



D5.12

Requirements for new standards and guidelines to implement innovative designs in 10MW – 20MW offshore wind turbines

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1 INTRODUCTION

1.1 SMART deliverable definition of task D5.12

S - specific

M - measurable, meaningful,

A - agreed upon, attainable, action-oriented

R - realistic, relevant, results-oriented

T - time-based, tangible, trackable

Deliverable No: 5.12	Title : Requirements for new guidelines and standards needed to implement the innovations in the market
Month Due: 24	Participants: GL-RC, GL-GH, CRES, DTU
Brief Description: Taking the deliverable 5.11 "technology roadmap" as point of departure the need for development of new standards and guidelines will be evaluated. Own research as well as information exchange with the project partners will form the basis of the results.	
Specific targets: The core questions to be answered in this deliverable are: i) Can the innovative technologies be safely deployed using existing guidelines and standards? ii) Are standards and guidelines available from other industries? iii) What guideline improvements are needed?	
Measure of success: Clear identification of the need for development of guidelines and standards in the technology roadmap of the major innovations.	
Participant contributions GL-GH: coordination DTU: review and advisory role CRES: review and advisory role GL-RC: main contributor, review of existing standards and guidelines, drafting of requirements for innovative technologies	

1.2 Objective

The intention of this report is to provide an overview of the existing standards and guidelines applicable to the innovative wind turbine components developed within INNWIND.EU in order to accelerate their way from the laboratory towards an implementation to a real 10MW or 20 MW offshore wind turbine. A gap analysis is performed which will identify shortages or missing requirements in state-of-the-art standards and guidelines and gives recommendations for further extension or redevelopment of offshore wind turbine certification standards and guidelines.

The report wants to demonstrate that the implementation of certification procedures in the early stage of research and development improves the time to market for innovative components developed within the INNWIND.EU project.

1.3 Scope

The development of innovations within the INNWIND.EU project has reached a well matured level and some component developments have left the conceptual phase already. At the current stage, the project has passed month 24 of 60 in total and is hence at about the half of the 5 years project duration time. Many components are already in a testing or laboratory prototype phase.

Based on the technology roadmap presented in work package (WP) 5.11 the six major innovations will be reviewed with respect to their needs of standards and guidelines.

In chapter 2 a brief overview on the six major innovations of the INNWIND.EU project is given. From the perspective of a certification body the achieved level of development are highlighted. The selected innovative components for cost effective 10-20MW offshore wind turbines are as follows:

- WP2: Active control for smart blades
- WP2: Passive control and structural optimisation for lightweight rotors
- WP3: Superconducting generators
- WP3: Pseudo direct drive generators
- WP4: Low-cost bottom-mounted support structures
- WP4: Cost effective floating support structures

In interaction with WP2, 3 and 4, the basic requirements for standards and guidelines will be established in a dialogue with the partners responsible for the 6 major innovations in the project.

In chapter 3 the current situation of available standards for each innovative component is presented by listing recommended standards and guidelines. Where the existing standards could not cover the innovative potential, recommendations for further extensions and redevelopment of standards and guidelines are provided.

The final review of the INNWIN.EU innovations with respect to their need for additional certification will take place at the end of the project (month 60) when the research activities have been completed and conceptual designs of the innovative concepts will be present. Therefore this report is a preliminary evaluation on the current development stage of the innovative components. The following steps to this deliverable are explained in the outlook, see section 1.6 .

1.4 The INNWIND.EU roadmap

According to the roadmap described in WP5.11 a typical path needed towards technology implementation in the market will be as follows:

- knowledge and design tool development
- component testing
- scale testing
- prototype testing
- certification

As an example, see below the time line of the INNWIND.EU roadmap is illustrated Figure 1-1.

Introducing the Roadmaps - Activities and milestones

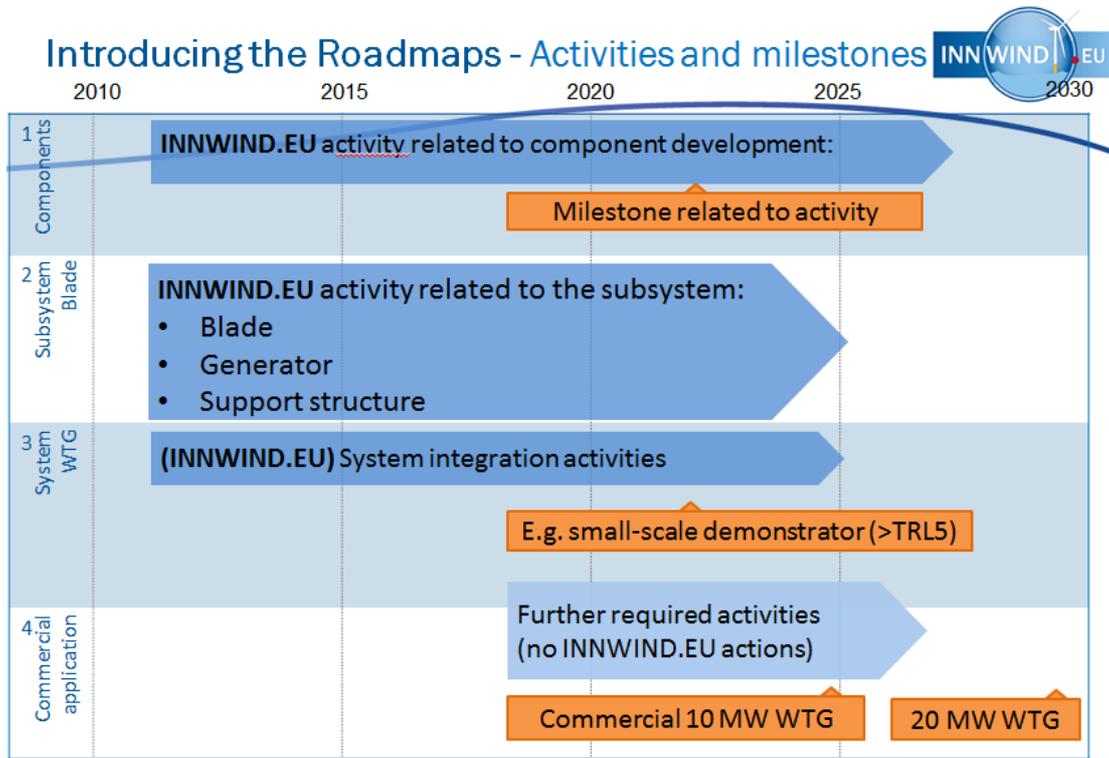


Figure 1-1: Innwind.EU scope for innovative activities

A more detailed rating of development stages can be found in defined Technology Readiness Levels (TRL's) which have been in use for decades in aeronautic or oil & gas industries (e.g. according to NASA, API 17N, or Carbon Trust). Within a INN WIND.EU workshop the application of TRL's have been discussed and decided to use TRL's for indicating the status of the various innovation developments.

1.5 Technology Readiness Levels and Certification

The technology roadmap for the different innovations shows large differences between the different innovations. The path to large scale commercial application is quite different for the different technologies under investigation. Within a workshop with participants from WP1 to WP5 the Technology Readiness Levels (TRLs) has been introduced to provide a rating scale for the stage of the INN WIND.EU innovations. Furthermore the application of the Manufacturing Readiness Levels (MRLs) has been discussed. A key conclusion of the meeting was that we need to focus on the identification of the critical technical elements of each innovation.

Figure 1-2 shows an example of a definition of technology readiness subdivided in 9 levels.

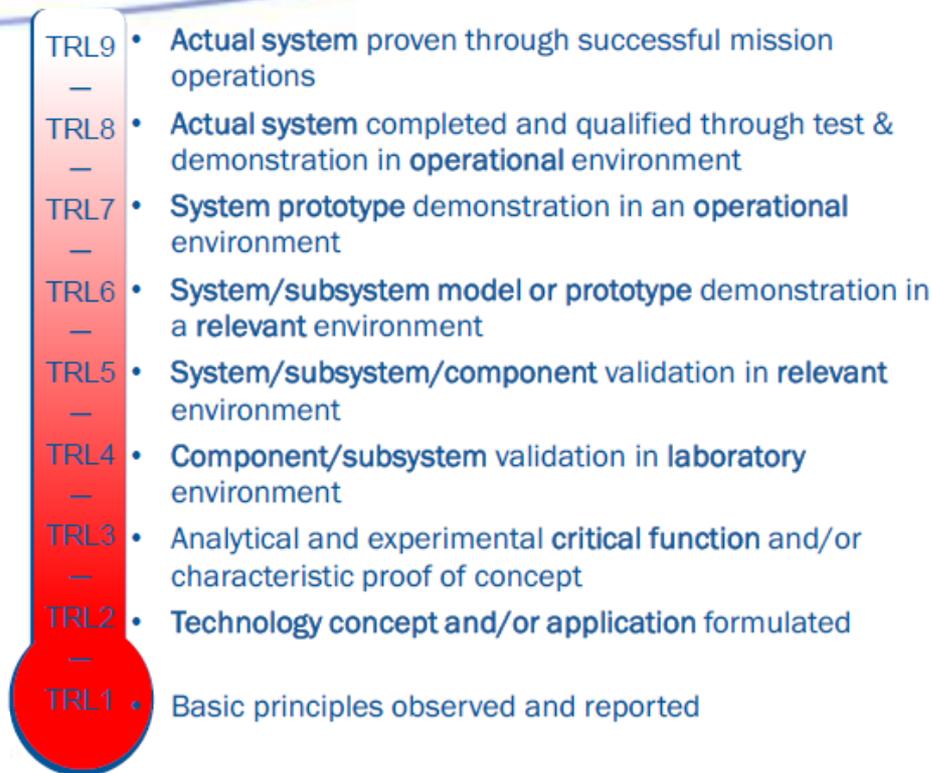


Figure 1-2: Technology Readiness Levels derived from NASA definition

Typically certification is of interest for components or complete systems at TRL's of 7 to 8 (full scale prototype or demonstrator operating in real environment). However, even in earlier stages certification could be applied and bring benefit to the component or system development. By achieving third party confirmation the next TRL level could be reached in shorter time period. For instance already the test campaign of a scaled model can be certified according to existing standards, as shown in section 0 . Here the tank test of floating wind turbine systems is described as a requirement for the certification of floating wind turbine systems. Such an early implementation of certification is corresponding for instance to TRL level 4.

1.6 Outlook

In deliverable D5.14 the requirements for new guidelines and standards needed to implement the innovations in the market will be followed-up finally in month 60 of the project. Through the continuous development of the concepts and the technologies within the WP's the requirements will be refined and updated.

Additionally guideline and standard proposals and solutions found within the WP's have to be forwarded to the international and national standardisation bodies. The proposals from the different tasks will be collected; a systematic review will be performed and summarized. Finally in case the innovative technologies are not sufficiently matured to develop proposals for standards the question how to include these in certification will be discussed.

A Summary report of proposed new text for guidelines and standards will be presented then in deliverable D5.22 which is aimed at the technical working committees of the standardization organizations, also at project finalisation in month 60.

1.7 Conclusion

The report provides an overview on the status of six selected innovative components from the INNWIND.EU project. Taken the INNWIND roadmap as starting point the innovations have been evaluated against the NASA technology readiness levels (TRL's). Then a review of existing standards and guidelines has been performed with respect to six selected innovative component. The availability of existing standards and guideline is comprehensive and many innovations presented by the project partners could be certified already according to state-of-the-art standards.

This applies on one hand for the aerodynamic and structural design of light weight rotors (airfoil design) and also for the optimised bottom fixed support structures. Active controlled blades and morphing airfoil sections on the other hand will probably need additional certification requirements.

This is the case in particular for the superconducting generator and the pseudo magnetic direct drive. Here the standards and guidelines have to be extended to achieve same safety levels in a certification as for conventional drive train concepts.

For floating support structures again a comprehensive collection of maritime and oil&gas standards is present. However, the today's lack of validated calculation tools and codes to simulate fully integrated floating wind turbine systems is requesting additional tests and inspection procedures during the certification. As a result of this review the performance of a tank test is recommended as an obligatory element in future floating wind turbine standards.

Based on the review of the developments of the project partners the grading of TRL's for the selected innovation is estimated as follows:

No	Work package task	TR Level
1	Task 2.1: WP2 Advanced smart control systems	TRL3-4
2	Task 2.3: Light weight rotor, Innovative materials	TRL3-7
3	Task 3.1: Super conducting generator	TRL4
4	Task 3.2: Magnetic Pseudo Direct Drive	TRL4
5	Task 4.1: Bottom mounted Offshore structure design	TRL4-5
6	Task 4.2: Floating foundation design	TRL4

Table 1-1: Technology Readiness Levels of INNWIND.EU innovation after month 24

2 OVERVIEW ON THE INNOVATIONS DEVELOPED WITHIN INN WIND.EU (STATUS MONTH 24)

2.1 WP2: Active control for smart blades

Active control on large rotor blades is using devices like trailing edge flaps and variable geometry airfoils with morphing leading and trailing edges. Synergistic combinations with passive control properties (e.g. self-regulating bend-twist coupling), see section 2.2, can be optimal. The potential of the active approach has been shown in simulations and at a laboratory level. The development of (parts of) rotor blades with sensors, actuators, control devices and power supply, supported by laboratory experiments and testing of concepts has been performed on a rotating test rig of 100kW turbine on the DTU test field. The intention of this 1:100 model was to close the gap between wind tunnel testing and full scale testing on a 10MW wind turbine.



Figure 2-1: Test rig at DTU test field with blade section 2.2m spanwise length and 1m chord

The innovations required here covers development of actuators, morphing technology with new actuator concepts, structural lay-out of sensors and actuators and their integration into the blade and controller design, enabling rapid use of nonlinear controllers and sensors for local inflow and stress. Here a strong interface to work package 1, Task1.4 “Advanced controls” exists. Innovative control algorithms in combination of new sensors and actuators can reduce the loading significantly. Load reduction in line with maintained energy yield directly reduces the cost of energy.

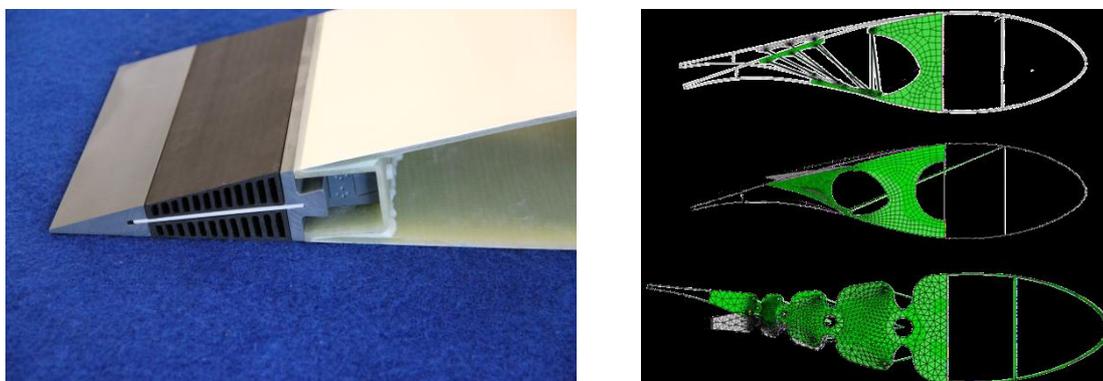


Figure 2-2: Morphing trailing edge concepts by NTUA and UPAT

Although there are long term experiences of aerodynamic actuators in the aviation industry it appears that for the application in the wind industry the additional cost for installation and

maintenance of such devices (e.g. flaps and variable geometry) are still too high compared to their benefits in reduction of loads and weight. Based on the experimental status the technology readiness level of active control devices can be found in the range of TRL 3 to 4 (analytical and experimental proof of function and characteristics of the concept).

References

- [1] Thanasis K. Barlas, Helge A. Madsen, "Rotating test rig", DTU Wind Energy, Technical University of Denmark, INNWIND.EU presentation on general meeting Hamburg October 2014
- [2] Vasilis Riziotis, "Task2.3: Active and passive loads control and alleviation (smart blades) design", NTUA, INNWIND.EU presentation on general meeting Hamburg October 2014
- [3] Karakalas A., Machairas T., Solomou A., Saravanos D., "Task2.3: Active and passive loads control and alleviation (smart blades) design", University of Patras, Mechanical Engineering and Aeronautics Department, INNWIND.EU presentation on general meeting Hamburg October 2014
- [4] Carlo L. Bottasso, Alessandro Croce, Federico Gualdoni, Pierluigi Montinari, "Novel active and passive load alleviation concepts", Politecnico di Milano, INNWIND.EU presentation on general meeting Hamburg October 2014

2.2 WP2: Passive control and structural optimisation for lightweight rotors

The overall objective of this work package is to define and assess innovative concepts for achieving lightweight rotor targets for very large offshore wind turbines using new aerodynamic and structural design opportunities. Within WP2 a number of investigations have been performed so far which will result in a significant reduction of cost of energy only in combination of a number of the developed innovations. The comprehensive research activities within this work package is focussed on the following sub tasks:

- high speed aerodynamics at blade tip taking compressible effects into account
- new thick, flat back airfoils for the blade inboard and root area
- high speed tip airfoil using CFD taking compressibility effects into account.
- validation of aerodynamic characteristics of the developed airfoils by wind tunnel measurements (MEXICO)
- integrated aerodynamic/structural design optimization.
- benchmarking of aeroelastic design tools in particular concerning the determination of blade torsional deflection
- structural concepts like grid-stiffened-, variable stiffness and internal truss structure taking the production process into account
- characteristics and design of build-in structural bend twist- and bend camber couplings as well as morphing blade sections
- combined passive and active load control concepts – identification of optimum characteristics by application of advanced CFD-structure-control-simulations.

Passive control on wind turbine rotor blades can be achieved by intelligent structural layout which takes the deformation of the blades during operation into account. Due to structural coupling of bending and torsion modes, the deformations can result in stabilising local inflow conditions. A synergistic combination of adaptive characteristics from passive built-in geometrical or structural couplings between deformations and active control will lead to the new light weight blade design.

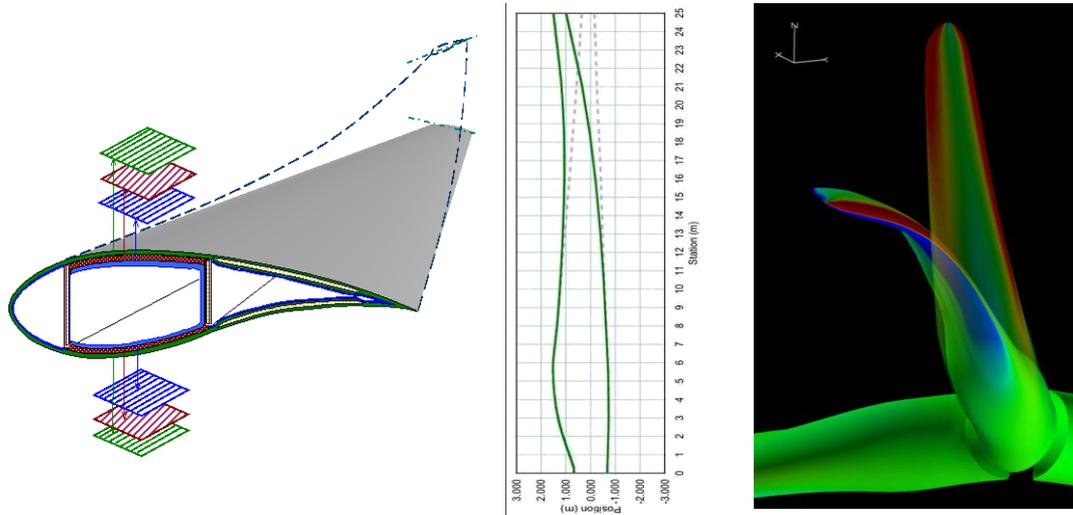


Figure 2-3: A Twist-flap Coupled Blade Design to alleviate fatigue loads (on the left with material coupling and on the middle with a curved blade (Sandia), right simulated emergency shutdown with EllipSys3D)

The following deliverables have been developed in the second period of the INN WIND.EU project:

- D2.11 “New aerodynamics rotor concepts specifically for very large offshore wind turbines”
- D2.13 “Validation of high rotational speed aerodynamics by wind tunnel tests”
- D2.21 “Benchmarked aerodynamic-structural design methods”
- D2.31 “New concepts to control the load along the span of the blade, passive, active and mixed”
- D2.12 “New airfoils for high rotational speed wind turbines”

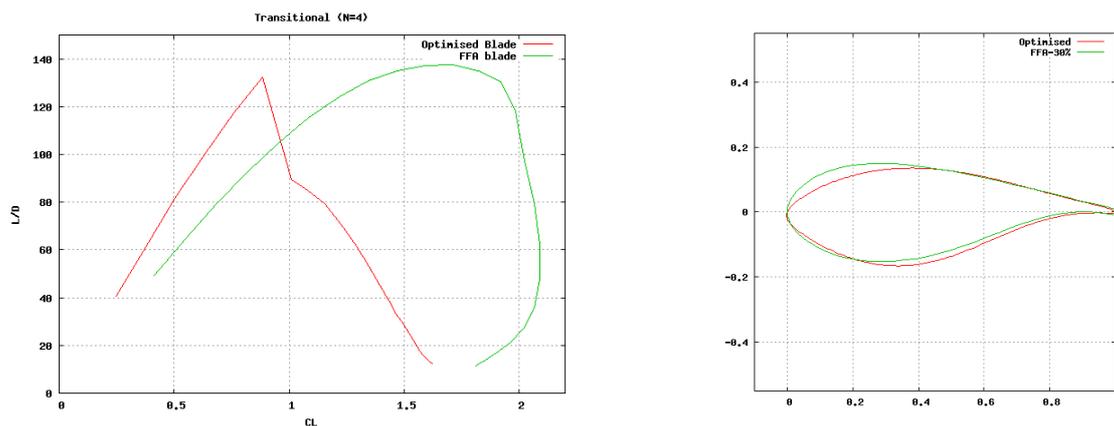


Figure 2-4: Left is shown the lift-drag curves comparison for a blade with a thickness of 30% (with transition) and right the respective airfoil contours

Deliverable D2.13 “Validation of high rotational speed aerodynamics by wind tunnel tests” has been provided new experimental data for validation of the aerodynamic models used for design of the new high tip speed, low induction rotors with new airfoils. Further some measurements with so-called “add-ons” often used by the industry were tested. Three different parts were investigated; a gurney, a spoiler and a serration.

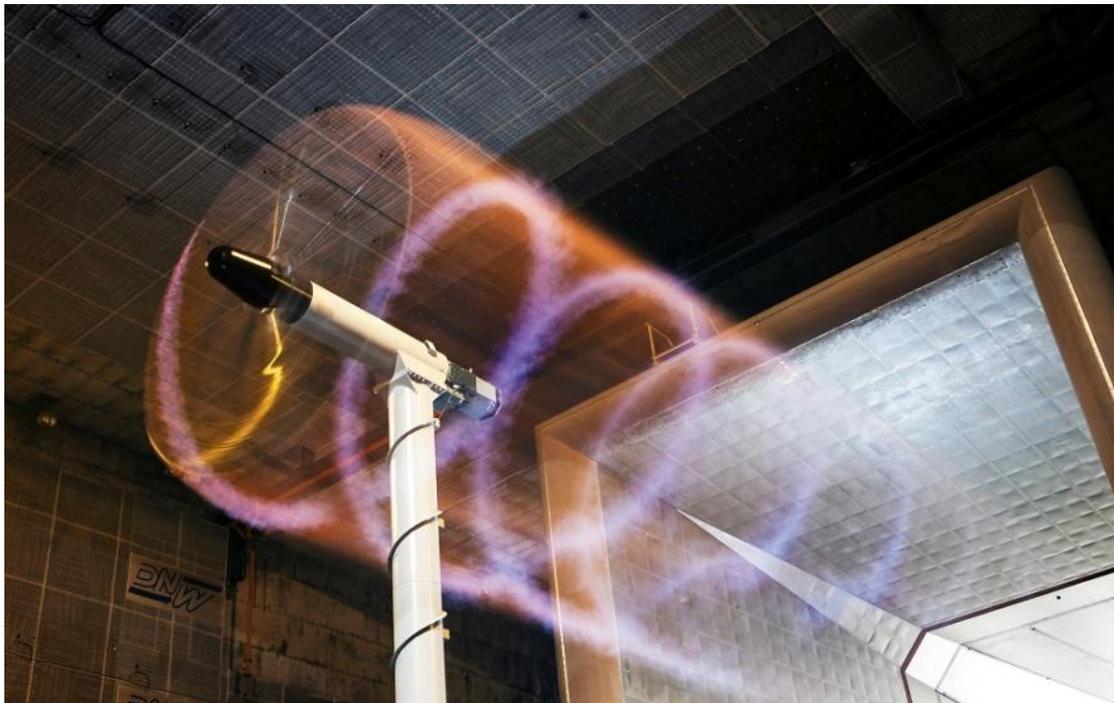


Figure 2-5: The 5m MEXICO model rotor installed in the DNW 9.5x5m wind tunnel late June 2014

The various improvements for the rotor blade design for 10-20MW wind turbines delivered within this work package show very different technology readiness levels with respect to their implementation into full size prototypes and market introduction. The development of new airfoils and extended code capabilities to simulate complex aerodynamics as well as build bend-twist coupling will get probably industry standard soon. This is represented by a technology readiness level of 6 to 7.

On the structural side of this work package the implementation of innovations like truss spars or passive morphing will take some further years to become ready for industrial production. These structural innovations need further experiments, testing, and proof of their long term reliability on medium sized wind turbines first. Therefore the TRL will be in a range of 3 to 4 base on the status of their experimental validation, see also the complete TRL definition in Figure 1-2.

References

- [1] D2.13 " New MEXICO experiment", K. Boorsma, J.G. Schepers, September 2014
- [2] <http://www.eswirp.eu/>. In European Strategic Wind tunnels Improved Research Potential, 2014
- [3] J.G. Schepers and H. Snel. MEXICO, Model experiments in controlled conditions. ECN-E-07-042, Energy Research Center of the Netherlands, 2007

2.3 WP3: Superconducting generators

The first prototypes of marine engines using super conductors (SC) are already in operation, especially in Asia (Kawasaki (Japan), Dongfang (China), Doosan (South Korea)). These marine engines have a rated power range from 1 MW up to 20 MW.

A working prototype of a SC generator for wind turbines does not exist now. At present several studies are carried out worldwide regarding the application of SC generator for the wind market. Following projects are known so far:

Europe:

- INN WIND: 10 – 20 MW direct drive
- SUPRAPOWER (Tecnalia and KIT): 10 MW direct drive
- HORIZON 2020 (Envision DK & Eco5): 3.6 MW direct drive for onshore wind turbines
- SEATITAN (AMSC Austria): 10 MW direct drive

USA:

- Emerson & University of Houston: 10 MW direct drive

South Korea:

- Doosan Engine & KERI: 10 MW direct drive

The actual status of development of SC generators within INN WIND.EU project reached a technology readiness level of TRL4 by validating the functionality of a SC coil in the laboratory, see also the complete TRL definition in Figure 1-2.

The first eight downscaled superconducting coils (type of coils: HTS 2G) for demonstration and test purposes were manufactured and tested at Siemens Erlangen. The main goals of the tests were to examine the behaviour of these coils and to measure the critical current at different temperatures (30 K and 77 K) and the AC losses at 30 K.

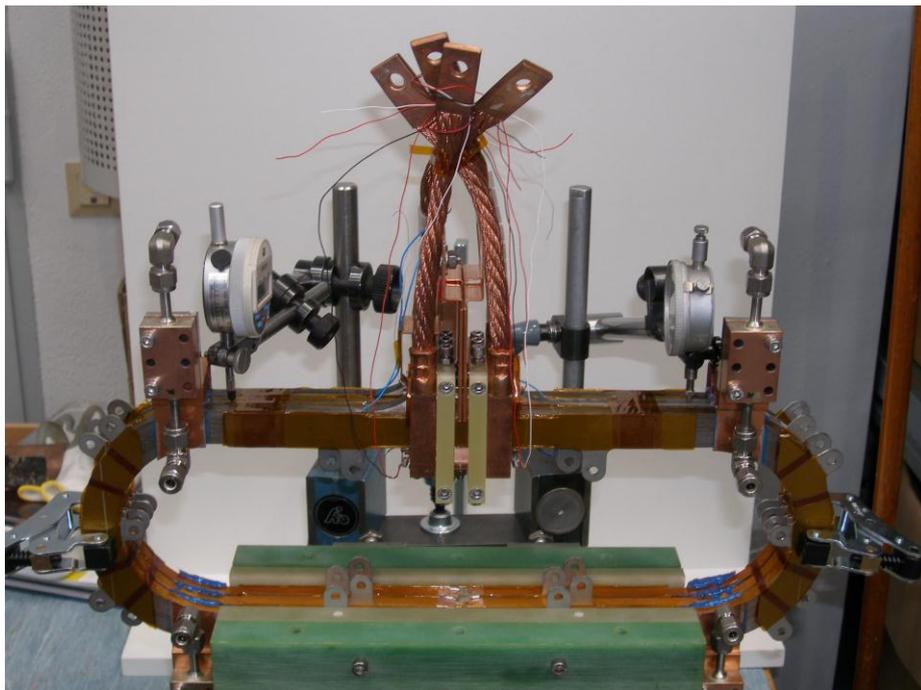


Figure 2-6: Assembly of three SC coils with cooling system and mechanical support (@Siemens Corporate Technology, Erlangen)

These results give first impression and hint of the critical and necessary requirements for industrial manufacturing of superconducting coils and therewith for a DNVGL Technical Note and future standards and guidelines also.

The next step will be to assemble a superconducting generator to test the behaviour of the complete system including cooling of the superconducting coils. The experiences made (positive and negative also) and the tests results are essential to identify the crucial requirements for the manufacturing and operation of SC generators including the connected subsystems and components (cooling system, frequency converter).

References

Polinder, H., (2014), Presentation 'WP3 Electromechanical Conversion – Project Meeting Hamburg October 2014'.

Abrahamsen, A. B. A., (2014), Presentation 'Task 3.1 Superconducting generators – Status of D3.12 and D3.13'.

Chen, Z., (2014), Presentation 'Task 3.3 – Power Electronics'.

2.4 WP3: Pseudo direct drive generators

Within subtask 3.22 a Magnetic Pseudo Direct Drive (PDD) has been designed. The demonstrator with a scale ratio of about 1:70 has a power output of 100-200 kW and is designed where possible to have the same electro-magnetics, mechanical and thermal stresses that would be present in the full scale machine (10MW generator).

Design tools has been developed and employed to estimate key performance indicators for the 10-20 MW class. Analytical prediction of the magnetic flux distribution in magnetic gears and 'pseudo' direct-drive machines PDD has been determined.

A first laboratory test of the demonstrator on a test bed achieved a power transmission of 150kW at an efficiency of about 96%. However some delamination of embedded magnets was found during the first test campaign in spring 2015. The lessons learned from the magnet delamination will be incorporated in a new design.

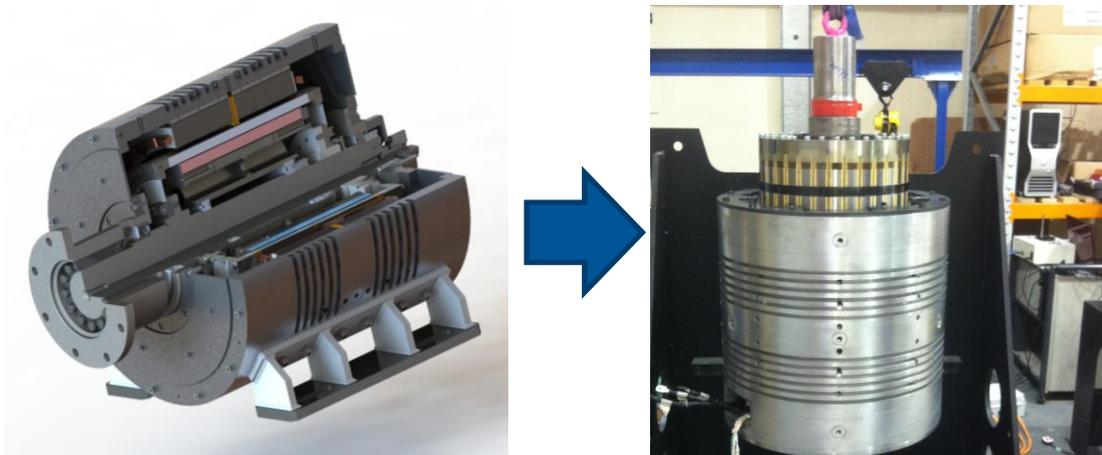


Figure 2-7: Design of a 150kW demonstrator for pseudo magnetic drive

The mainly successful test campaign in the laboratory including the experience made with respect to design and manufacturing of a prototype allows a technology readiness level of TRL4 (component validation in laboratory environment).

2.5 WP4: Low-cost bottom-mounted support structures

The innovations of work package WP4.1 comprises:

Innovative materials:

- Sandwich tubes (LUH) and joining techniques

Soil & foundation

- Piles and soil modelling (DTU)
- Soil structure interaction (IWES)
- Suction buckets (AAU)

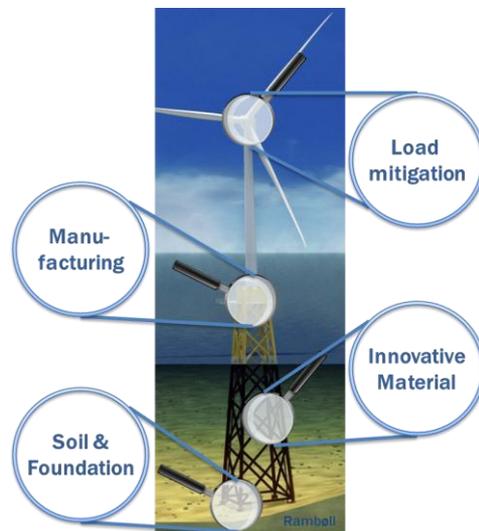
Load mitigation

- Structural control and loads (FW-OLD)
- Vibration absorbers (Fhg-LBF)
- Effect of load mitigation controls (Fhg-Kassel)

Manufacturing

- Mass-producible Jackets (Ramboll)

Furthermore a design of semi-submersible structure for water depth of 50m and beyond has been introduced. The pile which is attached to the mud line by an articulated joint is stabilised by mooring lines.



The technology readiness levels of the different research activities in work package 4 show a range of TRL4-5.

2.6 WP4: Cost effective floating support structures

Floating support structures for wind turbine are a novel technology. Still only a few full scale prototypes are in operation and measurements of existing floating concepts are rare. Therefore experiments with scaled floating models in wave tanks in combination with wind modelling are a cost effective approach to gather data for referencing and validating the dynamics and loads of Floating Offshore Wind Turbines (FOWT).

The state-of-the-art of simulation codes and tools for FOWT have been documented in detail in the deliverable D4.21. In deliverable D4.22 issues from previous tank test campaigns of scaled FOWT has been collected. They have been compared to the different scaling methodologies, and pointed out critical aspects and recommendations for future tests

In October 2014 a test campaign of 1:60 scaled model of a semi-submersible has been successfully performed. Within this test an innovative approach has been applied to model rotor varying trust and wave loading simultaneously. Further tank tests with a tension leg design (TLP) are ongoing. The measurement data of these model tests are of high importance for the validation and calibration of integrated floating simulation tools.



Figure 2-8: Measurement campaign at Ecole Centrale de Nantes, France, (LHEEA). The design of the floating model is based on the OC4/DeepCWind

Based on the test model designs and the validated design tools a floating substructure design for a 10MW wind turbine will be designed.

The early stage of development of floating structure design within INN WIND.EU represents a technology readiness level of TRL4 (component validation in laboratory environment).

3 STANDARD AND GUIDELINE STATUS OF INN WIND.EU INNOVATIONS

This report would like to stress out why standardisation and certification is needed in an innovation project:

- Standardisation helps the manufacturers, industry and investors to make their product safer and reduce risks during operation
- Due to an evaluation by an independent third party of the entire system failures or safety gaps could be detected
- Enables a defined quality and safety levels for a product

For the design of offshore wind turbines the IEC61400 series have been established in the wind industry and are used world-wide since decades. Many countries have taken over these standard packages for their national requirements for providing permissions for installation and operation of offshore wind farms. The most relevant IEC61400 standards are given below (relevant editions for certification are marked in **bold**):

- **IEC 61400-22: Conformity Testing and Certification of Wind Turbines**
- **IEC 61400-1: Design Requirements**
- IEC 61400-2: Small Wind Turbines
- **IEC 61400-3: Design Requirements for Offshore Wind Turbines**
- **IEC TS 61400-3-2: Design Requirements for Floating Offshore Wind Turbines**
- **IEC 61400-4: Gears for Wind Turbines**
- **IEC 61400-5: Rotor Blades Wind Turbines**
- **IEC 61400-6: Tower and Foundations for Wind Turbines**
- IEC 61400-11: Acoustic Noise measurement Techniques
- **IEC 61400-12-1: Power performance measurements**
- **IEC 61400-13: Measurements of mechanical loads**
- IEC 61400-14: Declaration of sound power level and tonality
- **IEC 61400-21: Measurement of power quality characteristics**
- **IEC TR 61400-23: Full scale blade structural testing**
- **IEC TR 61400-24: Lightning protection**
- IEC 61400-25(-1-6): Communication
- IEC TS 61400-26: Availability
- **IEC 61400-27: Electrical simulation models**
- IEC 60076-16: Transformers for wind turbines applications

3.1 Certification of active controlled smart blades

The certification blades with active control devices (like flaps) will primarily consider the blade as the major braking system and therefore responsible for the safety of the entire offshore wind turbine. Based on the principle of redundancy each blade shall be able to break down the turbine individually during severe environmental conditions or an emergency case (a two blade rotor will have a lower redundancy than a three bladed rotor and has to consider higher safety margins).

Furthermore the control and safety system has direct interface to the blade operation. Therefore the assessment of control algorithms shall be a part of the certification of an active controlled smart blade.

3.1.1 Available standards and guidelines

The following standards and guidelines represent the state-of-the-art for the certification of rotor blade designs.

Name	Description	Date / Edition
DNVGL-ST-0376	DNV GL Standard, Rotor blades for wind turbines	2015 DRAFT (1)
DNV-OS-C501	DNV Offshore standard, Composite Components	2013-11
	DNV GL Class Programme for coatings for protection of FRP structures with heavy rain erosion loads	2015 DRAFT (1)
DNVGL-ST-0076	DNV GL Standard, Design of electrical installations for wind turbines	2015 DRAFT (1)
IEC 61400-24	lightning protection system	2002
DNVGL-ST-0361	DNV GL Standard, Machinery design for wind turbines	2015 DRAFT (1)
ISO 9001	Quality management systems - Requirements	2014-07-25
ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories	2005-05 Edition 2.0
ISO 1172	Fibre volume content	1998
ASTM D3171 (CFRP), D2584 (FRP)	Constituent Content of Composite Materials	1999

(1) expected to be available end of 2015

Table 3-1: Available standards and guidelines for rotor blade design

Currently DNV GL is developing a new blade standard which is in the internal and external hearing process. The DNVGL-ST-0376 “Rotor blades for wind turbines” standard will be published by the end of 2015. Within this standard the experience with certification of large scale rotor blades (6.0MW, 7.0MW, and 8.0MW are currently produced by the industry) have been embedded and results of several research activities (among others the INN WIND.EU project) have been integrated.

The existing standards mentioned above are applicable for most of the innovative features of WP2 and active controlled smart blades. Further recommendations for future update of standards and guidelines are given in the next chapter.

3.1.2 Required extensions or redevelopments of standard and guidelines

The detailed description of blade characteristics is crucial for the certification of new rotor blades. Design assumptions for the following structural blade characteristics shall be documented and made available as interface data for turbine design purposes:

- blade mass properties
- elastic properties of the blade
- natural frequencies and damping parameters
- aerodynamic characteristics, including any additional aerodynamic devices such as flaps, vortex generators, or gurney flaps

The reported aerodynamic characteristic shall be detailed enough to ensure a realistic load and performance analysis of a wind turbine. This should include the full 360° range of angle of attack and all flow regimes, at all analysis locations.

3.1.3 Testing and inspection within certification

Generally, all new blade designs shall be full-scale tested. The objective of the blade test is to:

- validate the assumptions made during the design analyses
- identify relevant failure modes for certain design details, and verify their strength, in order to improve blade design
- identify manufacturing details prone to damage initiation

For this purpose, the blade shall be subjected to the following tests and measurements:

- mass and centre of gravity
- vibration tests (natural frequencies and damping)
- deflection and strains in static bending
- strength of design details during and after cyclic loading in a fatigue bending test

In section 2.5.14 of DNVGL-ST-0376 “Rotor blades for wind turbines” it is stated that special design features requires Appropriate design verification methods including analyses methods, factors, and testing shall be established by the designer (and agreed with DNV GL) for any special design features, such as:

- sectional joints
- mechanisms
- truss work
- stiffeners
- scarf joints
- tip brakes

Testing of composite components has a long tradition in certification of rotor blades and is still a mandatory requirement. Despite the fact that the simulation tools for calculation of composites have been improved remarkable over the last decade, the reproducibility of the quality of composite material is still a challenge. Therefore testing remains a suitable measure to approve the quality and reliability of (large scale) rotor blade by testing. The following recommendations are given by the DNVGL-ST-0376 “Rotor blades for wind turbines” standard:

In section 2.6.1 of DNVGL-ST-0376 “Rotor blades for wind turbines general requirements for testing and intermediate level testing are depicted. In many cases, it may be appropriate or even necessary to supplement material coupon tests and full scale blade tests by further testing on an intermediate level. When certifying a rotor blade for compliance with the present standard, such intermediate level testing may be applied for the following purposes:

- as part of the design verification process, by using test results as design values in structural verification analyses
- as partial substitute for full scale blade testing

Usually, validation and testing of a rotor blade design is primarily based on two types of tests: material coupon tests on the one hand, and full scale blade tests on the other hand. In a validation and testing concept often referred to as the “building block approach”, these two types of tests can be considered as the lowest and the highest level of a test pyramid as shown in Figure 3-1.

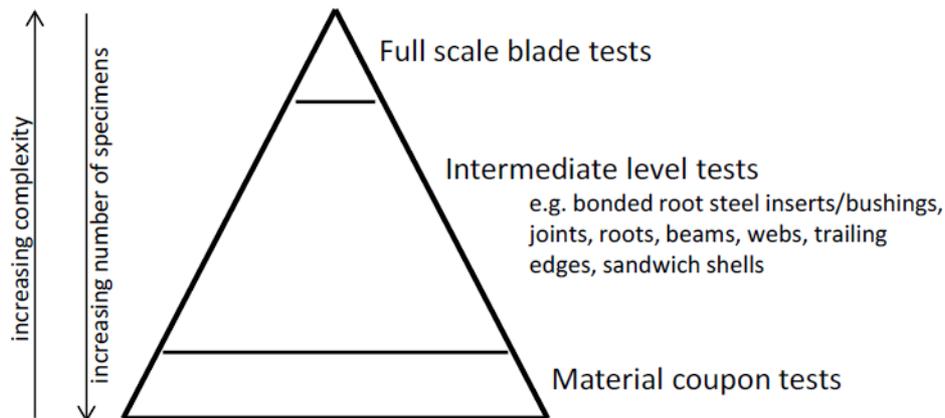


Figure 3-1: Test pyramid according to DNVGL-ST-0376

Intermediate level testing shall be part of the design verification process for the following design features:

- laminated or bonded metallic inserts for bolted connections
- critical or highly loaded bonded joints
- critical or highly loaded scarf joints or structural connections
- connections in sectional blades
- tip brake systems

Beside testing physical inspections during production of (large) rotor blades should be defined. As part of the production documents, also the final inspection shall be recorded. At least the checks listed below are required to be performed or checked for completeness (if performed earlier in manufacturing process) as part of the final inspection for every blade. A specific test procedure and acceptance criteria shall be in place for each inspection:

- plausibility and completeness check of the data and entries in control sheets and inspection lists. Verification of data (CTQ) compliance with acceptance criteria
- work progress slips and check sheets which accompany the rotor blade through the production process
- check of the geometry including accuracy of profile data, trailing edge thickness
- determination of the mass and the centre of gravity
- check of the balance quality for each set of blades
- surface quality and appearance
- drainage system;
- functional checks of installed systems (to include – but not limited to)
- brake systems
- flaps or moving devices
- sensors and monitoring systems
- lightning protection systems

References

- [1] Composite materials handbook, Volume 1: Polymer matrix composites, Guidelines for characterization of structural materials, Department Of Defense Handbook MIL-HDBK-17-1F, 2002-06-17
- [2] DNV GL Class Approval Programmes for materials, various documents, 2015, DRAFT (2)
- [3] Tanaka K., Kageyama K., and Hojo M. "Pre-standardization study on Mode II Interlaminar

- Fracture Toughness for GFRP in Japan”, Composites, Vol. 26, 1995, p. 257
- [4] VDI 2014, Development of fibre- reinforced plastics components, September 2006
- [5] Failure criteria for FRP laminates in plane stress, NASA/TM-2003-212663, November 2003

3.2 Certification of passive controlled blades and optimised lightweight rotors

The review of applicable standards and guidelines for new (large) rotor blades made in chapter 3.1 is valid for the approval of passive controlled blade designs and optimised lightweight rotors as well.

3.2.1 Available standards and guidelines

See chapter 3.1.1

3.2.2 Required extensions or redevelopments of standard and guidelines

See chapter 3.1.2

3.3 Certification of superconducting generators

The present chapter presents the actual status of the task “Requirements for new standards and guidelines to implement innovative generator designs with installed superconducting materials”.

For superconducting (SC) generators the significance and values of existing standards (e.g. IEC) and guidelines (e.g. GL Guideline for the Certification of Offshore Wind Turbine, Edition 2012) for generators shall be assessed and the differences to the existing standards and guidelines shall be defined. Additional requirements for design, manufacturing and testing of SC generators will be developed and published as DNVGL Technical Note.

Besides new requirements for generators the cooling system of the superconductors inside the generator and the connected frequency converter have to be considered as well.

3.3.1 Available standards and guidelines

The relevant standard series which defines the requirements for design, manufacturing and operation of rotating machines and generators is IEC 60034 “Electrical rotating machines”. Within this standard series IEC 60034 no requirements regarding superconductors installed in generators are specified so far.

3.3.2 SC frequency converter

In principle from technical point of view it is possible to use one of the three frequency converter types within the INN WIND.EU project:

- a) State-of-the-art voltage source converter

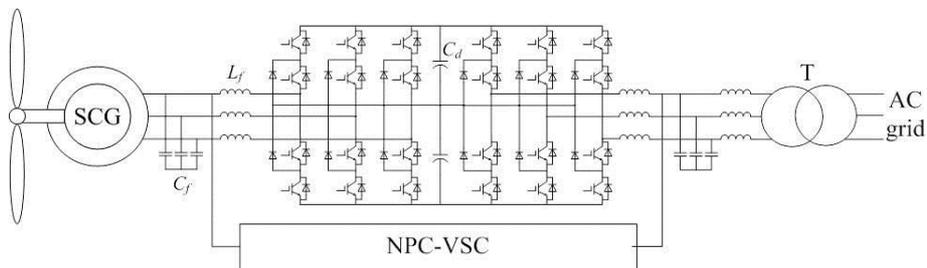


Figure 3-2: Parallel 3-Level voltage source converter

- b) Modular multilevel converter (e.g. ‘Hexverter’)

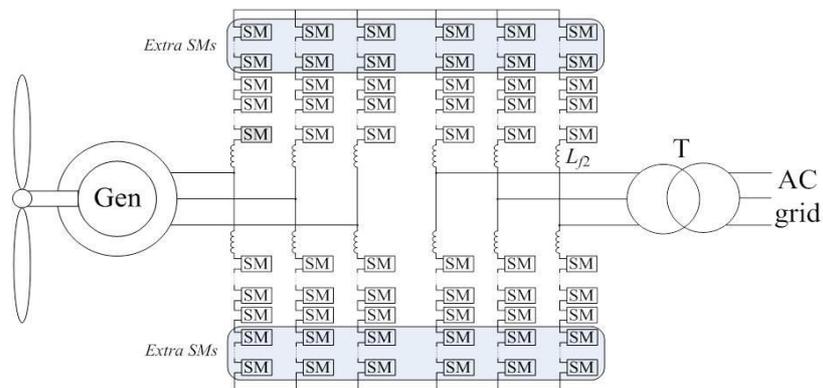


Figure 3-3: Modular multilevel converter

c) Current source converter

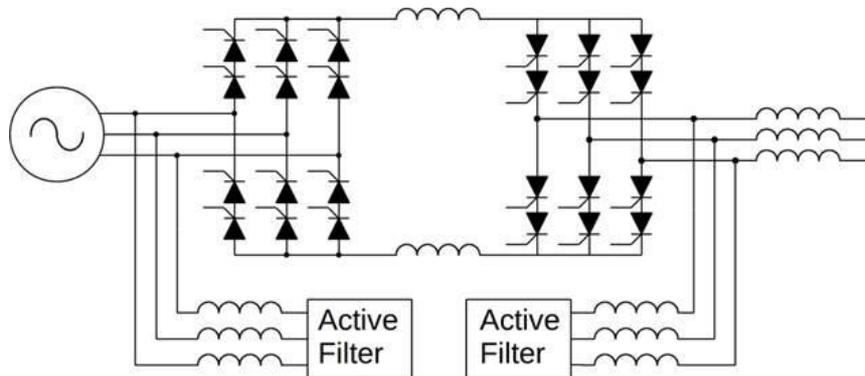


Figure 3-4: Current source inverter (with active filter)

Independently from the final chosen type of frequency converter type the requirements for frequency converters are specified in the IEC standards IEC 62477-1 (for low-voltage applications) and IEC 61800-4 (for medium-voltage applications). Within the year 2015 the new IEC standard IEC 62477-2 for medium-voltage frequency converters will be published. This standard has the status of a 'group standard', therefore it will replace the standard IEC 61800-4 as the relevant standard for wind applications with publishing.

In combination of the converter with a SC generator especially additional requirements for the short-circuit protection have to be considered which may be not specified in the above listed IEC standards for frequency converter. Conditioned by the SC generator the short-circuit currents at the machine-side of the converter are extremely high. This has to be considered in the protection functions within the converter. Installation of additional fuses in the terminal box of the generator may be a possibility of modified protection on the machine-side.

If a modular multilevel converter is installed, a segmentation of the generator winding system is necessary.

3.3.3 SC cooling system

The steadiness of the cooling system for the superconductors inside the generator is of highest importance for the SC generator to avoid breakdown of the superconducting condition of the SC coils. Therefore, a redundancy of defined parts, components and/or measurement devices may be necessary.

The maintenance and repair of the cooling system shall be possible without warming-up of the rotor to minimize the times of standstill (e.g. waiting time to cool down the SC coils to the operational temperature).

The complete cooling system including rotary feed-through (if necessary, depending on the cooling concept and the arrangement of the superconducting material) have to operate without any problems even at the extremely challenging environmental conditions offshore.

3.3.4 Required extensions or redevelopments of standard and guidelines

In comparison with the production and operation of common generators many 'new' aspects and requirements have to be considered for SC generators. During phase of design study following

items are identified as critical and therefore have to be considered in future updates of standards and guidelines (e.g. in DNVGL Technical Note):

- Observation of maximum allowed bending radius of superconducting wires at manufacturing of coils
- Avoidance of operation near critical current of superconducting coils
- Implementation / consideration of relevant parameter (maximum operational current, allowed temperature range, etc.) in Wind Turbine Control or Frequency Converter Control
- Deformation of coils at full current
- Danger of delamination of coils after cooling down
- Cooling of complete rotor or only of coils (installed in vacuum)
- Rotating or fixed superconducting coils
- Correlation 'superconductor type' – 'operational temperature' – 'critical current'
- Short-circuit protection concept of generator and frequency converter due to high short-currents in the generator and therewith on the generator side of the connected frequency converter
- Extremely challenging environmental conditions for the overall system (generator and cooling system incl. rotary feed-through) at offshore sites
- High torque / high short circuit forces and their impacts to the wind turbine (e.g. loads)

The manufacturing and testing of the first prototype SC generator may deliver more critical items which have to be considered in future updates of standards and guidelines (e.g. in DNVGL Technical Note). For SC generators in the range of 10-20MW rated power output future standards and guideline should specify manufacturing and testing surveillance as a mandatory requirement for certification.

At this moment of time only a broad outline of suitable standards and guidelines for SC generators in the range of 10-20MW exists in IEC and DNVGL. A possible content of a DNVGL Technical Note is already present. To create and finalize this Technical Note including the requirements for the design, manufacturing and operation of SC generators further experiences and results from the SC generator performance tests are necessary.

3.4 Certification of pseudo direct drive generators

The review of applicable standards and guidelines for pseudo magnetic direct drives has not been completed yet and will be completed within the update of this report in deliverable D5.14.

3.4.1 Available standards and guidelines

See chapter 3.3.1

3.4.2 Required extensions or redevelopments of standard and guidelines

Recommendations for new standards and guideline for the certification of pseudo magnetic direct drives will be completed within the update of this report in deliverable D5.14.

3.5 Certification of optimised bottom-mounted offshore support structures

The Figure 3-5 illustrate the definitions of the DNV GL for structural components for offshore support structures.

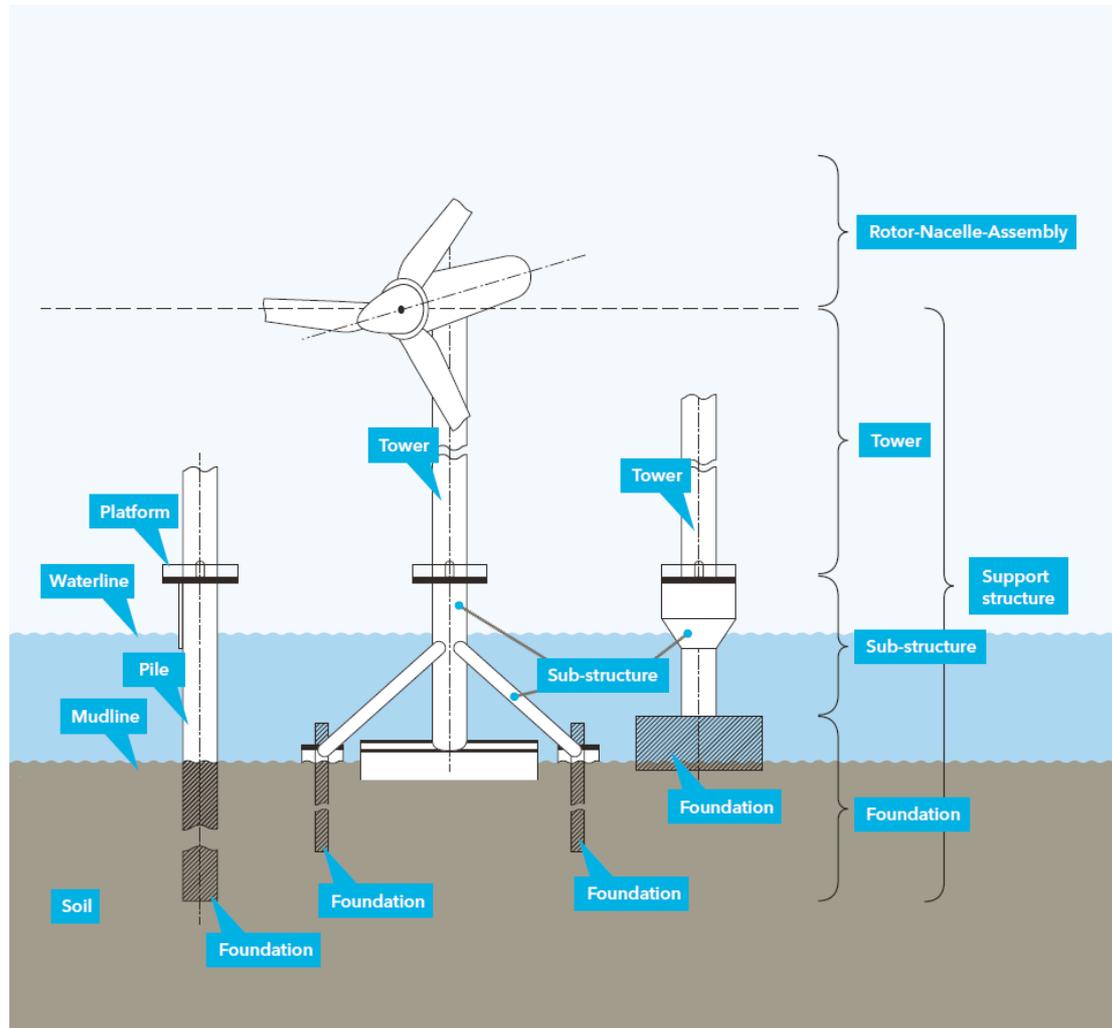


Figure 3-5: Definition of offshore wind turbines structural components

3.5.1 Available standards and guidelines

For offshore structures a large pool of standards and guidelines exists which are applicable for the certification of the optimised bottom mounted support structures designed within INN WIND.EU.

Reference	Title
DNV-OS-B101	Metallic Materials

DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD Method)
DNV-OS-C401	Fabrication and Testing of Offshore Structures
DNV-OS-C502	Offshore Concrete Structures
EN 196-1	Methods of testing cement - Part 1: Determination of strength
EN 197-1	Cement - Part 1: Composition, specifications and conformity criteria for common cements
EN 197-2	Cement - Part 2: Conformity evaluation
EN 206	Concrete – Specification, performance, production and conformity
EN 1090-1	Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components
EN 1090-2	Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures
EN 1992-1-1	Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings
EN 1993-1-1	Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1993-1-5	Eurocode 3: Design of steel structures - Part 1-5: Plated structural elements
EN 1993-1-6	Eurocode 3: Design of Steel Structures, Part 1-6: Strength and Stability of Shell Structures
EN 1993-1-7	Eurocode 3: Design of steel structures - Part 1-7: Plated structures subject to out of plane loading
EN 1993-1-8	Eurocode 3: Design of steel structures - Part 1-8: Design of joints
EN 1993-1-9	Eurocode 3: Design of steel structures - Part 1-9: Fatigue
EN 1993-1-10	Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties
EN 1993-2	Eurocode 3: Design of steel structures - Part 2: Steel Bridges

EN 1993-3-1	Eurocode 3: Design of steel structures - Part 3-1: Towers, masts and chimneys - Towers and masts
EN 1997-1	Eurocode 7: Geotechnical design – Part 1: General Rules
EN 1997-1	Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing
EN 1998-5	Eurocode 8: Design of structures for earthquake resistance - Part 5: Foundations, retaining structures and geotechnical aspects
EN 10025-1	Hot rolled products of non-alloy structural steels
EN 10025-2	Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels
EN 10025-3	Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels
EN 10025-4	Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels
EN 10204	Metallic products – types of inspection documents
EN 10225	Weldable structural steels for fixed offshore structures – technical delivery conditions
EN 12495	Corrosion Protection of Fixed Offshore Structures
EN 13670	Execution of Concrete Structures – Part 1: Common rules
Model Code 1990	CEB-FIP-Model Code 1990

Table 3-2: basic standards and guidelines for the certification of bottom mounted offshore support structures

The documents in Table Table 3-3 include acceptable methods for fulfilling the requirements in the standards. See also current DNV GL List of Publications. Other recognised codes or standards may be applied provided it is shown that they meet or exceed the level of safety of the actual standard.

Reference	Title
DNVGL-RP-0005	RP-C203: Fatigue design of offshore steel structures
DNVGL-RP-0048	Soil mechanics and geotechnical engineering

DNVGL-RP-GROUTCON	Grouted Connections
DNV-RP-A203	Qualification Procedures for New Technology
DNV-RP-B401	Cathodic Protection Design
DNV-RP-C201	Buckling Strength of Plated Structures
DNV-RP-C202	Buckling Strength of Shells
DNV-RP-C204	Design Against Accidental Loads
DNV-RP-C205	Environmental Conditions and Environmental Loads
DNV-RP-C207	Statistical Representation of Soil Data
DNV-RP-E303	Geotechnical Design and Installation of Suction Anchors in Clay
DNV-RP-J301	Subsea Power Cables in Shallow Water Renewable Energy Applications
Classification Notes 30.1	Buckling Strength Analysis
Classification Notes 30.6	Structural Reliability Analysis of Marine Structures
AISI 316	
EN 10088-1	Stainless steels - Part 1: List of stainless steels
EN 50308	Wind Turbines – Protective measures – Requirements for design, operation and maintenance
IEC61400-1	Wind Turbines – Part 1: Design Requirements
IEC61400-3	Wind Turbines – Part 3: Design requirements for offshore wind turbines
IEC61400-22	Wind Turbines – Part 22: Conformity testing and certification of wind turbines

Table 3-3: Informative standards and guidelines applicable for large support structure for offshore wind turbines

In the following further standards and guidelines are listed which have interfaces to structural design of bottom mounted offshore support structures.

Reference	Title
DNVGL-ST-SUBSTR	Offshore Substations for Wind Farms
DNVGL-ST-0376	DNV GL Standard, Rotor blades for wind turbines
API RP 2X	Recommended Practice for Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians
ASTM C348	Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars
BS 7910	Guide on methods for assessing the acceptability of flaws in fusion welded structures
BSH 7004	Standard Baugrunderkundung. Mindestanforderungen für Gründungen von Offshore-Windenergieanlagen.
Petersen, C, Stahlbau	Stahlbau, 3. Auflage Braunschweig, Wiesbaden, Vieweg Verlag 1993
Seidel, M. Zur Bemessung geschraubter Ringflanschverbindungen von Windenergieanlagen	Zur Bemessung geschraubter Ringflanschverbindungen von Windenergieanlagen, Schriftenreihe des Instituts für Stahlbau der Leibniz Universität Hannover (Heft 20), Aachen, Shaker Verlag, 2001
Schmidt, H, Neuper, M.	Zum elastostatischen Tragverhalten exzentrisch gezogener L-Stöße mit vorgespannten Schrauben, Verlag Ernst & Sohn, Stahlbau 66 (1997), Vol. 3, pages 163-168
IIW-1823-07 ex XIII-2151r4-07/XV-1254r4-07	Recommendations for Fatigue Design of Welded Joints and Components, International Institute of Welding (IIW/IIS), December 2008
ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods
ISO 6934	Steel for the prestressing of concrete
ISO 6935	Steel for the reinforcement of concrete
ISO 12944	Paints and varnishes - Corrosion protection of steel structures by protective paint systems
ISO 19901-2	Seismic design procedures and criteria
ISO 19901-8	Petroleum and Natural Gas Industries - Specific Requirements for Offshore Structures - Part 8: Marine Soil Investigations
ISO 19902	Petroleum and Natural Gas Industries - Fixed Steel Offshore Structures
ISO 22475-1	Geotechnical investigation and testing - Sampling methods and groundwater measurements - Part 1: Technical principles for execution

NACE RP0176	Corrosion Control of Steel Offshore Platforms Associated with Petroleum Production
NORSOK M-501	Surface preparation and protective coating
NORSOK N-004	Design of Steel Structures
NS 3473:2003	Prosjektering av betongkonstruksjoner. Beregnings- og konstruksjonsregler.

Table 3-4: Related standards and guidelines with interface to structural design

3.5.2 Required extensions or redevelopments of standard and guidelines

Currently no additional requirements are seen for the certification of the optimised INN WIND.EU structural design of 10-20MW offshore support structures. The innovations of work package WP4.1 comprises:

- tower out of sandwich material
- bonded joints
- suction bucket
- semi-submersible structure which is attached to the mud line by an articulated joint and stabilised by mooring lines.

The wide scope of existing standards and guidelines for offshore application combined with standards from maritime and oil&gas industry covers the innovative design of INN WIND.EU task 4.1.

3.6 Certification of floating support structures

3.6.1 Available standards and guidelines

Offshore standards with focus on floating wind turbine structures

Reference	Title
DNV-OS-J103	Design of Floating Wind Turbine Structures
GL-IV-2	Rules and Guidelines – IV Industrial Services – Part 2: Guideline for the Certification of Offshore Wind Turbines
DNVGL-SE-0073	Project certification of wind farms according to IEC 61400-22
DNVGL-SE-0074	Type and Component Certification of Wind Turbines
DNVGL-SE-0190	Certification of Wind Power Plants
DNV Classification Notes No. 30.4	Foundations
DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD Method)
DNV-OS-C103	Structural Design of Colum-Stabilized Units (LRFD Method)
DNV-OS-C105	Structural Design of TLPs (LRFD Method)
DNV-OS-C106	Structural Design of Deep Draught Floating Units/Spars (LRFD and WSD Method)
DNV-OS-C301	Stability and Watertight Integrity
DNV-OS-C502	Offshore Concrete Structures
DNV-OS-D101	Marine and Machinery Systems and Equipment
DNV-OS-E301	Position Mooring
DNV-OS-J101	Design of Offshore Wind Turbine Structures
DNV-OS-J201	Offshore Substations for Wind Farms
DNVGL-RP-0005	RP-C203: Fatigue design of offshore steel structures
DNV-RP-C205	Environmental conditions and environmental loads
DNV-RP-J301	Subsea Power Cables in Shallow Water Renewable Energy Applications

GL-IV-1	Rules and Guidelines – IV Industrial Services –Part 1: Guideline for the Certification of Wind Turbines
GL-IV-7	Rules for the Certification and Construction – IV Industrial Services – Part 7: Offshore Substations
GL TN Grouted Connections	GL Renewables Certification Technical Note – Grouted Connections for Offshore Wind Turbines, Edition 2013
GL TN GCC	GL Renewables Certification Technical Note – Certification of Grid Code Compliance

- ABS, "ABS - Final Report - Floating Wind Turbines", 1st Edition, American Bureau of Shipping, Issued May 2012
- API RP 2FPS, "Recommended Practice for Planning, Designing, and Constructing Floating Production Systems", 1st Edition, American Petroleum Institute, Issued March 2001
- DNV, "Energy Report - Guideline for offshore floating wind turbine structures", Rev.0, Report no: 129G6V8-7, Issued December 2009
- DNV-OS-C101, "Design of Offshore Steel Structures, General (LRFD Method)", Issued October 2008
- DNV-OS-C201, "Structural Design of Offshore Units (WSD method)
- GL Industrial Services, "Guideline for the Certification of Offshore Wind Turbines", Edition 2012
- GL Industrial Services, "Part 6: Offshore Technology – Chapter 2: Mobile Offshore Units", Edition 2007
- IEC 61400-3-Ed.1, "Wind Turbines - Part 3: Design requirements for offshore wind turbines", International Electro-technical Commission (IEC), 1st Edition 1.0, Issued 2009
- ISO 19900, "Petroleum and natural gas industries - General requirements for offshore structures - Part 1: Metocean design and operating considerations", 1st Edition, Issued December 2002
- ISO 19901-7, "Petroleum and natural gas industries – Specified requirements for offshore structures – Part 7:2011 Stationkeeping systems for floating offshore structures and mobile offshore units"
- ISO 19904-1, "Petroleum and natural gas industries - Floating Offshore Structures - Part 1: Monohulls, semi submersibles and spars", Issued February 2006

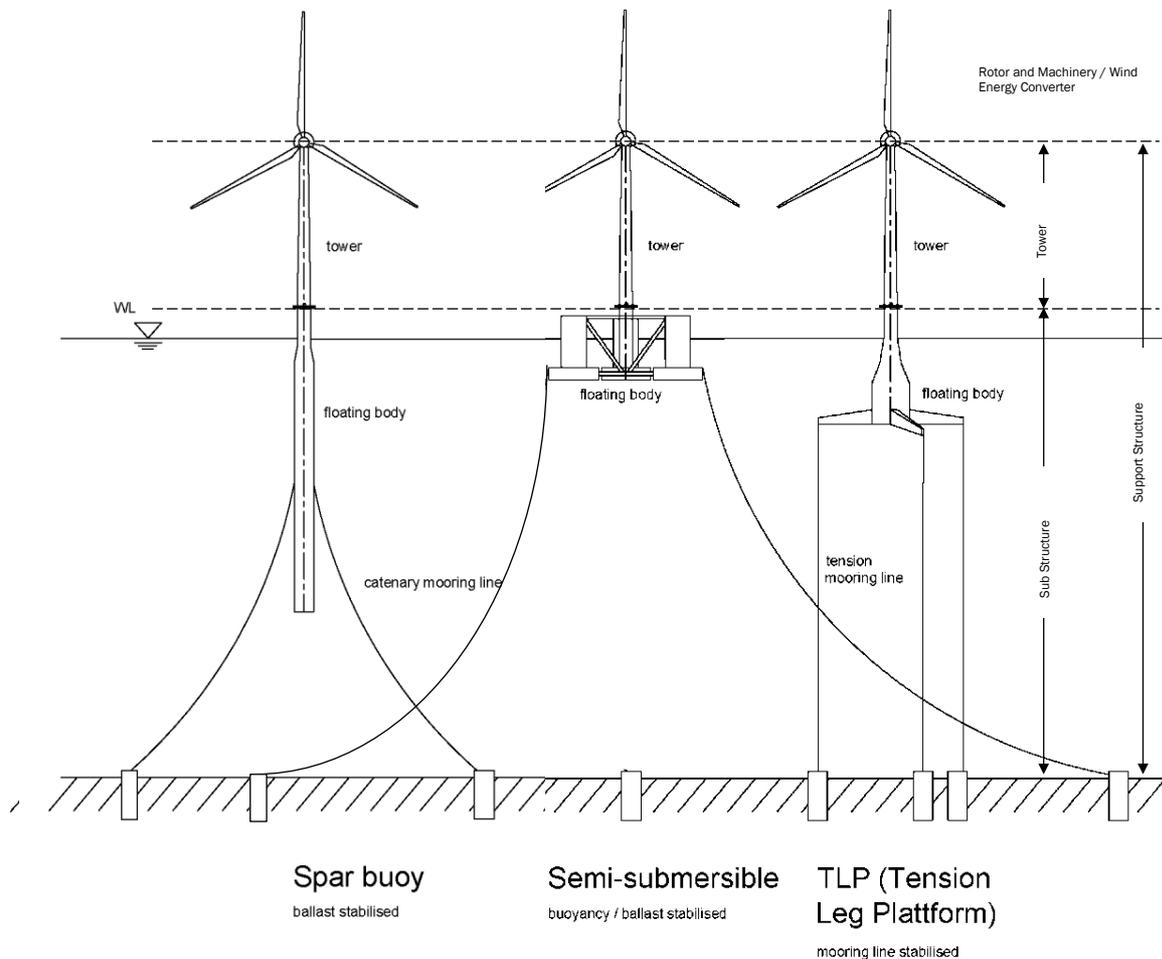
3.6.2 Required extensions or redevelopments of standard and guidelines

Currently several institutions are developing specific floating wind turbine standards. One of the first completed standard is the DNV-ST-J103 "Design of Floating Wind Turbine Structures". GL 2012 edition of offshore wind turbine certification guideline covers the complete spectrum for the certification of bottom fixed offshore turbines and includes additionally guidance for floating wind turbines including Risk analysis, Safety Requirements, Requirements for mooring, Load case definitions, load analysis and Stability

Special requirements for floating wind turbines:

- Specific load case definition
- Blade pitch control including effects of motion
- Intact and damaged stability (e.g. IMO MODU code)
- Mooring requirements and failures
- Motion monitoring (measurements/sensors)

3.6.3 Development of DNVGL Certification Procedures for Floating Wind Turbines



The DNVGL certification scheme for floating wind turbines and its related components consists out of six milestones:

- Conceptual Design Assessment
- Design Basis Assessment
- Design Assessment
- Type Certification
- Project Certification
- In-Service and periodic monitoring

These stages representing specific Technology Readiness Levels (TRL's), typically used in aerospace engineering or oil & gas industries (e.g. according to API 17N or Carbon Trust). On one hand the modules are forming prerequisites for the next module and allow a step-by-step certification process. On the other hand a straight forward certification process, e.g. heading directly for a full floating project certificate, is a possible certification strategy.

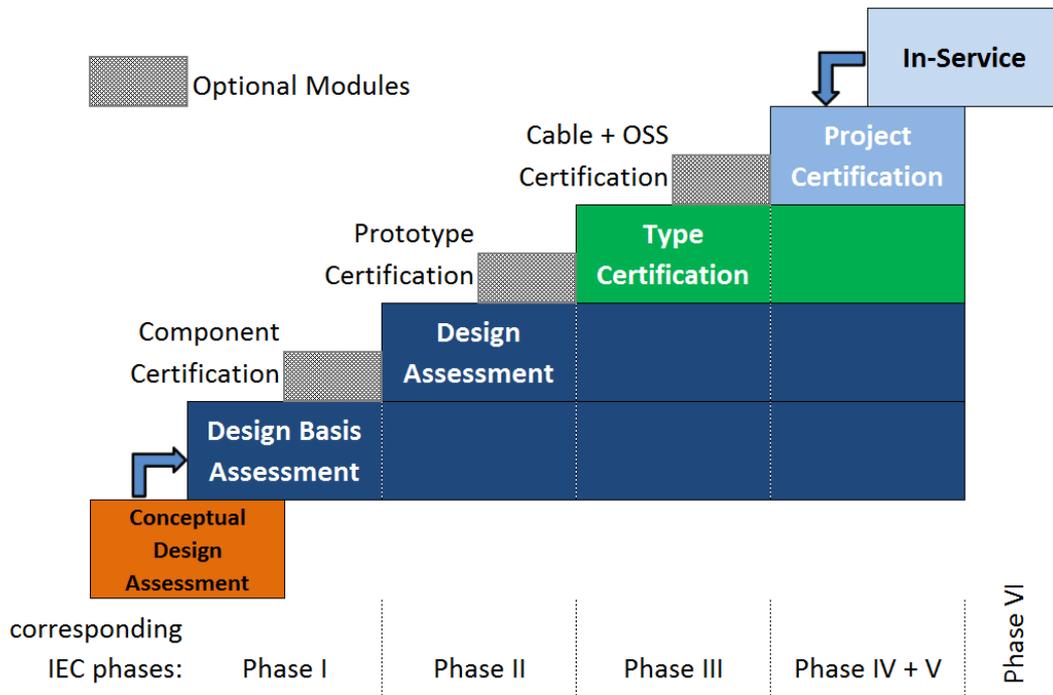


Figure 3-6: DNV GL modular certification system for floating wind turbines

The stages described above correspond to the certification phases defined in DNV GL SE documents and the phases I to VI of the IEC 61400-22 certification scheme.

The Conceptual Design Assessment supports the development of a floating concept in the early stage by individual scope of assessment and content of reviews. This stage corresponds typically to a TRL 3 to 4.

The assessment of the Design Basis requests already clearly defined boundary conditions and methodologies for performing the design without having a detailed design ready (typically TRL 5 to 6).

The Design Assessment covers the steps necessary to achieve a TRL of about 7 to 8. The Design Basis shall be completed successfully. This assessment includes an independent load analysis, model tests, and an approval of the integrated structural system consisting of wind turbine and support structure (tower, floating body, and station keeping system).

In case a prototype is part of the development plan to test a full size floating concept during a limited period, DNV GL can provide a confirmation for a safe prototype installation. Here DNV GL offers optionally the Prototype Certificate which covers all relevant elements of the Design Assessment in combination with a survey of the substructure (floating body and station keeping system) manufacturing.

When the development reaches the level for starting manufacturing of a number of turbines for a specific project or a serial production the Type Certification covers the survey during the manufacturing of the components and a type testing programme (typically TRL 9). A successfully completed Design Assessment is mandatory.

For the planning, the installation, and the operation of a full floating wind farm the Project Certification is recommended. It is based on a completed Component Type Certificates or a complete floating wind turbine Type Certificate. The conditions of a specific site and the

compatibility with the type certified design will be checked. A manufacturing survey of the specific components appointed for the site in question and their transport and installation will be witnessed by DNV GL inspectors. After a successful commissioning of the full wind farm the Project Certificate will be issued.

Finally, the validity of the Project Certificate shall be maintained by annual periodic monitoring of the installed floating units which involves in-service survey and approval of the maintenance, repair and inspection programme.

In general subsequent phases shall not be initiated before previous or dependent phases are completed and approved. For example, prior to verification of the manufacturing phase, the design basis phase and the design phase shall both be completed and approved. Therefore the manufacturing of the components for the project shall not be started before the design is approved and survey is agreed. Alternative ways and the related risks shall be discussed and agreed with DNV GL in advance.

Each certification stage is completed with a Statement of Compliance. A Statement of Compliance will be provided, given that all open items found in the review phase can be closed. In this statement, the conditions under which the assessment has been performed will be clearly expressed. The documentation reviewed will be listed together with review comments.

3.6.4 Additional Load Cases

Design Situation	DLC	Wind conditions	Marine conditions	Other conditions	Type	γ_F
Power production plus occurrence of fault	10.1 10.4	NTM $V_{hub} = V_t$ or V_{out} EWM $V_{hub} = V_{ref}$	Irregular sea state with $H_s(V)$	Transient condition between intact and redundancy check condition MIS	U	A
	10.2 10.5	NTM $V_{hub} = V_t$ or V_{out}	Irregular sea state with $H_s(V)$	One single line break, Redundancy Check MIS	U	A
	10.3 10.6	NTM $V_{hub} = V_t$ or V_{out}	Irregular sea state with $H_s(V)$	Leakage MIS	U	A

3.6.5 Floating certification modules and their deliverables

Optional Services Assessments + Final Certification Reports (CR) Statements

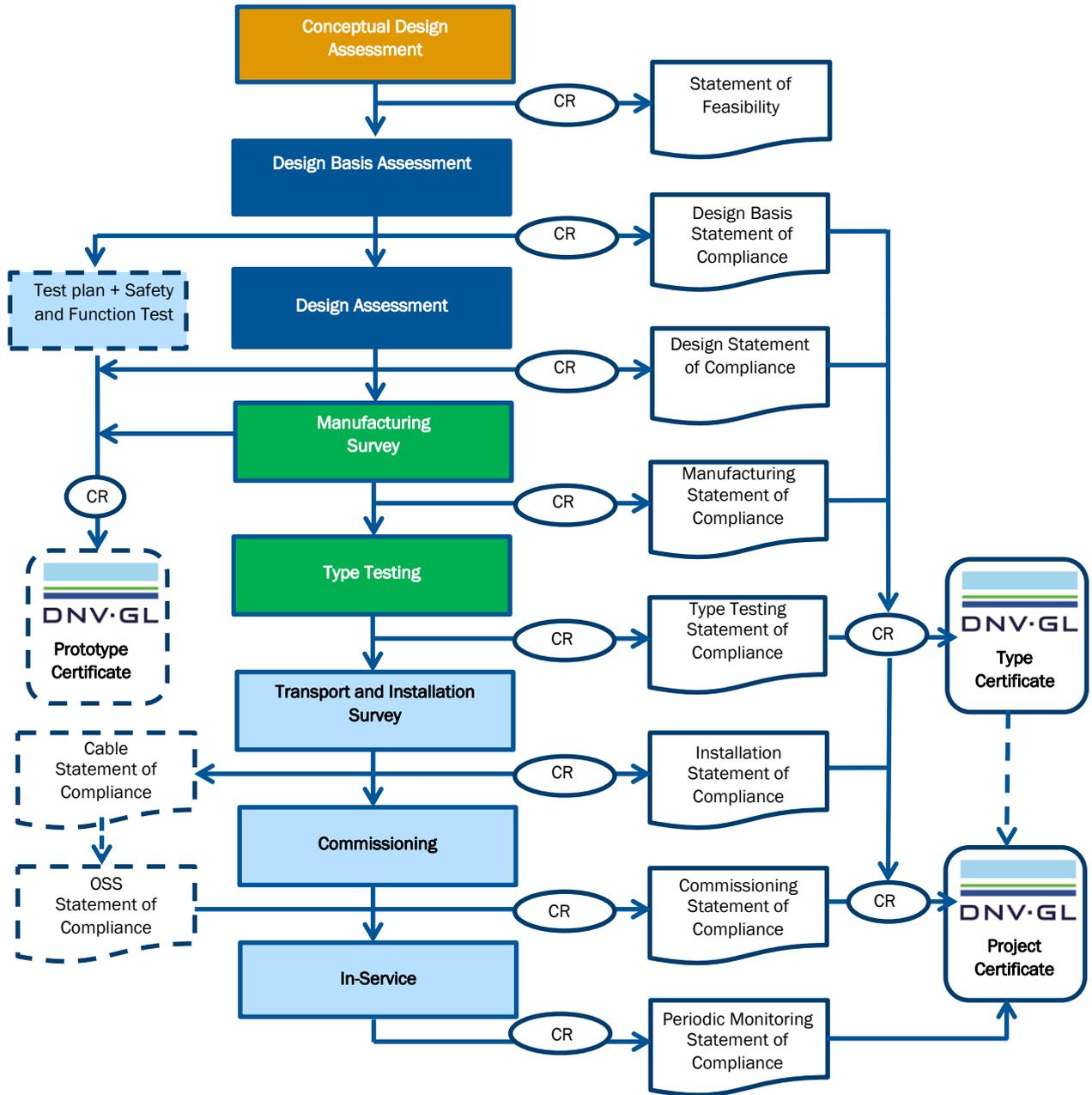


Figure 3-7: Certification modules and their deliverables