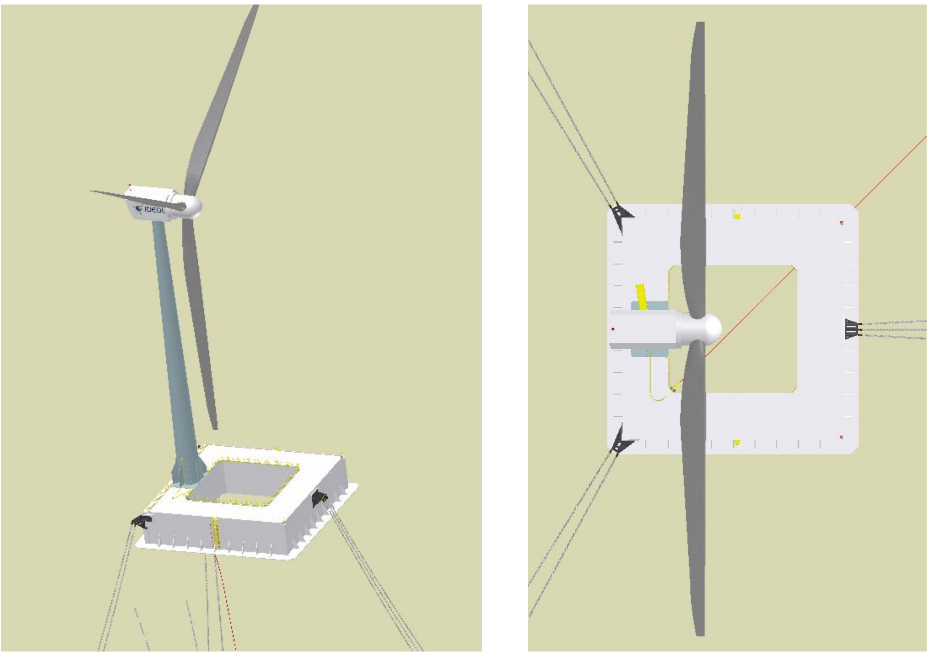

FIGURE 1 VIEWS OF RING FLOATER

The tower is located aft of the floater, the three mooring lines shown on Figure 1 spur forward towards the extreme wave conditions. The mooring system is site-dependent (number and type of mooring-lines). The umbilical (in red) is going subsea through the moonpool. The number of mooring lines will be adjusted on a site-by-site basis.

3.2 APPLICABLE CODES AND STANDARDS

Floating offshore wind turbines will be subject to rules and regulations from several sources. They are ranged by order of precedence as follows:

- National/regional authorities rules which will be site-dependent,
- Classification society rules which will be class-dependent,
- Operator/test site specification which are also site-dependent,
- Marine operation warranty surveyor rules,
- Industry standards which should be relatively stable.

National authorities generally address facility and personnel safety as well as environmental issues. In general, the rules of **HOLD** will be considered. Access and working space requirements will be set according to European standards as they are usually more stringent in respect of accesses, headroom, etc…

Classification society rules address insurance-related issues during the life of the platforms. They consequently encompass third party and owner personnel safety, structural integrity, stability, etc… Marine operations do not fall within the scope of the classification except as far as the integrity of the classified floater is concerned: Class will typically witness mooring installations, check the stability and structural analyses covering the transit conditions and perform an as-installed survey.

The classification / certification body is not yet selected but the following classification societies have both developed floating wind turbine rules and a substantial track record of certifying / classing offshore concrete structures:

- Lloyd’s Register,
- Det Norske Veritas,
- Bureau Veritas.

Operator/test site specifications will normally set operating conditions, preferences in terms of system redundancy, emergency response, durability... This may have impacts on design criteria if additional margin is needed on a given component to meet a larger durability than insurance standards would require. Once site-specific conditions will be known, they will be incorporated in the present document.

The purpose of marine operations warranty survey is two-fold:

- ensuring that no harm will be caused to the people involved in, and exposed to the consequences of a marine operation;
- ensuring that the structures involved in marine operations are not damaged and ready for service as planned.

We will base on Noble Denton guidelines for marine operations as a starting point.

A number of industry standards will be used to design components. Part of them is listed in the next sections.

We summarised in Table 1 the main codes that the floating wind turbine shall comply with.

Order of precedence	Description	Code considered
1	**International regulations**	IMO codes & regulations
2	**National regulations**	**HOLD**
3	**Class for hull and mooring**	LR, GL, BV or DNV
4	**Operator / site specs**	**HOLD**
5	**Marine warranty surveyor**	Noble Denton
6	**Industry standards Hull, Mooring, umbilical**	ISO 19900 series
6	**Industry standards Turbine**	IEC 61400 series

TABLE 1 BASIC CODES AND STANDARDS TO BE COMPLIED WITH BY ORDER OF PRECEDENCE

3.3 TECHNOLOGY TARGET DEPLOYMENT SITES

Target installation sites for this technology are located along the coast of developed countries exposed to strong and frequent sustained winds. This includes North East and North West Atlantic, the North Sea, North China Sea, the coasts of Japan and Taiwan, the Mediterranean Sea, North American Great Lakes and other closed seas.

For Floatgen project the platform is planned to be installed in North East Atlantic, the Mediterranean and the North Sea.

The system will be competitive against fixed foundations from approximately 40m water depth. In areas with benign wave conditions or challenging geological conditions, it can be competitive in shallower waters.

4. DESIGN PHILOSOPHY

4.1 SAFETY AND ENVIRONMENT PROTECTION

1.1.1. Safety philosophy

The safety of the system and personnel onboard will rely on:

- Adequate signalling of the structure to prevent collisions,
- Stability and watertight integrity in intact and damaged conditions,
- Structural integrity of all components,
- Ease of access and escape of personnel in normal, accidental and bad weather conditions,
- Adequate systems redundancy in case of loss of power,
- Redundancy of the mooring system,
- Protection of personnel from rotating parts and harmful components / substances,
- Adequacy of design loads to the exposure time in transient conditions,
- Safety equipment to enable the safe escape of personnel,
- Emergency response procedures and equipment readiness to help rescue operations as a last resort.

For transient conditions due to damages, it shall be verified in particular that the repair time of a given component is in line with the design exposure time considered.

For example, if the repair time of a given component is 1 week (or less), then the stability of the platform must be verified under 1-year return period environments with this component ineffective. For periods less than 30 days, the 10 year return period environment would apply.

Due consideration shall be given to the stability and access criteria considered in damaged situations (seized nacelle yaw system, pitch control of a blade, damaged compartment, damaged personnel transfer equipment, etc…).

4.1.1 PROTECTION OF THE ENVIRONMENT

All materials shall be selected to prevent any pollution to the marine environment.

No oil spill will be allowed during platform operation, offshore installation works, decommissioning

The mooring system design will be consistent with local environment protection rules in particular if noise limitations are required during offshore works, certain areas need to be free of mooring-line d=chafing on seabed, etc…

4.1.2 MANAGEMENT OF ACCIDENTAL CASES

In general, the consequences of all single point failures shall be checked and analysed. The analysis shall put in perspective operational, safety, integrity and remediation criteria.

Accidental loads shall be combined with safe and realistic environmental conditions. For example, as mooring line failures are very long to be repaired, the damaged condition is checked against the design return period environment with safety factors decreased compared to the intact condition.

The following failures have been identified so far and shall be considered:

- Loss of one mooring line,
- Seizing of one blade pitch system
- Seizing of nacelle yaw system,
- Loss of grid power,
- Damaged compartments,
- Loading of one mooring line up to the breaking load,
- Consequences of dropped object,
- Collision with a crew boat,
- etc…

This list will be extended and a hazard / risk / failure mode register will be updated during the course of the project.

4.2 PLATFORM OVERALL DESIGN

4.2.1 LOAD LINE CONVENTION

Although the floater is not a ship and has unusual proportions, it will be designed to comply with the provisions of IMO 1966 Load Line convention (as amended since then), except damage stability conditions which will be assessed as per IMO MODU code (see subsequent sections on stability).

In particular, all water-tightness and weather-tightness provisions shall be fulfilled and the minimum freeboard set in this convention shall be respected both in transit and in place. This may be necessary in case the unit is towed in international waters or in case the platform is considered as a ship by the state of the deployment site.

4.2.2 STABILITY VERIFICATIONS

Stability shall be verified based on IMO MODU code. In particular, height coefficients and minimum wind speeds shall be considered as per this code even though other values are used for the design of the turbine or mooring system.

When the turbine is in standby condition, it will orientate so that wind loads are minimised. The same assumptions in terms of azimuth, blade pitch error and the related environmental return period as in the IEC design code for wind turbine foundations shall be considered.

The consequences of a fault of either the yaw orientation of the nacelle or the blade pitch should be assessed in terms of stability. It is a minimum requirement that the platform is stable with sufficient margin under the 1-year return period environment with these components non-operational. Larger return periods may be required in case typical repair times are larger than 1 week.

Attention shall be paid to the variation of wind loads on the blades with the list of the platform. If an additional heeling moment due to blade lift occurs at any inclination of the platform, it shall be accounted for in the stability analysis.

Damage stability calculations shall be performed in accordance with the MODU code.

In case on-site wind speeds are larger than MODU code wind speed (100 knots at 10m), this larger wind speed shall be considered in the verification of the stability of the platform. Wind speeds for stability verification are usually the 1-minute averaged wind.

During transit, the stability of the platform shall be verified based on the 10-year return period 1-minute average wind speed.

4.2.3 HULL STRUCTURAL INTEGRITY

The structure of the floater shall in general be designed in accordance with Class. Tubular structures shall comply with API RP 2A and other frame works with Eurocode 3. Attention shall be paid when designing the tower, its foundation and the hull to the natural frequencies which may be excited by the turbine.

Details of loading conditions, methods, etc… are provided in the Platform Structural Design Brief (document to be issued).

In the fatigue analysis of all components, cases with the turbine in service as well as cases with the turbine in parked condition should be considered. The turbine will typically be in operation between 80% and 98% of time depending on the wind conditions at the installation site.

4.2.4 STATION KEEPING

The floater is kept in position by its mooring system. It shall be designed according to class rules complemented by ISO 19901-7 “Station-keeping systems for floating offshore structures and mobile offshore units”. Criteria apply to mooring line tensions, anchor holding capacity and fatigue life safety factor.

The minimum breaking load of the chain shall be based on the corroded, *i.e* end of life breaking load.

4.2.5 UMBILICAL

The section of the umbilical shall be determined based on the cost/power output balance.

The design of dynamic cables shall be based on API SPEC 17E “Specification for subsea umbilicals” In particular, dynamic analyses shall be run to confirm bending radius and tension of the umbilicals and verify them against supplier data.

The cross section of the cable shall be verified against fatigue loads and it shall be verified that the umbilical does not interfere with the mooring lines or the hull.

Loads at the bend stiffener/hull connection shall be derived from these analyses so as to define structural interfaces. The design of the pulling head will be driven by offshore installation constraints.

4.3 DESIGN FOR ALL PHASES OF PLATFORM SERVICE LIFE

4.3.1 DESIGN LIFE

The design life of the floating wind turbine is 2 years.

Adequate safety factors will be considered for the fatigue performance (depending on the criticality and inspectability of the areas). Applicable safety factors are provided in the relevant design brief document. As a minimum, the following components shall be designed with a safety factor of 5 (*i.e* with a design life of 10 years):

- The umbilical and its subsea connections,
- The mooring lines, subsea connections to hull and anchors.

Other critical areas which are visually inspectable are to be designed with a safety factor of 3 applied to the design life. For example, when inspectable, the connections of the mooring system to the hull shall be designed with a fatigue safety factor of 3.

Other components shall comply with class requirements.

4.3.2 TRANSIENT CONDITIONS

Transient conditions will be considered in the design of the floater. As a minimum the following situations shall be considered:

- All damaged conditions as specified in 4.1.2,
- Loss of grid power,
- Mooring hook-up when not all lines are connected,
- Platform launching,
- Tower/turbine erection,
- Platform transportation to offshore site,
- Platform hook-up operations,
- Platform condition after mooring hook-up but prior grid power supply.

The duration of each of these operations will be documented later so that the associated environments can be selected and combined to each particular loading scenario.

4.3.3 MAINTENANCE PHILOSOPHY

The hull and main structural items shall be designed so that no maintenance of the floater is required except inspection and damage repair. When important safety improvements or cost savings can be met by replacing some components, it can be considered. In all cases, an option free of maintenance shall be designed as a reference.

Mooring line connections to the platform shall be kept above water surface except if local regulations do not allow this.

4.3.4 MANUFACTURING AND CONSTRUCTION

The hull and all equipment will be built in materials which are proven for service in a marine environment.

No equipment requiring project-specific qualification shall be selected so as to enable reaching project schedule. In the event that qualification is required for a component, it shall be integrated early in the project.

The design shall consider constructability at all stages and for all components. This shall be met by seeking approval of all drawings and specifications by the party responsible for construction. Construction procedures shall be prepared so as to enable the smooth completion of the works and to help carrying out risk assessments.

All tolerances considered in the design shall be sufficiently slack to allow quick construction of the hull. The impact of these tolerances shall be considered by the designer on all aspects of the platform (positioning of equipment, weights, buoyancy, loads, corrosion protection, etc…)

As a general rule all shapes shall be kept as simple as possible.

4.3.5 OFFSHORE INSTALLATION

The design shall be planned to ease offshore installation tasks. Sufficient space shall be present onboard for offshore installation crew to operate safely and efficiently. Installation aids shall be considered in the design in terms of platform arrangement, structural strength, power supply, handling and all necessary aspects.

Design verifications will reflect planned offshore installation procedures and offshore installation procedures will reflect both main / support vessels capabilities and platform design limitations.

The safety of personnel will be monitored and considered through the application of a Health, Safety and Environment plan.

4.3.6 DECOMMISSIONING

Decommissioning shall be considered from the design phase by allowing sufficient provisions for dismantling the structure. Decommissioning will basically consist in disconnecting the umbilical, disconnecting mooring lines from the platform, towing the platform back to dismantling port, removing mooring lines and umbilical and recycling all components.

A decommissioning plan shall be prepared prior to the completion of platform construction so that specific constraints and equipment may be included in the design and fitted on the platform. A noxious substances register will be kept up to date along the project and inventories recorded in order to ease dismantling and recycling processes.

5. ENVIRONMENTAL CONDITIONS

5.1 WATER DEPTH, DENSITY, TEMPERATURE

The water depth to be considered will be different at each site analysed. Effects of astronomical tides and storm surges shall be considered in the design.

As the concept is not much depth-sensitive, it should be sufficient to design the platform and mooring system at the average depth and then perform sensitivity checks of loads at all extreme water levels. These effects shall however be checked sufficiently early in the design process.

The water density will be at the minimum value possible on site so as to maximise draft and minimise stability.

In case the platform is built in fresh water, the reduced density shall be accounted for in all stability / buoyancy / ballast calculations.

5.2 MARINE GROWTH

Marine growth on mooring lines and on the hull shall be considered in the design of the structure.

Its effects in all aspects of the floating wind turbine shall be considered: increase of drag loads, increase of structure weight (in terms of integrity, stability, etc…), accessibility for maintenance, accessibility to boat landings, etc…

In particular, design loads on mooring lines and umbilical will be assessed with and without marine growth.

5.3 ICE AND SNOW ACCUMULATION

Ice and snow accumulation effects on the whole structure shall be assessed at relevant locations. The thickness and density will vary depending on whether the accumulation is due to icing of snow, freezing fogs, etc…

The data is site-specific. Impacts on all aspects of the structure shall be considered. In particular, detrimental effects on platform stability, wind loads, additional loads due to ice and snow weight, potential seizing of mechanical equipment, etc… are anticipated.

5.4 WAVE AND WIND SPECTRA MODELING

Wave spectra will be based on JONSWAP spectrum. The peakedness parameter ⍰ is given by the following equations as per DNV CN 30.5 Ref [R11]:

$$\gamma = 5 \quad \text{for} \quad \frac{T_p}{\sqrt{H_S}} \leq 3.6$$

$$\gamma = \exp 5.75 - 1.15 T_p / \sqrt{H_s} \quad \text{for} \quad 3.6 \leq \frac{T_p}{\sqrt{H_s}} \leq 5$$

$$\gamma = 1 \quad \text{for} \quad 5 \leq \frac{T_P}{\sqrt{H_s}}$$

The NPD wind spectrum as described in API RP 2SK ref [R11] will be considered in designing the hull and the mooring system whereas all wind spectra provided by IEC will be the basis of the verification of the wind turbine. IEC normally uses Kaimal’s spectrum.

5.5 ATMOSPHERIC CONDITIONS

The demonstrator is planned to be installed offshore in a European tempered climate. The atmospheric conditions will be typical of these areas, *i.e.* featuring mild temperatures, high humidity rates and sea-water spraying.

- External areas can be classified as follows:
- Submerged zone: Areas which are permanently immersed in the seawater, This area extends from the seabed to 4m below the water line.
- Splash zone: areas which are alternately dry / wet This area extends from 4m below to 5m above the water line.
- Dry external surfaces: Areas which are never in contact with waves. These areas will however be subject to water spraying. This area extends from 5m above the waterline upward.

Internal areas can be classified as follows:

- Internal surfaces with controlled atmosphere In these areas, there will be no water-spraying and only controlled moisture. These areas include the tower and transition piece.
- Bottom of internal compartment, foot of bulkheads and side shell walls These areas will be in contact with sea-water from possible minor leaks and will be subject to drying / wetting as in the splash zone.
- Upper part of bulkhead walls and under-side of deck These surfaces will only be exposed to moisture due to evaporation / condensation cycles within compartments

All equipment and structural components shall be able to operate under the maximum and minimum atmospheric temperatures.

5.6 CURRENT PROFILE

In the event that only the surface current is available, the current variation with depth shall be based on DNV recommendations as set in ref [R11].

The current will be considered as the sum of the current due to tide, v_{tide} and the current due to wind, v_{wind}. This yields:

$$v(z) = v_{tide}(z) + v_{wind}(z)$$

With $v_{tide}(z) = v_{tide} \cdot \left(\frac{h+z}{h}\right)^{1/7}$

and $v_{wind}(z) = v_{wind} \cdot \left(\frac{h_0+z}{h_0}\right)$

Where:

v(z) is the total current velocity at level *z*
z is the distance from the still water level
v_{tide} is the tidal current and is calculated from the surface current,
v_{wind}=0.015 U_0 is the wind-generated current velocity at still water level
h is the water depth at still water
h_0=50m is the reference depth for wind-generated current.

5.7 OPERATIONAL ENVIRONMENTS

Operating windows will be based on wind conditions like on fixed turbines or land-based turbines but also wave height and current speed.

The following criteria will be used as a guidance operating condition:

- Wind speed between cut-in and cut-out speed,
- Current speed equal to the 1-year return period conditions

Wave conditions equal to the 99% non-exceedance wave height at the site of interest.

These conditions will be used as the conditions of design load case 1-6 as per IEC 61400-3. They will guarantee that the turbine can operate with less than 1% standby due to wave conditions.

A sensitivity check shall be performed under 1-year, 10-year and 50-year return period environments to ensure that load increases are not catastrophic and do not lead to dynamic instabilities. These cases will be considered as damaged cases.

5.8 ENVIRONMENTS DURING TRANSIENT CONDITIONS

All type of transient conditions shall be considered and checked for the platform as a whole and all its components. Transient conditions include conditions during construction, offshore installation, remediation to damage, maintenance, etc…

Temporary conditions may be verified under 1-year return period environments provided they last less than 7 days in total.

Critical weather-limited operations shall be considered to run under the maximum weather windows for both the normal operation and contingency plans.

5.9 EXTREME DESIGN ENVIRONMENTS

5.9.1 RETURN PERIOD OF EXTREMES

The structure of the hull and tower shall be designed for the 1:50 year return period design event. In absence of site-specific joint-probability data, the following environmental combinations shall be used as a basis for the design:

	Wave return period	Wind return period	Current return period
Wave dominated event	50-year	5-year	5-year
Wind dominated event	5-year	50-year	5-year
Current dominated event	5-year	5-year	50-year

TABLE 2 50-YEAR RETURN PERIOD EXTREME ENVIRONMENTAL COMBINATIONS

As the platform has a design life of 2 years, its mooring system will be designed for the 1:10 year return period design event in both intact and damaged condition.

An additional check under 100-year return period environments with abnormal environment / damaged condition safety factors will also be done.

Combinations in Table 3 detail basic design normal extreme environmental conditions. The environmental combinations presented in Table 4 below shall be considered in abnormal environment condition when no site-specific joint probability distributions are available.

	Wave return period	Wind return period	Current return period
Wave dominated event	10-year	1-year	1-year
Wind dominated event	1-year	10-year	1-year
Current dominated event	1-year	1-year	10-year

TABLE 3 10-YEAR RETURN PERIOD EXTREME ENVIRONMENTAL COMBINATIONS

	Wave return period	Wind return period	Current return period
Wave dominated event	100-year	10-year	10-year
Wind dominated event	10-year	100-year	10-year
Current dominated event	10-year	10-year	100-year

TABLE 4 100-YEAR RETURN PERIOD EXTREME ENVIRONMENTAL COMBINATIONS

5.9.2 GUIDANCE DESIGN CONDITIONS AT SITE

The following water level variations apply:

- Water depth: HOLD m LAT
- Tide range: HOLD m
- Positive storm surge: HOLD m

Non-directional extreme design environments are summarized in the following table:

Return period	**100-year**	**50-year**	**10-year**	**5-year**	**1-year**
H_s (m)	HOLD	HOLD	HOLD	HOLD	HOLD
T_{pmax} (s)	HOLD	HOLD	HOLD	HOLD	HOLD
T_{pmin} (s)	HOLD	HOLD	HOLD	HOLD	HOLD
Wind speed (1hr @10m) m/s	HOLD	HOLD	HOLD	HOLD	HOLD
Total surface current (m/s)	HOLD	HOLD	HOLD	HOLD	HOLD

TABLE 5 SUMMARY EXTREME DESIGN ENVIRONMENTS – DEMONSTRATOR DEPLOYMENT SITE

The 99% non-exceedance significant wave height as taken from the reference scatter diagrams is provided in the next table:

Non-exceedence percentile	Significant wave height
99%	HOLD
90%	HOLD
50%	HOLD

TABLE 6 99, 90, 50 PERCENTILE NON-EXCEEDANCE WAVE CONDITION - DEMONSTRATOR DEPLOYMENT SITE

5.10 JOINT WIND / WAVE COMBINATIONS

5.10.1 NORMAL OPERATION ENVIRONMENTS

Normal operation environmental cases corresponding to load case 1-1 in IEC 61400-3 have been derived from wave / wind correlation diagrams. They correspond to the most probable significant wave height.

Wind speed at HHm [m/s]	**Wave conditions**		**Wind speed at HHm** [m/s]	**Wave conditions**	
	Hs [m]	**Tp** [s]		**Hs** [m]	**Tp** [s]
4	HOLD	HOLD	15	HOLD	HOLD
5	HOLD	HOLD	16	HOLD	HOLD
6	HOLD	HOLD	17	HOLD	HOLD
7	HOLD	HOLD	18	HOLD	HOLD
8	HOLD	HOLD	19	HOLD	HOLD
9	HOLD	HOLD	20	HOLD	HOLD
10	HOLD	HOLD	21	HOLD	HOLD
11	HOLD	HOLD	22	HOLD	HOLD
12	HOLD	HOLD	23	HOLD	HOLD
13	HOLD	HOLD	24	HOLD	HOLD
14	HOLD	HOLD	25	HOLD	HOLD

TABLE 7 NORMAL SEA-STATES

5.10.2 FATIGUE ENVIRONMENTS

Fatigue sea-states to be considered in the verification of the fatigue performance are listed in Appendix 1.6 [HOLD].

5.10.3 EXTREME OPERATING SEA-STATES

Extreme operating sea-states corresponding to load case 1-6 in IEC 61400-3 are listed in Table 8. They correspond to the maximum sea-states under which the turbine will be considered operating.

Wind speed at HHm [m/s]	**Wave conditions**		**Wind speed at HHm** [m/s]	**Wave conditions**	
	Hs [m]	**Tp** [s]		**Hs** [m]	**Tp** [s]
4	HOLD	HOLD	15	HOLD	HOLD
5	HOLD	HOLD	16	HOLD	HOLD
6	HOLD	HOLD	17	HOLD	HOLD
7	HOLD	HOLD	18	HOLD	HOLD
8	HOLD	HOLD	19	HOLD	HOLD
9	HOLD	HOLD	20	HOLD	HOLD
10	HOLD	HOLD	21	HOLD	HOLD
11	HOLD	HOLD	22	HOLD	HOLD
12	HOLD	HOLD	23	HOLD	HOLD
13	HOLD	HOLD	24	HOLD	HOLD
14	HOLD	HOLD	25	HOLD	HOLD

TABLE 8 EXTREME OPERATING SEA-STATES

6. HYDRODYNAMIC AND MOORING DESIGN METHOD

6.1 STABILITY ANALYSIS

In general, sufficient stability shall be granted to the platform in place in intact and damaged conditions with the turbine both free to idly rotate and with blades or the nacelle seized in the most unfavourable condition.

In transit condition, provision shall be given to the potential increase of loads due to the non-availability of adequate power supply to orientate the turbine.

Rule wind speeds shall also be checked against actual site wind speeds so that they are not under-estimated.

Stability also has an impact on wind turbine loads. A stiffer platform in pitch will yield smaller loads in operational conditions but tends to increase loads on the tower in extreme storm conditions.

6.2 HYDRODYNAMIC LOADS CALCULATION

Hydrodynamic loads include current, first order wave loads and second order wave loads.

First order wave loads have an impact on:

- Platform motions and hence turbine loads,
- Hull wave global loads,
- Tower loads,
- Mooring system loads including drag, inertia and flexibility,
- Mooring system and particularly mooring connectors fatigue.

Current loads can be disregarded in the structural analysis of the structure provided members are not slender.

Wave drift and low frequency loads shall be considered in the design of the mooring system. Its impact on the turbine loads through coupling with the mooring system shall be assessed and considered in the design if non-negligible.

In areas where large current speed occur, Aranha correction of wave drift loads shall be considered.

Attention shall be paid to the application of viscous damping in structural analyses, especially if mapping of diffraction-radiation pressures is applied to the structural model.

6.3 MOORING ANALYSIS

Mooring system analysis shall consider all effects of importance:

- Wave frequency loads,
- Second order drift and low frequency loads,
- Full QTF formulation in relevant cases,
- Alteration of drift loads due to current speed,
- Current effects such as Vortex-induced motions,
- Mooring line dynamics.

6.4 MOORING COMPONENTS

All mooring components shall show proven and adequate durability for the service of the platform. Besides regular mooring line tension loads, attention shall be paid to in- and out-of plane bending of mooring components.

Although the floaters are anticipated to operate in shallow waters where there exist no evidence of bending fatigue failure of mooring lines, wind turbine loads may lead to larger static environmental loads on the mooring system in operating conditions than in typical shallow water oil and gas applications. This may yield unexpected chain and connectors fatigue damage and shall be assessed by calculation.

7. GENERAL ARRANGEMENT AND UTILITIES DESIGN

7.1 PLATFORM LAYOUT

The primary function of the platform is to support a wind turbine and maximise its power yield; the tower and platform shall consequently be optimised towards this goal. The ease of maintenance of the turbine shall also be taken into consideration so that the operational downtime in case of failure is minimised.

In summary, it shall be an objective that the layout of the platform maximises the operational uptime of the turbine it supports without impairing safety of personnel and the environment.

Provisions shall be given in designing the general arrangement of the platform to:

- Turbine aerodynamic performance,
- Platform hydrodynamic performance,
- Platform stability and balance,
- Facilities and accesses necessary for the maintenance of the platform,
- Accesses to all areas of the hull for maintenance,
- Platform damage control,
- Routing and integrity of mooring system and umbilical,
- Safety zones segregations (helicopter access, sea access, installation operations, lifting operations, high voltage areas, muster and evacuation, etc…).

The layout of the platform shall be designed so that access is possible under wind / wave conditions similar to fixed wind turbines. It is anticipated that sea access will be less critical on a floating platform as relative motions during vessel transfers at sea are usually smaller than relative motions between a fixed structure and a vessel. Access to equipment within the tower shall be possible from main deck.

7.2 ACCESS

Access on board shall be done using typical surfer landings. The main deck shall be surrounded by handrails.

Access to turbine shall be normally closed and sufficiently high above deck to prevent flooding of the door by waves in adequate conditions.

Access by helicopter shall be possible on main deck in less favourable conditions.

Access to compartments shall be made through watertight manholes on main deck. In all compartments with one horizontal dimension larger than 4m, two access manholes shall be provided as a minimum.

Dry access to all compartments shall be possible even in damaged condition.

Ladders, platforms and handrails shall be provided in tanks for inspection.

Access shall be possible to all primary structural components. In particular, all pre-stressing bar / tendon anchor, critical weld and highly stressed area shall be made accessible by platforms, ladders or the like. Access to compartments shall be designed according to the latest recommendations from IACS and class.

7.3 EQUIPMENT TO BE INTEGRATED

A provisional list of equipment to be integrated is listed here below:

- Transformers,
- Main switchboard,
- Auxiliary and emergency switchboards,
- Power and signal cables to / from shore,
- Turbine tower transition piece,
- Mooring chain stoppers,
- Mooring winch complete with stand to hook-up mooring lines,
- Navigation and work lights,
- Helicopter assistance equipment,
- Handrails, ladders, etc…
- Boat landing,
- Cable connection,
- Towing brackets / bollards,
- Port mooring and positioning assistance bollards,
- Sounding pipes,
- Vents,
- Bilge piping / pumps
- Oily water separator and / or pollution prevention equipment where needed,
- Safety and evacuation equipment,
- Sensors for platform monitoring (stress gauges, accelerometers, tanks monitoring, etc…),

7.4 INTERFACE WITH MOORING AND UMBILICAL

Beyond the structural function of the interface with the umbilical and mooring, the interface shall also enable easy offshore installation and require no maintenance.

Provision shall be given to enable the hook-up of the mooring lines and umbilical. Provisions shall also be given to move and transfer installation aids on deck. Installation aids may be large and weigh tens of tons.

7.5 BILGE / BALLAST SYSTEM

As the platform will be unmanned, a bilge system is not mandatory. It is however recognised that pumping arrangements can be useful for a demonstrator and they will be installed on Demo 1. A water ingress alarm system shall be fitted in all tanks necessary for the stability of the platform. The data from this monitoring system shall be monitored from the shore control room.

The bilge and ballast system shall also enable:

- Manual sounding of all tanks,
- Emptying of all tanks by portable means even in damaged conditions,
- Ballasting of the platform for balance purposes in installation condition.

Emptying of tanks may be done by pumping the water within the tanks. In all cases, vents will be needed for this purpose. Air pressing is not an option as concrete is generally not gastight.

8. STRUCTURAL DESIGN

8.1 BASIC PRINCIPLES – DESIGN LOADS

The platform proposed is aimed at providing a floating support to a wind turbine. As such the hull structure is subject to:

- dynamic loads as the bedplate of a rotating equipment,
- wave static and dynamic loads as a floating offshore structure,
- platform accelerations due to its motions resulting from environmental loads,
- large mooring loads when compared to the size of the platform (like a tanker single point mooring),
- All kind of operating loads such as boats mooring loads, installation loads, umbilical loads…

Aerodynamic, hydrodynamic wave, mooring and functional loads being of the same order of magnitude, no design procedure currently used in the civil, wind or offshore industry will be directly transferable to the floating wind turbine.

Current loads will be negligible on the structure; they will be accounted for through mooring line and umbilical tensions.

Wave loads calculation procedure shall enable to account for inertia as well as diffraction loads; this may be through either direct mapping of wave pressure from the diffraction-radiation calculation onto the FEM model or application of pressure fields on the hull yielding the exact bending, torque and shear wave forces on the hull, or calibrated Morison equation models.

Second order wave drift loads will be accounted for through mooring system design loads.

Slamming and green water loads shall be accounted for in the design of equipment located on deck and the deck itself. The tower transition piece will most probably be subject to wave impact loads and shall be designed accordingly.

Wind loads on the turbine will be accounted for through interface loads at the transition piece and the extraction of loads from dynamic simulations.

Hydrostatic pressure will probably not be a major issue in purely structural terms. However, offshore floating concrete structure rules require that a minimum portion of the wall thicknesses be in compression in all conditions. This will be considered in the design of the primary structure.

8.2 STRUCTURE DYNAMIC BEHAVIOUR

A modal analysis of the whole structure shall be performed in order to confirm that the turbine will not operate within rotation rates yielding unacceptable dynamic excitation of the structure.

It is anticipated that the global analysis will have to account for mooring system stiffness and mass, hull dry mass and added mass, offset of the turbine on the floater and structural properties of the tower.

It is also possible that the hull structure influences the eigen frequencies of the tower as the tower will not be rigidly connected to hull. Local connection softness may influence the overall natural frequencies of the platform and shall as such be considered in the design.

All these effects shall be assessed in a single model taking into account all effects or through several models linking local and global behaviours.

8.3 MATERIALS AND DURABILITY

As a base case, the hull is planned to be built in reinforced concrete. BV does not publish specific guidelines for the design of floating offshore concrete structure and refer to Eurocode or other relevant codes. LR provides design guidance which mainly provide additional requirements to existing British Standards (now superseded by Eurocode). We will base the design on Eurocode complemented by other relevant rules such as DNV or ACI.

Reinforcement bars and pre-stressing tendons protection will be based on the application of sufficient concrete cover thickness in connection to the permeability of the concrete mix under consideration. Cathodic protection will also be applied to protect reinforcement steel in way of cracks and carbonation areas. There shall consequently be electrical continuity of all bars to ensure that the cathodic protection is effective. The choice between sacrificial anodes, impressed current cathodic protection or a combination has not yet been made.

The durability of steel structures is closely linked to proper earthing and coating. It shall be kept in mind that cathodic protection can cause hydrogen embrittlement for high-strength steel grades such as bolting and wires.

All materials used shall feature proven performance for the project design life. All grades shall be selected from proven offshore structure grades. Hull structure appliances will be selected among classification society grades.

Unusual and project-specific grades shall be limited to areas where they are absolutely necessary.

Pre-stressed members anchorage shall also be visible for periodic inspection where practical.

8.4 SECONDARY STRUCTURES AND HULL OUTFITTING

Improper connection of secondary structures on primary structural members has led in some instances to catastrophic failures. They shall consequently not be neglected in the design of the platform.

As in any marine structures, bolted manholes will need to be placed to gain access to all compartments. These manholes will need to be located close to the corners of the compartments and hence in stressed areas.

All secondary and tertiary structures shall not be directly connected to main re-bars so as to prevent the main structure from cracking in case these tertiary structures are overloaded. Weak links to control the failure of secondary structure can also be envisaged in some areas.

Load paths shall carefully be designed for platforms aimed at carrying personnel as the controlled failure of an overloaded personnel platform may be worse than the controlled damage of the primary structure carrying this platform.

Also, attention shall be paid to ensuring the water-tightness of pipe, cable penetrations and embedment plates within the hull and bulkheads.

9. REPORTING AND FORMAT OF INFORMATION

9.1 CONTENTS OF REPORTS

All reports shall contain sufficient information to be self-supporting. In particular, the basic data used in a report shall be reminded along with the reference from which it is taken.

All codes and standards used in the report shall be listed. A sufficient level of detail shall be provided in the results to enable accurate checking of the results as part of quality control.

Hydrodynamic analysis reports shall contain as a minimum the natural periods calculated by the analysis software as well as listings of added mass, radiation damping, wave excitation forces and wave drift loads and damping.

In structural analyses, the resultant of load cases, combinations, listings of code check values, deflected shapes of the structure under the governing load cases and modal analysis results.

In mooring analysis, statistics of all variables (motions, loads on lines, anchors, etc…) shall be provided for all load cases along with statistics of wind, wave and current intensity. Modal analysis results shall also be provided.

9.2 UNITS

In general, all results shall be reported in metric units and preferably in units of the international system:

- Time : seconds (s)
- Frequencies: Hz and multiples, rad/s
- Length : metres (m) or millimetres (mm)
- Mass : kg, metric ton (m-ton)
- Forces : Newtons and mutliples (N, kN, MN), alternately ton-force (m-ton)
- Moments : Newton.metres and multiples (N.m, kN.m, MN.m)
- Accelerations : m/s^2
- Speeds : m/s
- Angles : degrees

Drawings shall be drawn in accordance with ISO standard conventions.

9.3 AXIS CONVENTIONS

The forward end of the platform is opposite to the turbine, the aft end is at the turbine end. Sides are either sides of the symmetry plan of the floater.

The reference frame is defined as follows:

- Z is vertical, positive upwards,
- X is in the symmetry plan of the floater, directed forward,
- Y is positive to portside, perpendicular to the 2 other axes.

The origin of the platform reference frame is located:

- In the symmetry plan of the platform,
- On the lower side of the bottom of the platform,
- At the aft-most point of the hull in the symmetry plan of the platform, excluding skirt and appurtenances.

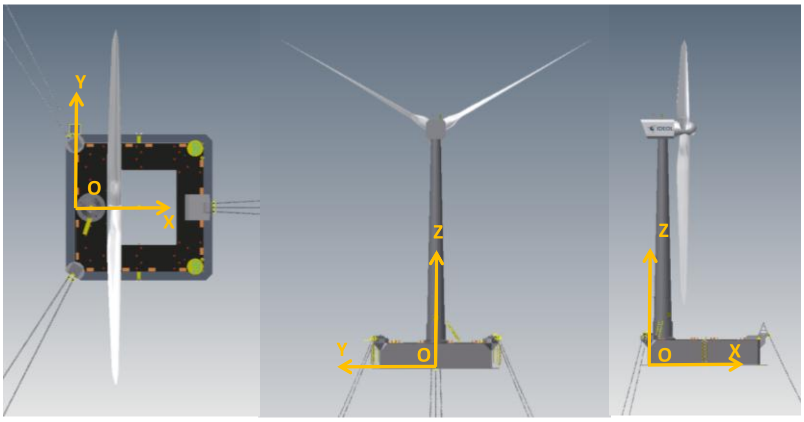

FIGURE 2 AXIS CONVENTIONS OF THE PLATFORM REFERENCE FRAME

The direction of environmental conditions is defined as the direction from which they come with respect to the Geographic North at the point considered. The direction can be merged with the North of the UTM grid applicable at the location considered.

For example, the direction of current flowing from East (*i.e* towards West) is 90° whereas the direction of waves coming from North West is 312.5° and the direction of wind blowing from the South is 180°.

Geographic conventions are reminded on the rosette in Figure 3.

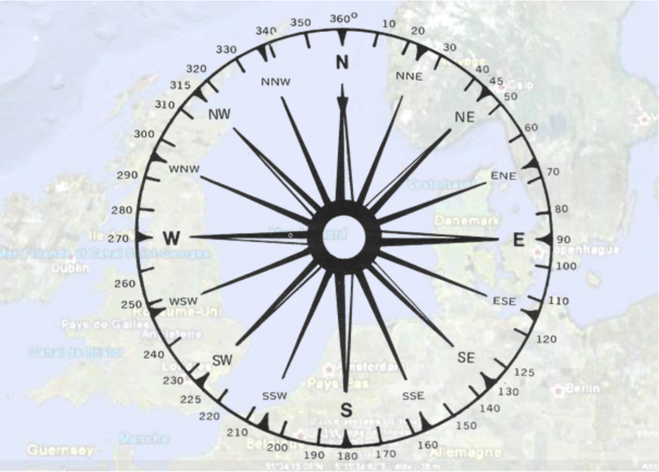

FIGURE 3 GEOGRAPHIC DIRECTION CONVENTIONS

10. FLOATER KPI’S

10.1 FLOATER TO TURBINE MASS RATIO

Floater to turbine mass ratio depends radically of the floater technology.

Despite the unique case of floating turbine in operation with very high ratio (25) ratios from 2 to 5 times could be achievable

10.2 SUPPORTING STIFFNESS IN TILTING DIRECTION

The reaction of the floater in producing a staying up moment in case of deviation is the main function of the floating system. The concept of the floater is responsible of the stiffness of the wind turbine support and its dynamics. The range is very wide and the main stiffness is the most indicative assessment of the floater performance. In some cases there could be a limit in the stability. This limit could also be understood as an important KPI.

10.3 DEGREE OF PITCH, YAW AND SURGE RELATED TO STEEL WEIGHT

The dynamics of the floater is influence by the turbine thrust and wave loads. The degree of pitch movements can be adjusted by introducing different designs for the same thrust forces that will make that the degrees of pitch angles vary significantly and therefore power production is impacting positively or negatively. However the lower degrees of pitch angles are obtained by the use of more weight and steel (size, ballast...) in the floating platform and then cost and marine operations are impacted as the cost will increase.

The more the design is fully integrated by accommodating thrust forces and wave loads, by designing specific control mechanisms, the lower need of increasing the weight in the platform.

10.4 COMPLEXITY OF MASS MANUFACTURING AND INSTALLATION

The cost can be influence severely by introducing design optimizations to enable a much automatic manufacturing process. This could influence in a certain manner the design of the floater and more validation and simulations will be needed in order to validate those restriction conditions introduce by the mass manufacturing, in terms of dynamics, weight and operations. Also some designs are more easily adjusted and optimized than others and this could influence in the long term by volume increase the decision of a floater design when there is a batch of possible solutions for similar water depths and site conditions.

10.5 SPECIFIC SUBSTRUCTURE COST

The Specific substructure cost is defined as the ratio between cost of platform construction and towing, mooring system procurement, installation and hook-up and the installed (nominal) power.

10.6 MOORING COST AND FOOTPRINT

The mooring design must keep the position of the floater on a position but it must also resist the loads inputs. Therefore the selection of an appropriate mooring design is a key and sometimes there is no much choice depending on the type of floater solution. Some of the mooring systems are complex and costly and this must be considered in the selection of a Floating Turbine.

10.7 CABLE DESIGN AND COST

Cable that transport the power from the wind turbine to the shore consists of a cable called static and another called dynamic. Design of the dynamic cable depends not only on electrical parameters such as power and voltage but also on dynamic forces due to the movement of the platform. Thus, design of the cable is a key in which concerns the correct operation of the wind turbine. The Cost ratio over the installed power and the depth at the platform position is a good indicator of the quality of the design.