Requirements for the wind turbine (Demo 1)

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Requirements for the wind turbine (Demo 1)

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Brief Summary

The objective of task 2.2 is to establish which are the main requirements of the wind turbine in order to obtain a cost effective solution.

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1. EXECUTIVE SUMMARY

The main objective of the **Floatgen** is to demonstrate the technical and economic feasibility of two different multi-megawatt integrated floating-wind turbine systems in deep waters, in order to extend deep offshore wind resources and demonstrate a decrease of costs for electricity generation down to competitive level.

The objective of task 2.2 is to establish which are the main requirements of the wind turbine in order to obtain a cost effective solution.

The scope of this document is to list the basic requirements that will apply to the wind turbine. 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.

Other documents pertaining to the floating system, integrating system and regulatory framework collects the data necessary for the design of these specific tasks.

2. ACRONYMS

WTG	Wind turbine generator
FOWT	Floating offshore wing turbine
LV	Low voltage
MV	Medium voltage
HV	High voltage
dB	Decibels
THD	Total Harmonic distortion
SW	Software
FW	Firmware
Q	Reactive power
A	Active power
LSS	Low side speed
HSS	High side speed
IEC	International electro-technical committee
DNV	Det Norske Veritas
GL	Germanischer Lloyd
Weibull	Wind speed probability distribution

3. CODES AND STANDARDS APPLICABLE

General Standards

1. IEC 61400-1 Wind turbines – Part 1: Design Requirements
2. IEC 61400-3: Wind turbines – Part 3: Design requirements for offshore wind turbines
3. Germanischer Lloyd Guideline IV Part 2 Offshore 2012
4. DNV-OS-J101

Electrical standards

1. Boletín Oficial del Estado del 24/10/06. P.O. 12.3 Requisitos de respuesta frente a huecos de tensión de las instalaciones eólicas. Resolución de 04-10-2006.
2. Asociación Empresarial Eólica. Procedimientos de verificación, validación y certificación de los requisitos del P.O. 12.3 sobre la respuesta de las instalaciones eólicas y fotovoltaicas ante huecos de tensión. Versión 10. Enero 2012.
3. EN50160:2007 Voltage characteristics of electricity supplied by public distribution networks.
4. IEC 61400-21:2008 Wind turbines – Part 21: Measurements and assessment of power quality characteristics of grid connected wind turbines
5. IEC 61400-24 Wind turbines - Part 24: Lightning protection

Structural codes

1. EuroCode no. 3: “Design of Steel structures”.

4. REQUIREMENTS

4.1 STRATEGIC REQUIREMENTS

G80-2.0MW class IA for FLOATGEN project shall keep as much as possible the same design solutions than G80-2.0MW class IA onshore WTG.

4.2 Life and power requirements

G80-2.0MW class IA for FLOATGEN shall be designed for 20 years design life.

G80-2.0MW class IA for FLOATGEN shall be designed for 2000kW as nominal power with current electrical technology of a Double Fed Machine (DFM) keeping as much as possible the same electrical solutions than the GAMESA G8X wind turbines.

4.3 Tower height / blade clearance

4.3.1 MINIMUM INTERFACE LEVEL

Assuming that the wave crest can surpass the floating body level at certain cases, the minimum interface level, that is, the level at which the substructure and the tower are joined together, must ensure that the wave crest will never reach the tower bottom.

4.3.2 MINIMUM PLATFORM LEVEL

In general, the external platform level will be between the interface level and the tower access door level

4.3.3 MINIMUM HUB HEIGHT

As long as no other aerodynamic or design constraints exist (like the ones involved with shear profile of the specific site), minimum hub height will depend on the minimum clearances to be maintained from the blade tip to the different levels described hereafter:

- Minimum height from blade tip to personnel accessible areas $\min \Delta z_{tip-platf} = 3\,m$

- Minimum height from blade tip to the highest object without an impact in the blade airflow ($Z_{highestobject}$). For example the Davit Crane, the lightning or the handrails in the platform.

  $\min \Delta z_{tip-object} = 1\,m$

- Minimum height from blade tip to water line. GL Offshore 2012 recommends a $\min \Delta z_{tip-WL} = 1.5\,m$ accounting for the vertical motion of the floating wind turbine. A 7 m gap for contingency of local spraying should be added to this minimum clearance. This gap should be checked for the worst dynamic case of the whole system, considering different wave elevations and nacelle/blades orientation.

Besides, in the case that local requirements or guidelines from any Authority Having Jurisdiction (AHJ) require a clearance between the blade tip and the water line, this shall be taken into account.

4.3.4 MINIMUM TOWER LENGTH

The minimum tower length for the minimum hub height is calculated as follows:

$$L_{tower\,\min} = Z_{HH\,\min} - Z_{IF\,\min} - \Delta z_{COG\,hub}$$

Where,

- $Z_{HH\,\min}$ = Minimum hub level
- $Z_{IF\,\min}$ = Minimum interface level
- $\Delta z_{COG\,hub}$ = Distance from tower top to the hub centre of gravity.

4.4 General arrangement requirements

4.4.1 COORDINATE SYSTEM

The WTG standard coordinate systems shall be applied to the G80-2.0MW class IA for FLOATGEN. The different coordinate systems are specified as follows (see Figure 1 and Figure 2):

- Blade co-ordinate system (blade): Location at blade connecting flange, rotating with the blade adjustment angle.

- Shaft co-ordinate system (stationary): Location at main bearing, non-rotating.
- Shaft co-ordinate system (rotating): Location at main bearing, rotating.
- Distance from hub centre to main bearing: 1.71 m
- Co-ordinate system at tower top (tower top): Location at tower top flange, fixed to tower.
- Co-ordinate system at Tower bottom (tower bottom): Location at tower bottom, (x-axis parallel to tower top x-axis).
- Hub co-ordinate system (hub): Location at blade connecting flange, fixed to the hub. (z-axis as in blade co-ordinate system).

Root section is considered as blade root (Interface between extender and blade).

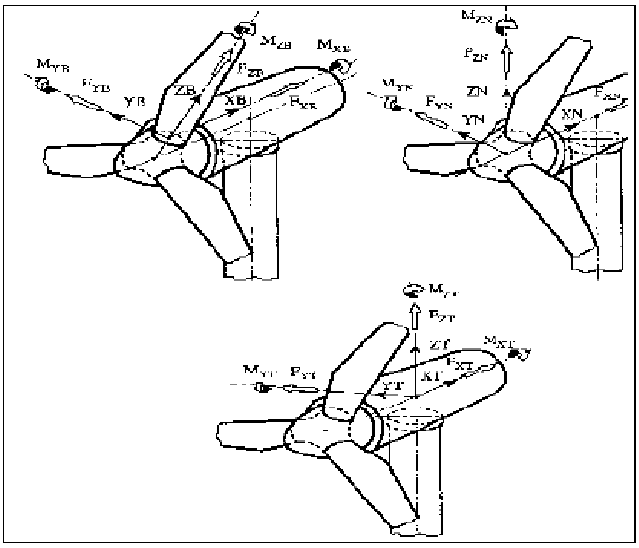


Figure 1. Coordinate systems assumed for loads computations.

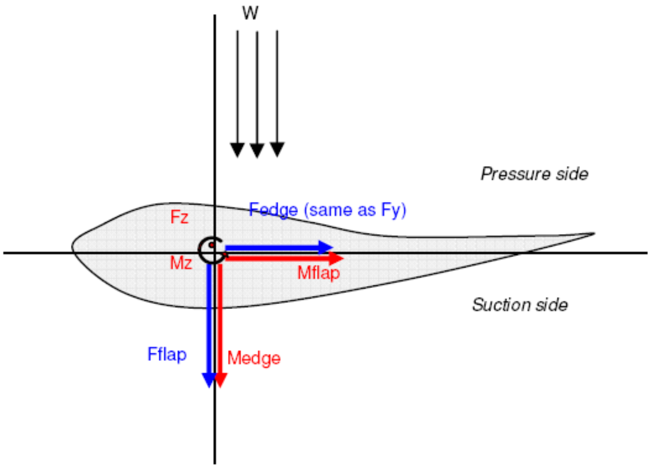


Figure 2. Coordinate systems assumed for Blade loads.

4.4.2 GENERAL ARRANGEMENT / GEOMETRICAL REQUIREMENTS

The main general arrangement and geometrical parameters of G80-2.0MW class IA for FLOATGEN are:

Rotor orientation	Horizontal
Rotor situation	Upwind
Rotor rotation	Clockwise
Tilt Angle [deg]	6
Conning [deg]	-2
Rotor diameter [m]	80
Number of blades	3

Table 1. G80 for FLOATGEN main geometrical parameters.

The positive variation sense for conning and tilt angles are (see Figure 3):

- Cone angle: positive towards the nacelle.
- Tilt angle: positive towards sky.

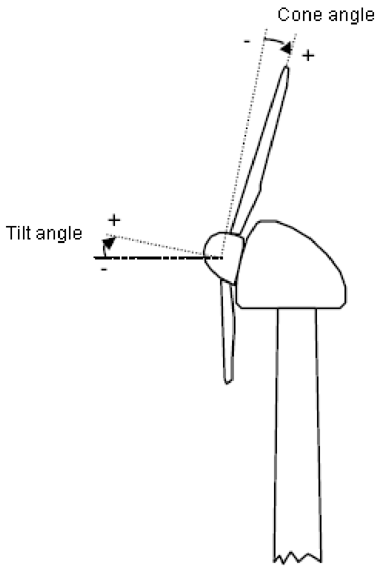


Figure 3. Tilt and cone angles definition.

4.5 Functional and operational requirements

4.5.1 OPERATIONAL REQUIREMENTS

G80-2.0MW class IA for FLOATGEN operational parameters are:

Frequency	50	Hz
Nominal speed	15	m/s
Rated power	2.0	MW
Wind speed operational range		
Vin	4	m/s
Vout	25	m/s
Vre-start	22	m/s
Operational speed range		
Minimum rotor speed	9.9	rpm
Nominal rotor speed	16.71	rpm
Maximum rotor speed	18.9	rpm
OGS triggering level (to emergency)	1985	rpm
Over speed by PLC (to stop)	1900	rpm
Generator operational speed range		
Minimum generator speed	1000	rpm
Maximum generator speed	1900	rpm

Table 2. G80 for FLOATGEN main operational parameters.

4.5.2 ROTOR BALANCE REQUIREMENTS

4.5.2.1 STATIC BALANCE

The maximum difference of static moment at hub of 330kg·m is allowed for finished blades within the same rotor. This value includes uncertainties because of measurement.

4.5.2.2 AERODYNAMIC BALANCE.

The maximum pitch angle ("self-pitch") deviation between the three blades of a rotor shall be 0.115º.

4.5.3 INCLINATION REQUIREMENTS

Inclination criteria for all equipment to operate in inclined condition – mainly priming of pumps and sloshing of tanks- are to be addressed.

During transportation the maximum heel angle, from a functional point of view, shall be lower than the one that makes the tower base bending moment equal to the maximum allowed bending moment. It shall be pointed out that this angle depends also on the acceleration that shall be lower than the maximum acceleration allowed during operation.

As guidance, values of accelerations, displacements, inclination ranges for all degrees of freedom, and other relevant information about whole structure behavior, obtained in previous estimations will take into account.

4.5.4 CONTROL REQUIREMENTS

An effective controller for FOWT must be designed to meet multiple control objectives. As a consequence several control loops must be designed with great care in order to reach the required performance. In addition, the requirements imposed during the design procedure must be focused not only on reducing the extreme and fatigue loading, but also maximizing the energy capture. Therefore, an adequate control system must be designed to meet the following requirements:

- Set the rotor speed, the generator torque and the produced power, to a required set-point.
- Maximize power capture along the entire operating range.
- Prevent the excitation of structural modes.
- Attenuate dynamic loads in tower, blades, drive-train and platform components.
- Regulate the wind turbine power in the presence of the wind and marine conditions provided by the design load cases.
- Provide a smooth transition among the operational modes (start, stop, run, run connected, idling and emergency)
- A clear procedure to be tuned.

4.5.5 COMMUNICATION AND MONITORING

4.5.5.1 COMMANDS NEEDED TO OPERATE THE WIND TURBINE

It must be possible to select a change of state for the wind turbine done by a remote operator or local operator.

1. Start the wind turbine
2. Stop the wind turbine
    a. To PAUSE.
    b. To STOP
    c. To EMERGENCY.

It must be possible to select a regulation condition by a remote operator according to environmental requirements, grid codes, etc.:

1. Active Power demand P
2. Reactive Power demand Q
3. Grid Voltage demand V
4. Frequency demand
5. Power Factor demand Cos ϕi
6. Hourly synchronization demand
7. Shadow control

4.5.5.2 INFORMATION NEEDED TO OPERATE THE WIND TURBINE

It must be possible to remotely provide all necessary information with an appropriate update frequency for each variable, for proper wind turbine operation.

It must be possible to block remote commands locally on the machine without precluding the remote visibility of information for the wind turbine operation.

It must be possible to get key information regarding the diagnose and prognosis of the wind turbine in order to make a decision when a failure is about to occur.

The information related with a wrong behavior of the wind turbine should be clearly understandable by using clear instructions about the maintenance action to be done.

4.5.5.3 COMMANDS NEEDED TO MAINTAIN THE WIND TURBINE

It must be possible to charge SW-FW updates to each logical node of the wind turbine by a remote maintainer.

It must be possible to handle remotely the switch gear and the devices that could help to identify and isolate failures.

It must be possible to perform a visual inspection of blade remotely by using an IP-webcam.

It must be possible to be able to maintain rotor position fixed for at least Y configuration by a remote operator or local operator to allow the accessing by helicopter.

It must be possible to launch remotely auto diagnosis.

4.5.5.4 INFORMATION NEEDED TO MAINTAIN THE WIND TURBINE

It must be possible provide remotely all necessary information for each system (logical node), with an appropriate update frequency for each variable, for proper wind turbine maintenance. It is not needed provide this information in real time. If the communication with SCADA is lost, it should be possible to retrieve this information once communication is re-established.

This information shall be accessible by temporary files. Once the behavior of the WTG is not correct then the file shall be created and accessible on demand from remote.

4.5.5.5 OPERATING AND SAFETY SYSTEM

The control system should have taken into account uncertainty in the models, by this reason a robust and stability requirements are defined.

Gain margin for Control loops G_M	G_M > 6 dB no collocated
Phase margin for control loop P_M	P_M > 25 deg no collocated >35 deg collocated

The control system should take into account the disturbances. The system should avoid excitation the natural and forced frequencies of the WTG.

Sensitivity of disturbance for Control Loops S_{LOOP}	S_{LOOP} < 6 dB

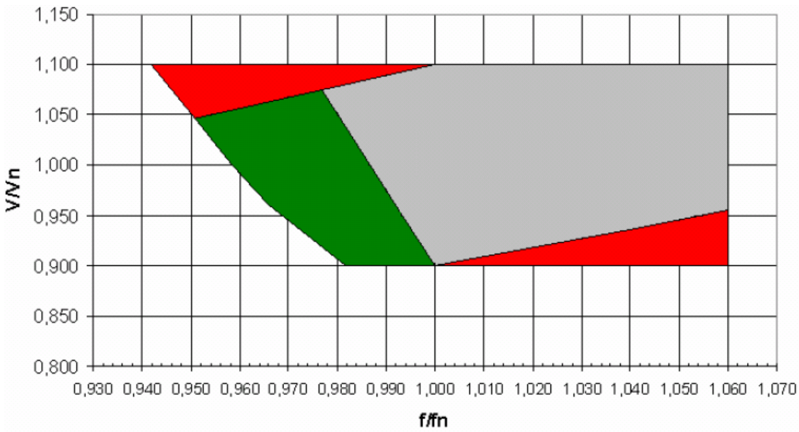
4.6 Electrical requirements

All the electrical requirements stated in this chapter are referred to LV side of Power Transformer, unless any other application point is indicated.

4.6.1 GENERAL ELECTRICAL REQUIREMENTS

Requirement reference	Requirement definition	Value
4.6.1.1	Rated Voltage	690 V
4.6.1.2	Rated Frequency	50 / 60 Hz
4.6.1.3	Rated Apparent Power	2105 kVA
4.6.1.4	Rated Reactive Power	655 kVAr
4.6.1.5	Rated Active Power	2000 kW
4.6.1.6	Power Factor	0.95c to 0.95i

4.6.2 VOLTAGE AND FREQUENCY RANGES OF OPERATION

Requirement reference	Requirement definition	Value
4.6.2.1	Voltage range of operation at rated Frequency	±10% - [759 , 621] V
4.6.2.2	Frequency range of operation	[47 , 53] Hz / [57 , 63] Hz
4.6.2.3	Voltage – Frequency operation Area	 • Grey area – Continuous operation • Green area – Maximum 60 seconds • Red area – Maximum 10 seconds: 0.9 < V/f < 1.1
4.6.2.4	Minimum ramp of frequency variation	2Hz/s

4.6.3 REACTIVE POWER CAPABILITIES

As stated in requirement 5.1.1.vii, WTG is required to operate in a power factor range of 0.95 inductive to 0.95 capacitive. In this sense, the minimum levels to fulfill of power factor in front of nominal power and the voltage range defined in 5.1.2.i are shown in the table below.

WTG at nominal Power – 2MW			
Voltage (pu)	**Power Factor**		
	0.95i	**1**	**0.95c**
1.1	Yes	Yes	Yes
1.05	Yes	Yes	Yes
1	Yes	Yes	Yes
0.95	Yes	Yes	Yes
0.9	No	Yes	No

Table 3. Q vs V requirements at rated power power

4.6.4 VOLTAGE RIDE THROUGH

WTG shall be able to operate in front of VRT envelopes as stated in this chapter. The next figures show the required voltage events that shall be supported and the associated current injection requirements.

Apart from the next requirements definition, the fulfillment of the requirements stated in ref [1] and [2] regarding the LVRT characteristic (voltage profile and current injection issues) for Spanish market is a must.

4.6.4.1 LVRT ENVELOPE.

The WTG must remain connected over the red line shown in the next figure.

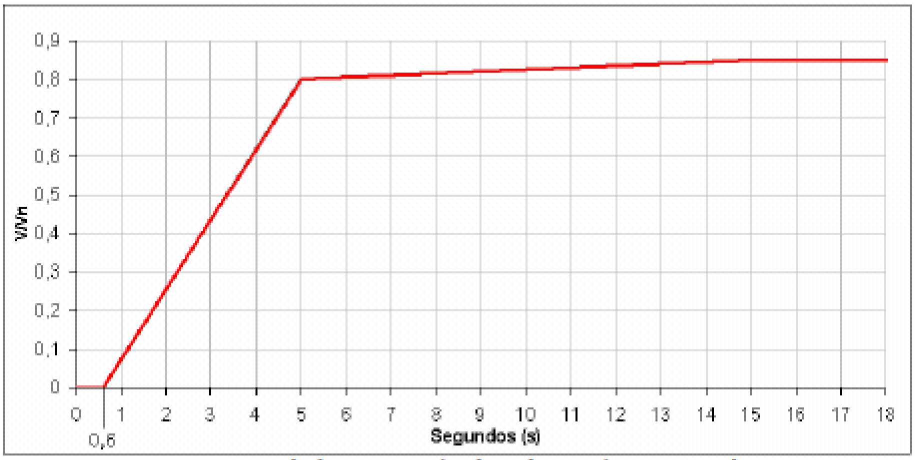


Figure 4. LVRT envelope to be supported by WTG

4.6.4.2 HVRT ENVELOPE.

The WTG must remain connected below the red line shown in the next figure.

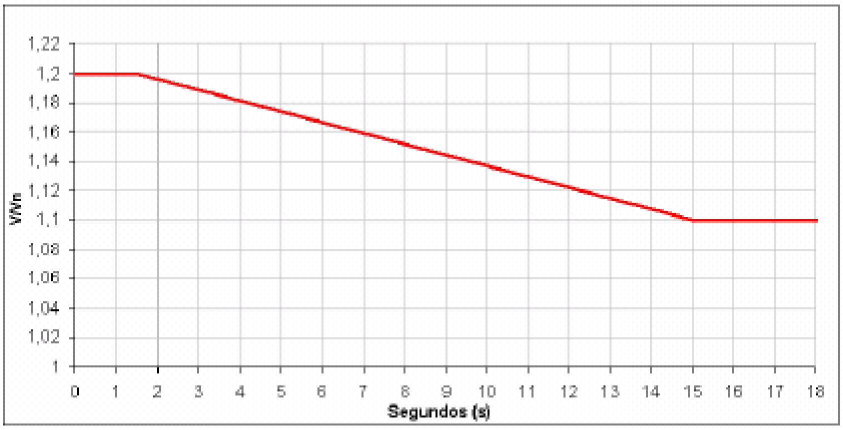


Figure 5. HVRT envelope to be supported by WTG

As each country states its own minimum requirements, the voltage profile shown in the last figures shall be completely configurable by means of parameters in the Converter firmware.

4.6.4.3 REACTIVE AND ACTIVE CURRENT INJECTION

Besides the last two requirements showing the required voltage ride through supportability, in some countries it is required concrete reactive and active current injection or consumption. In this sense, the characteristic to be implemented by means of configuration parameters in the WTG converter regarding this matter is shown in the next figure.

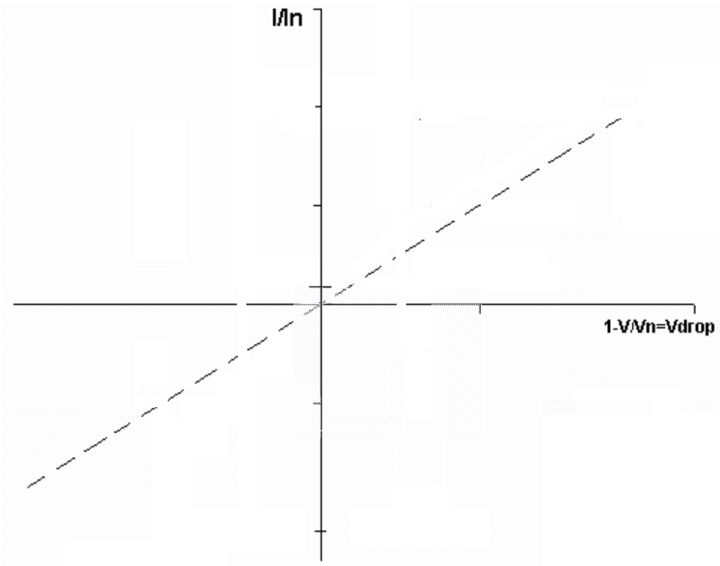


Figure 6. Characteristic of Q injection during voltage dips and voltage control scheme

WTG shall count on the characteristic of voltage support after the dip clearance, again with configuration parameters to determine the Q injection and working time.

4.6.5 RAMPING OF ACTIVE AND REACTIVE POWER

The WTG shall have the next minimum values for Power ramping.

Requirement reference	Requirement definition	Value
	Active Power	
4.6.5.1	Active power positive variation ramp	75 kW/s
4.6.5.2	Active power negative variation ramp	- 100 kW/w
4.6.5.3	Active power ramp for stopping the WTG	- 2000 kW/s
4.6.5.4	Active power ramp for emergency stop	Instantaneous
Reactive Power		
4.6.5.5	Reactive power positive variation ramp	25 kVAr
4.6.5.6	Reactive power negative variation ramp	- 25 kVAr

Table 4. G80 Power Ramping

4.6.6 POWER QUALITY

THD: The WTG shall be designed to support a THD in the MV grid of at least 2%.

Power Quality: Energy quality measurements shall be performed, following the standard IEC 61400-21 in its current version.

Voltage Asymmetry: The referred Asymmetry index is conceived as the quotient between the voltage modules of inverse and direct sequences. The WTG shall be able to operate with an asymmetry index less than 20%, present in the grid.

4.6.7 ELECTRICAL PROTECTION – LIGHTNING AND GROUNDING

The WTG shall be correctly protected to lighting by means of a lightning current transmission system from the blades and nacelle and the rest of critical envelopes to the ground, in order to avoid the current flow through sensible components.

The electrical components shall count on over-voltage protection devices in order to avoid any lighting event coming from the electrical system of the Wind Farm.

All these protection systems shall be designed and conceived to assure a correct protection and the protection level to reach is, as minimum, level I according to IEC 62305; IEC 61400-24 and IEC61024 shall be taken as reference.

The parameters that will define the correct execution and design of the grounding system shall be:
Guarantee the security of personnel – applying IEC 60479-1 and IEC 61936-1

Guarantee the security of the installation – designing maximum grounding impedance according to IEC62305-3

4.7 STRUCTURAL REQUIREMENTS

4.7.1 GENERAL

Unless otherwise stated, as a general requirement to ensure the structural integrity of the wind turbine, the following standards shall be followed:

- IEC 61400-3
- IEC 61400-1
- Germanischer Lloyd Guideline IV Part 2
- DNV-OS-J101

Where additional local or national requirements are present, these requirements shall be followed as well. In all cases the most demanding criteria shall be followed in order to fulfill each of the above regulations.
No visual inspection of the welding's during the lifetime of the structure is to be considered for the design.
G80-2.0MW class IA for FLOATGEN structural components shall withstand operational loads derived from functional and operational requirements as defined in 4.5 during wind turbine life as defined in 4.2

4.7.2 WTG DYNAMIC REQUIREMENTS

4.7.2.1 DYNAMIC REPONSE

The main global resonance frequencies of the WTG structures shall avoid with a margin of at least 10% the main loads frequencies. These requirements are for non-orthogonal modes.
Main loads frequencies to be avoided are:

- LSS Rotational frequencies and its harmonics: 1P, 3P

- HSS Rotational frequencies and 1st harmonic
- Gearbox meshing frequencies and harmonics
- Imposed vibrations by the Substructure and anchoring system.

These main global frequencies shall also have a minimum margin of 10% between them:

- 1st and 2nd Tower resonance frequencies
- Blades resonance frequencies (flap and edge)
- Rotor/Drive Train bending and torsion resonance frequencies
- Drive Train/Generator bending resonance frequencies
- Rear and Lower structures resonance frequencies

4.7.2.2 LOAD ASSUMPTIONS

The load hypothesis and the definition of load cases to be followed during the design of the turbine will be based on IEC standards which are referenced by the usual design guides. In relation to the load hypothesis and the definition of the design cases the wind turbine shall fulfill IEC standards that establish a predominant criterion of the definition of cases according to DNV and IEC61400-3, along with design cases arisen from GL2005 and IEC61400-Ed2 which will be self-imposed by internal criterion.

4.7.3 STRUCTURAL REQUIREMENTS FROM CONTROL PERSPECTIVE.

The control of the wind turbine must ensure that the maximum accelerations of the main structural components and also floater pitch motion are below acceptable limits.

For that purpose a detailed results of the nacelle accelerations and pitch angles (time series) shall be calculated and evaluated at least on relevant nacelle subcomponents and hub coordinate systems.

4.8 DESIGN ENVIRONMENTAL REQUIREMENTS

These data will constitute the input for, among others, the control system. Design environmental requirements

In general, if not specified in this paragraph, environmental requirements are according to IEC 61400-1 and Germanischer Lloyd Guidelines (last revisions).

4.8.1 TEMPERATURE

Operational range: Minimum: -30ºC, Maximum: +40ºC

4.8.2 HUMIDITY

Relative humidity ≤ 100%.

4.8.3 SOLAR RADIATION

Blade shall support a solar radiation intensity of 1000 W/m2 in every machine state; operation, stopped, and starting (according to GL guidelines last revision)
No structural degradation or aesthetic effects out of tolerances shall occur.

4.8.4 CORROSION

Corrosion requirements are according to ISO 12944-2. Protection against corrosion shall be achieved through the use of paints/Varnishes, suitable coating systems for metallic materials and/or through corrosion resistant materials selection.

Suitable corrosion resistant coatings and materials as well as the requirements and acceptance criteria shall be defined according to the corrosives levels by Materials and Processes Directorate.

According to the different components functionality or different exposure levels to environmental factors such as relative humidity, UV radiation, dissolved salt, condensed moisture, oils, etc; each corrosives level will have different acceptance requirements and tests associated, and different corrosion protections systems may be defined.

Only suitable materials with guaranteed properties at WTG operational and environmental conditions will be used. Materials and processes selected for the WTG design and manufacture will guarantee the design performance as well as the economical and safe operation of the WTG for the complete design lifetime.

Materials and processes selection will consider the demands to be fulfilled by the components such as the type of loads and the stress and durability requirements as well as the manufacturing capabilities, life cycle costs, safety, reliability and maintainability requirements for the WTG. Applicable certification regulations and guidelines will also be considered. Use of materials restricted by environmental regulations and directives will be kept to an absolute minimum and always in compliance with the applicable regulation.

4.8.4.1 CORROSION DURING OPERATION

Minimum protection is C5 for external parts and C4 for internal parts, in operation

4.8.4.2 CORROSION DURING TRANSPORT

The blade shall guarantee 0% corrosion on bushings and metallic components before assembly.

4.8.5 DUST

4.8.5.1 STANDARD CONDITIONS

The coat in any blade section shall be erosion resistance for the referred conditions, especially the leading edge.

4.8.5.2 HIGH DUST CONDITIONS

Specific high dust- high erosion requirements are defined in Ref 5.

If needed, specific coating protection shall be included in blades installed in sites under those conditions, in order to assure life durability for period in 11.7.2

4.8.6 PROTECTION DURING TRANSPORTATION

G80-2.0MW class IA components shall be equipped with protections against corrosion from the manufacturing facilities to the Wind Farm assembly.

4.8.7 AIR DENSITY & SEA LEVEL ALTITUDE

According to IEC, DNV and GL guidelines the air density value is 1.225 kg/m3. This value is variable according to values of height, temperature and humidity and a value and it could depend on the FLOATGEN test site.

Water level variation shall be taken into account for calculating the loads of an offshore wind turbine. For the definition of the air gap the extreme wave crest height (e.g. 50-year wave) and a safety margin of at least 1.0m has to be considered.

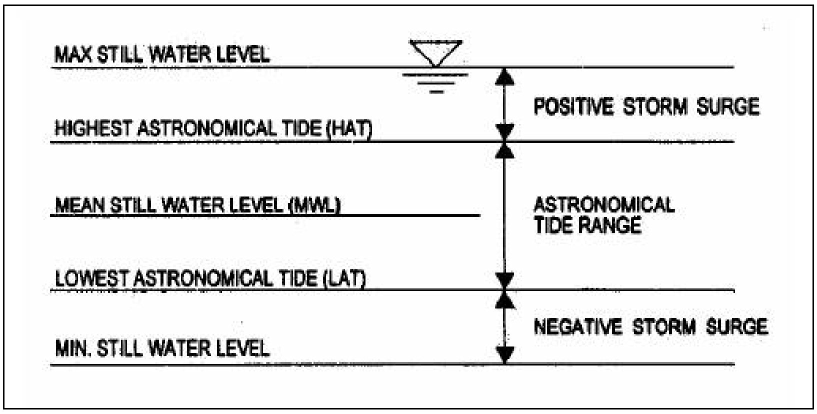


Figure 7. Water level definition according to DNV-OS-J101

4.8.8 STANDARD SITE-OCEAN CONDITIONS

The wave climate and other hydrographical parameters are site depended, therefore it is not possible to follow an “ocean class” approach corresponding to the IEC wind class definitions and then it’s not possible to define a standard site ocean conditions.

4.8.8.1 WIND CONDITIONS

The wind data values are to be defined for the FLOATGEN prototype test:

- Annual Mean wind speed.
- K Weibull parameter.
- Wind shear (overall).
- Turbulence intensity distribution.
- Site air density.
- V_{ref}

4.8.8.2 WAVE CONDITIONS

The wave climate is represented by the significant wave height Hs and spectral peak period Tp. Those parameters are site specific and shall be used in combination with suitable site specific spectral densities (or alternatively empirical formulation e.g. JONSWAP) to model the wave activity. The wave spectrum defines for certain duration (usually 30minutes to 3hours) a stationary process. Significant wave height Hs and peak period Tp have to be correlated to mean wind speeds Um.

Besides the normal condition wave data correlated with the wind extreme values of significant wave heights with several recurrence periods (e.g. 1 and 50 years) and corresponding peak periods shall be considered.

Misalignment between wave direction and wind direction shall be considered, up to a value of 180 degrees.

4.8.8.2.1 EXTREME INDIVIDUAL WAVE HEIGHT

The short-term probability distribution of individual wave heights within a stationary sea state can be assumed to follow a Rayleigh distribution:

$$F_{H|H_S}(h) = 1 - \exp\left(-\frac{2h^2}{(1-\nu^2){H_S}^2}\right)$$

Depending on stationary sea state duration and mean zero-up crossing period the highest wave height can be derived from following table:

No. of waves $N = T_S/T_Z$	Ratio H_{max}/H_S	
	mode $\sqrt{\frac{1}{2}\ln N}$	mean $\sqrt{\frac{1}{2}\ln N} + \frac{0.2886}{\sqrt{2\ln N}}$
500	1.763	1.845
1000	1.858	1.936
1500	1.912	1.988
2000	1.949	2.023
2500	1.978	2.051
5000	2.064	2.134

Table 5. Ratio of significant and individual wave height

4.8.9 STORAGE

Components, tools and packaging must be designed in order to allow storage in the open air for 4 months without specific maintenance.

Components, tools and packaging must be designed in order to allow indoor storage for 6 months without specific maintenance.

The design of the components must take into account the complete cycle time for the components in all the process stages [i.e. assemblies at factory, intermediate storages, transportation, port storages and erection] and the conditions on each of them.

The design of the components must provide accessibility to their inside in order to allow maintenance and handling tasks.

Regarding temperatures the WTG is expected to storage in the range -30º +50º.

4.9 SUPORTABILITY REQUIREMENTS

4.9.1 FAILURE RATE SUPPORTING INFORMATION

Compliance with the quantitative failure rate requirements shall be supported by detailed reliability data. The order of precedence for establishing the component failure rates shall be as follows:

- Gamesa Field experience based upon operational use that is the same or similar to operating conditions as defined for this product.
- Supplier Field experience based upon operational use that is the same or similar to operating conditions as defined for this product.
- In-house reliability life test data
- Failure rate prediction based upon standard data sources (MIL-HDBK-217, NSWC-98/LE1, NPRD, etc.).

Failure rates shall be supported with relevant engineering justifications in order to confirm that the rates represent the best available failure rate estimates. Calculated failure rates, with calculation assumptions (environmental factors, stress factors etc.) shall be provided.

For components exhibiting wear out failures, the supplier shall identify such components, and provide Weibull failure models which identify both the base failure data (field data or in-house life test data) and the Weibull distribution applicable parameter values (e.g. shape, minimum life and characteristic life parameters). Typically this will cover components incorporating parts such as bearings, gears, motors etc.., but not specifically limited to these. For example bearings L10 life time data / bearing types / lubrication methods shall be used to establish Weibull distribution model of failure.

The need for additional Reliability Life testing shall be identified and provided for those components for which insufficient life test data exists in order to show compliance with the life time requirements. This additional testing shall be based upon accelerated life testing, (ALT) or Highly Accelerated Life Testing (HALT).

For components that exhibit wear-in failures (i.e. failure rate reduces during the initial operating time), it shall be identified the environments stress screening tests (ESS) that are used in-order to screen out the infant mortality failures. The screening effectiveness shall be identified, and the effect upon reducing the component failure rate shown.

The total critical failures per year that can lead to a complete stoppage of the wind turbine (what will result in non-programmed visits per year) shall be defined.

MTBF values / Weibull Parameters at FRU level (Field Replaceable Unit: elements that can be replaced in the WTG) shall be provided.

4.10 ERECTION-ASSEMBLY-TRANSPORT REQUIREMENTS

The installation process will be the same with or without the MV cable install in the substructure.

The number of lifting operations at sea must be kept to a minimum. The number of components sent to the prototype site must be kept to a minimum [complete nacelle, complete tower and 3 blades].

The nacelle must be sent to the prototype site complete assembled, tested and with all the circuits [hydraulic, cooling] filled up.

It has to be possible to lift a complete nacelle with all the hydraulic and cooling circuits filled. The nacelle design must provide simple and accessible lifting points.

The components that are assembled inside the tower must be tested before sending the tower to the wind farm, including the elevator.

It must be possible to lift a complete vertical tower. Lifting points must be provided.

It has to be possible to lift the blades horizontally or vertically for the assembly.

It has to be possible to use the generator to turn the hub for the blades assembly

Tower cables shall be used as auxiliary power cables during the assembly operations

It shall not be needed to apply tightening torque to the bolted joints until the blade assembly has been finished. The pre-tightening load shall not exceed 600nm per bolt, using Makita.

The subsea cable must be routed before the assembly of the WTG. Anyhow, the WTG design must allow the routing of the subsea cable once the WTG has been erected.

The design shall use fast connectors for the cable arrangement.

It is needed an external connection box to connect auxiliary equipment.

The number of equipment to be maintained by an auxiliary power supply prior to the startup of the WTG has to be minimized.

Blades shall leave the blade factory fully equipped [Blade seal, bolts...].

Maximum wind speed limitations must be defined from Process, Health and Safety analysis

4.11 VALIDATION REQUIREMENTS

The G8X OFS WTG shall be verified/validated in accordance with the specific validation strategy. The aim of this strategy is to provide the different methods used for validate or verify the design requirements and /or design criteria.

A matrix is defined to shows the strategy of validation / verification of the WTG, seeing it as a group of methods (analogy, calculation, specimen or test) used to substantiate that all the component requirements during all the design steps (functional, mechanical, electrical…) are fulfilled.

When the validation method is a test, it is indicated the kind of test that will be made, being it a bench test (component) or Assembly line test (Nacelle / hub) or field test (WTG / Wind Farm).

4.12 MATERIAL REQUIREMENTS

Only suitable materials with guaranteed properties at WTG operational and environmental conditions will be used. Materials and processes selected for the WTG design and manufacture will guarantee the design performance as well as the economical and safe operation of the WTG for the complete design lifetime.

Materials and processes selection will consider the demands to be fulfilled by the components such as the type of loads and the stress and durability requirements as well as the manufacturing capabilities, life cycle costs, safety, reliability and maintainability requirements for the WTG. Applicable certification regulations and guidelines will also be considered. Use of materials restricted by environmental regulations and directives will be kept to an absolute minimum and always in compliance with the applicable regulation.

All materials will be treated in accordance with the relevant standards regarding quality and performance requirements. The environmental and operational conditions of the wind turbine will be taken into account for material selection, processes definition as well as inspections and maintenance requirements.

The design will define the materials and processes appropriately by calling out on the relevant engineering documents the applicable international and Gamesa specifications as required. Materials will be characterized to substantiate the design and demonstrate the fulfillment of the above mentioned requirements. Additionally, for the critical and structural materials representative design allowable will be developed for the relevant properties to be used in the WTG design.

Critical parts qualification for homologation and serial production shall be defined in the applicable Gamesa documentation. Gamesa Materials Specifications (GMS), Gamesa Process Specifications (GPS), Gamesa Product Requirements (GPR) shall be issued for every critical part, and a Gamesa Materials Data (GMD) shall be issued defining the materials design allowable.

The Materials and Processes requirements and limitations defined on these documents shall comply with or exceed the requirements stated in the certification authority guidelines.

4.13 Health, hygiene and safety at work requirements

Following design standards must be fulfilled:

1.1.1 European Union legal requirements (CE marking)

- Directive 2006/42/EC: Machinery
- Directive 2006/95/EC: Low Voltage
- Directive 97/23/EC: Pressure equipment
- Directive 89/686/EEC.

1.1.2 Harmonised standards:

- EN ISO 12100-1:2003: Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology (ISO 12100-1:2003)
- EN ISO 12100-1:2003/A1:2009
- EN ISO 12100-2:2003: Safety of machinery — Basic concepts, general principles for design — Part 2:

1.1.3 Other Requirements for design, operation and maintenance:

- EN ISO 14122-4:2004. Safety of machinery — Permanent means of access to machinery — Part 4: Permanent means of access to machinery. Fixed ladders (ISO 14122-4:2004)
- EN 50308:2004: Wind turbines – Protective measures – Requirements for design, operation and maintenance

In case of contradiction with harmonized standards, the latter is the priority

4.14 Environmental regulation requirements

Following national/international must be fulfilled:

- Environmental Guidelines for Wind Energy. IFC.
- Nature Conservation Guidance on Offshore Wind farm Development 2005. DEFRA.
- UNE 150301. Gestión Ambiental del proceso de Diseño y Desarrollo ECODISEÑO. AENOR.
- Stockholm Convention on Persistent Organic Pollutants
- Directive 2001/42/CE. Assessment on the effects of certain plans and programs on the environment
- Regulation 166/2006. European Pollutant Release and Transfer Register
- Directive 76/769/EEC. Restriction on the marketing and use of certain dangerous substances and preparations

- Regulation 987/2008.Regulation, Evaluation, Authorization and Restriction of Chemicals (REACH)
- Regulation 1272/2008. Classification, Labeling and Packaging of substances and mixtures
- Directive 2008/98/EC. Waste
- Directive 2008/1/EC. Integrated Pollution Prevention and Control
- Directive 2008/68/EC. Inland transport of dangerous goods
- IMA-EOL-024. Limited substances list
- IMA-EOL-024-A01. Carcinogen substances
- IMA-EOL-024-A02. Mutagen substances
- IMA-EOL-024-A03 Toxic to reproduction substances
- IMA-EOL-024-A04. USA Hazardous Air Pollutants (HAPs)
- ISO 14001. Environmental Management System
- Barcelona Convention: protecting the Mediterranean Sea.1976. Modified in 1995
- OSPAR Convention.1998
- Directive 92/43/CEE of habitat and 79/409/CEE of birds.
- Directive 2008/56/CE marine strategy
- European recommendation of the integrated management of coastal zones. 2007
- Bern Convention. Conservation of the wildlife and natural habitats
- Regulations 842/2006 Reduction in fluorinated greenhouse gases
- Directive 99/2008 Relative to the environmental protection through the criminal law
- Directive 58/2008 Classification, packaging and labeling of dangerous substances
- Directive 2/2009 Classification, packaging and labeling of dangerous substances
- Directive 2002/49/CE Assessment and management of environmental noise.
- Leakage collection system. GL Guidelines for the certification of Offshore Wind Turbines Edition 2005

5. KEY PERFORMANCE INDICATORS

5.1 KPI AS AN ASSESSMENT TOOL

The assessment of capabilities of a technology is difficult in the previous stages of demonstration. The analysis of global KPI may lead to an appropriate guidance of the design and the set of correct targets for the development.

Global KPI's are to be considered as technology capability evaluators and further targets together with the envisaged achievement path need to be considered. Present technology or present state of art set the reference frame for the KPI's and target set up process.

5.2 THE OVERARCHING KPI

The overarching KPI is always CoE. This defines the ability of any energy production system to deliver economic and social benefit and enables comparison of technology near applications. The main comparison for floating offshore would be with fixed offshore installations.

The levelised cost of electricity will be calculated using the following formula:

$$LCoE = \frac{L.I. + DO\&M}{E}$$

Where:

- LCoE (€/MWh): The levelled cost of generating electricity
- L.I. (€/y): Levelled investment
- DO&M (€/y): Annualised operation and maintenance cost
- E (MWh/y): Annualised energy production.

LCoE needs to be considered in an industrial framework and with the scope of the full installation Capex and the Opex expenses.

- To convert the capital cost in a levelised cost component, the levelised investment cost will be calculated:

$$L.I. = C \cdot P \cdot CRF$$

Where:

- C (€/kW): is the specific capital cost
- P (kW): is the capacity of the reference case
- CRF: the capital recovery factor:

$$CRF = \frac{d}{(1-(1+d)^{-N}}$$

Where:

- d (%) : discount rate
- N: lifetime

The reference project could be 500MW project, 40 km from shore, including all installation processes, electrical infrastructures and grid connection, O&M costs and financing. Full cost analysis need to be performed and final CoE provided. This could be done as a target for series manufacturing of floating supports and for forecast of costs according to sectorial offshore wind development.

Specific KPI's

For wind energy application, the energy extracting ability depends of the rotor swept surface. For the floating application several factors define itself as design drivers for the system. It is paramount to consider the overall plant efficiency in terms of resources used (not only the turbine, but infrastructures and services) related to its energy yield. Offshore plant cost up to now (for fixed installations) is approx the double of the turbine cost and BoP together with services represents a considerable part of the investment.

5.3 WIND TURBINE KPI'S

5.3.1 SPECIFIC POWER

Specific Power defined as the ratio between the nominal power and the rotor swept area define the power curve and is the direct definer of the capacity factor. Capacity factor will heavily impact the use of the infrastructures and services. Reference values for present offshore wind turbines are from 400 to 480 W/m2. Emerging designs will lower the specific power to 300 to 350 W/m2.

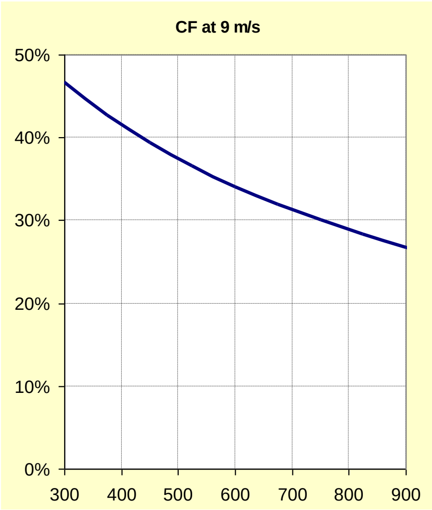


FIGURE 1 CAPACITY FACTOR AT 9M/S

Also the ratio between Onshore Specific Energy (defined as the ratio between yearly energy production and rotor diameter) and offshore Specific Energy could be an indicator for the different dynamic behavior between the WT running in an onshore vs. offshore environment. As much close to 1 means that the dynamic behavior is similar in both environments.

5.3.2 SPECIFIC TOWER HEAD MASS

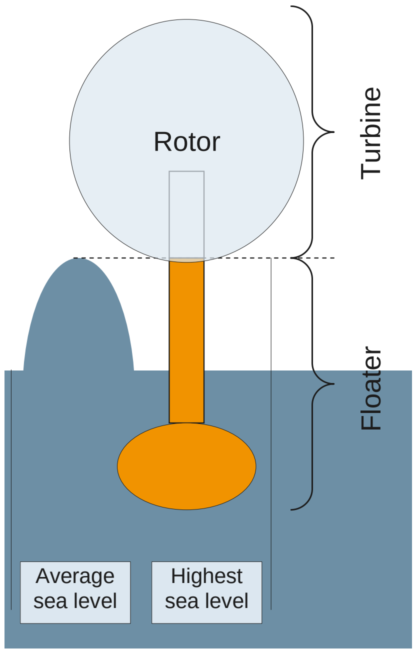


FIGURE 2 SWEPT SURFACE

Specific tower head weight as ratio over the swept surface is a comprehensive indicator of the use of expensive equipment, includes all the machinery and the rotor. Reference values for present offshore wind turbines are extremely high 35 to 45 Kg/m2. Commercial turbines onshore and emerging offshore designs are in the range from 20 to 25 Kg/m2.

5.3.3 SPECIFIC TURBINE MASS

Specific turbine mass as ratio over the swept surface is a comprehensive indicator of the use of overall material includes all the machinery and the rotor and also the tower or support structure from the highest sea level.

The standard cost of nacelle and tower are radically different, as indication cost per kg of steel structure lies between 1 and 2 €/kg and head mass cost typically for 5 times this amount.

Commercial turbines onshore and emerging offshore designs are in the range from 35 to 40 Kg/m2.

5.3.4 SPECIFIC ROTOR THRUST

Specific rotor thrust is defined as the ultimate thrust produced on the rotor including all certification safety factors and the extreme conditions both external and internal to the turbine. This means considering the 50 year repetition gust one internal failure and all the significant operation changes, power loss, over-speed etc. The Specific rotor thrust is a pressure figure of N/m2 and its reference value for onshore wind turbines is around 120 N/m2.

5.3.5 SPECIFIC ROTOR MOMENT AT HIGH SEA LEVEL

The rotor thrust is the key stability criteria for the floating device. The rotor thrust is applied close to the center of the rotor swept area.

Most advances in wind turbine design are based in the reduction of the extreme values of thrust. Both in extreme and fatigue values.

Specific rotor moment is defined as the moment produced at the junction of the turbine and the floater by the ultimate thrust produced on the rotor including all certification safety factors and the extreme conditions both external and internal to the turbine.

The rotor thrust moment is the main stability criteria for the floating device. The rotor thrust moment could be approximated by the previous KPI applied close to the center of the rotor swept area.

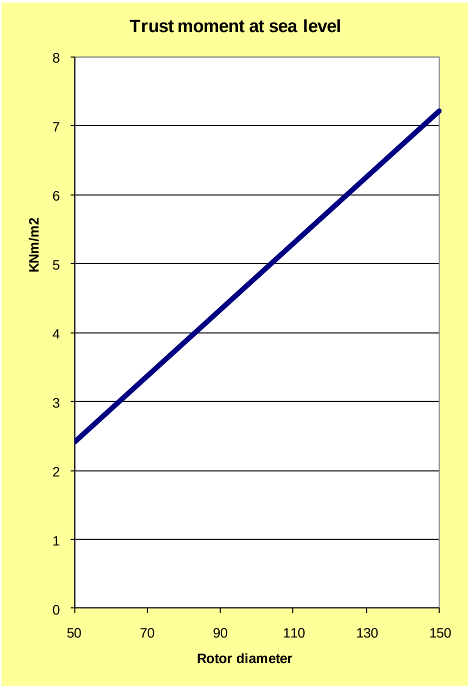


FIGURE 3 TRUST MOMENT AT SEA LEVEL

Specific rotor moment is defined as the moment produced at the junction of the turbine and the floater by the ultimate thrust produced on the rotor including all certification safety factors and the extreme conditions both external and internal to the turbine.

The rotor thrust moment is the main stability criteria for the floating device. The rotor thrust moment could be approximated by the previous KPI applied close to the center of the rotor swept area.

5.3.6 SPECIFIC TILTING MOMENT FROM DEVIATION

Specific tilting moment is defined as the moment produced at the junction of the turbine and the floater by the weight of the tower head mass and the tower due to the unbalance of the whole system taking into account the dynamic of the WT.

The two last KPI's are scale dependent. This means that its optimization depends of the whole system economics. The use of a KPI dependent of rotor size means that the target should be turbine size dependent.

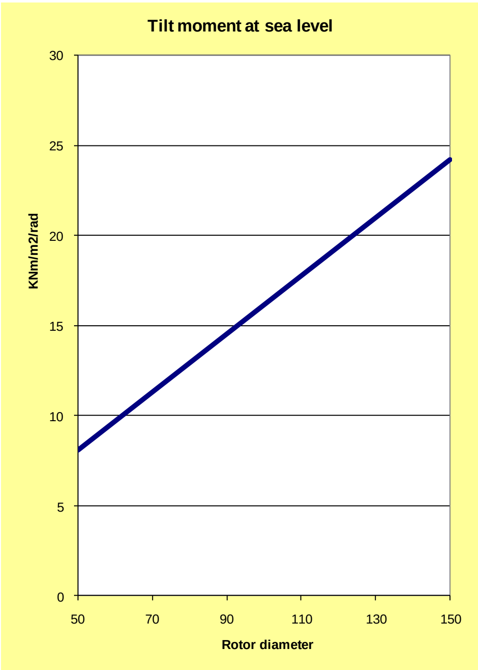


FIGURE 4 TILT MOMENT AT SEA LEVEL