HiPRWind

High Power, high Reliability, Off-shore Wind Technology

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Contact information (Coordinator):
Fraunhofer IWES, Germany
Jochen Bard
Tel: +49 561 7294 0
Fax: : +49 561 7294 100
E-mail: mbox@iwes.fraunhofer.de
Project website address: http://www.hiprwind.eu/

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1 Introduction

1.1 Project Context and Objectives

The HiPRWind project aimed at advancing the state of the art for multi-MW wind turbines offshore and in particular floating wind turbines. With a consortium of industrial companies, SME's, R&D organisations and universities, the design, fabrication, installation and operation of a MW-class floating wind turbine for research purposes was to be conducted. The beneficiaries in the HiPRWind consortium are listed below:

Industry:	- ABB (Switzerland) - Bureau Veritas (France) - IDESA (Spain) - Technip (France) - Vicinay Cadenas (Spain) - Ingeteam (Spain) - ALE-Spain (Spain)
SMEs:	- Micromega (Belgium) - Dr. techn. Olav Olsen (Norway) - Wölfel Beratende Ingenieure (Germany) - 1-Tech (Belgium) - QiEnergy (Spain)
Universities:	- NTNU (Norway) - University Siegen (Germany)
Research Organisations:	- Fraunhofer IWES and IKTS (Germany) - Narec (now ORE Catapult, UK) - SINTEF (Norway) - Tecnalia (Spain) - TWI (UK)

The first phase of the project was focused on a detailed design for a floating support structure matching a 1.5 MW wind turbine. The results of Work Package (WP) 1 were the base for Work Package 2, where fabrication led by IDESA, load out and installation of the whole floating system should be undertaken. The operation of the floating turbine was the scope of Work Package 3 under Tecnalia's lead. This was to cover the development, installation and operation of a comprehensive measurement system. Tecnalia would maintain operation of the wind turbine and of the sensor systems for at least one year to the end of the project.

Following commissioning, this unique research tool should be available to researchers also beyond the consortium under a shared access scheme and would provide a huge amount of field test data and valuable experiences for all aspects of floating wind turbines, e. g. the commissioning, the load out / installation, the maritime operation & maintenance. These results would feed into the R&D Work Packages WP4 (Advanced floater and moorings systems), WP5 (Controls, Power and Grid), WP6 (Condition and structural health monitoring) and WP7 (Advanced Rotor Concepts). The developments and theoretical results of these WPs could be evaluated with the field test data. Finally in Work Package WP8 (Turbine concept generation) all findings in the R&D should be summarized as related to 10 MW-class floating platforms.

Along with the scientific and technical work packages WP1 to WP8, the dissemination of the results has been conducted in Work Package 9. This WP9 developed and supported the public web site www.hiprwind.eu of the project and bundled all dissemination activities in the project. Work Package 10 conducted all required information management activities (preparation of public scientific reports, support of partners with regard to external information activities, etc.).

1.2 Execution and premature termination of the project

The first phase of the project involved mostly industrial companies dedicated to designing a floating support structure matching the chosen 1.5 MW wind turbine. The detailed design was performed in Work package 1. The scope of WP1 was the floater itself, the mooring system and dynamic cable, the control and operational supervision system. The design process was entirely supported by use of numerical simulation tools.

The results of WP1 constituted the working base of Work Package 2, where fabrication, load out and installation of the whole floating system were to be undertaken. Led by IDESA, the WP2 started the construction of the steel parts of the floater.

However, during the third period of the project, two key partners in the project first announced their suspension of work on HiPRWind and then formally withdrew from the Consortium on 30 June 2013. Therefore, the work plan for the remainder of the project required a complete revision. The focus was now on the replacement of those two key partners (and also of a partner, who left the project within the first year), and the search for new partners who could assume the tasks and contributions (wind turbine hardware, transport services, etc.) of the partners who had left. During the entire third period, even in a suspended period from May 2013 to October 2014, intensive planning and negotiation work has been done by the HiPRWind partners to re-distribute work, budget and tasks.

The project was re-started in October 2014. The amended Work Plan / Consortium included three new Spanish industry partners and collaboration with Norway's national "research infrastructure" project on floating wind, FlexWT, with is led by HiPRWind partner NTNU and with which a Letter of Intent had been signed. A new installation site was identified off the coast of Norway, where continued use of the research platform would be possible even after the regular end of the HiPRWind project in 2017, thus guaranteeing continued access to the HiPRWind platform as well as R&D results originating from it.

The circumstances described above required a design review to guarantee safe use of the HiPRWind test floater for an extended test period at the new site in Norway. A detailed analysis of the time constraints and associated risks was performed by both the HiPRWind and FlexWT partners for an extended period until March 2015, including several meetings between the consortia. Unfortunately, in the end, both the FlexWT and the HiPRWind projects identified too high risks for the consortia to continue with the work.

Without having a floating wind turbine for testing purposes, a termination of the HiPRWind project was inevitable. In an extraordinary General Assembly Meeting, the HiPRWind Consortium decided to request the termination of the HiPRWind Project, which has been accepted by the by the Commission taking effect on 30 June 2015

1.3 Final results and potential impacts

As part of the above mentioned termination, the HiPRWind Consortium has extensively documented the results and valuable contributions that nevertheless have been produced in order to valorise as much as possible the public investment as well as the investment made by the partners.

Even though no floating turbine could be realised, individual results of the R&D work packages give a valuable compilation of the approaches used to address major challenges of floating wind turbines, e. g.:

1. A complete floater design including detailed technical drawings
2. A concept for the mooring and dynamic cable arrangement with first results of the loads exposed by waves and currents
3. Experiences applicable to the manufacturing of large floating platforms
4. Concepts for O&M protocols, H&S recommendations, etc. for a long term operation of a floating wind turbine
5. Design approaches for access systems to floating wind turbines
6. Concept and laboratory tested prototype of a frequency converter optimised for use in (floating) multi MW offshore wind turbines
7. Detailed concepts for load measurement and structural health monitoring on floating structures (floater as well as wind turbine) prepared for installation on the platform
8. Data acquisition system design and detailed measurement plans

9. Material testing results for new rotor design approaches for large blades
10. A draft of the consistency of costs and the efficient use of resources for the project and the associated bussines model

Several other demonstration initiatives have already made use of the HiPRWind results. Many of the achieved findings and results of the work are documented in several public deliverables, which are made available via the HiPRWind project web site (www.hiprwind.eu).

2 Floating Wind Turbine Concept

2.1 Floater Concept Design, Evaluation and Engineering

From the very beginning of the platform concept development, spreadsheet models have been established to take into account global dimensions, weights and preliminary dynamic behaviour of different floating platforms. The main specifications of the designated test wind turbine such as its mass, nacelle and rotor inertia, description of the moment on the structure caused by the electrical torque, forces and moments exerted by the wind under different operating conditions have also be considered. These first spread sheet models have allowed partners to evaluate more than 15 concepts. An evaluation matrix and screening have been proposed defining several evaluation factors like cost (divided into fabrication, material and deployment cost), sea-keeping, size, experience, safety aspect, installation requirements, risks and so on. Finally the semisubmersible concept was chosen according to this evaluation matrix (see Figure 1).

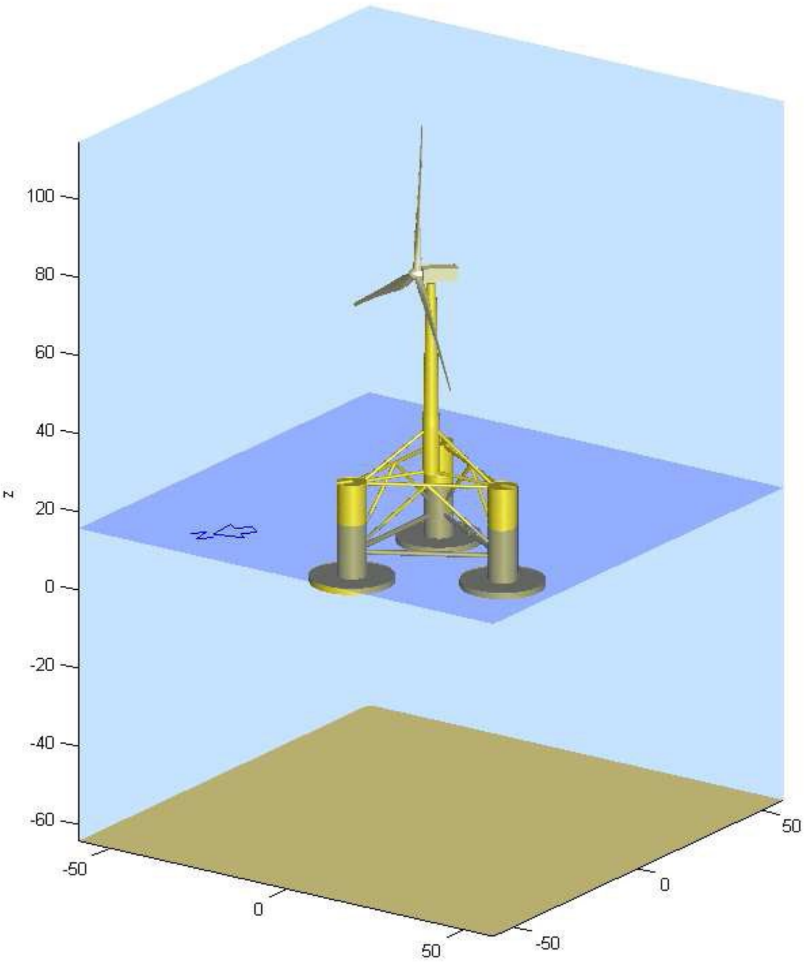

Figure 1: Final floater concept

Just after selection, the model has been established on a detailed spread sheet containing all variable design parameters. This first model has been used to calculate structural weights, hydrostatic characteristics and main dynamic properties as heave and pitch periods. This model has been used by all partners proposing improvements during the entire project. The model also includes systemized input data, which are automatically transferred to the preliminary hydrodynamic analysis model in an efficient way for design and optimization. Feedback from the hydrodynamic analyses has also been used to calibrate simplified dynamic response calculation in the spread sheet to further increase the efficiency of the optimization process.

An optimization study was performed by varying main geometrical input parameters and performing hydro dynamic response analyses for all parametric combinations. After the first optimization loop, global structural load analyses for design of the bracing system have been performed using a simplified structural model in WADAM. This work has been completed. Some partners have run these simulations in parallel to code-to-code validations. Separate hydro dynamic analyses have been performed for determination of extreme loads on the heave plates. These analyses have been verified by model testing in a wave tank. A methodology for the implementation of viscous damping of the heave plates was established.

The technical feasibility of the concept depends mainly on dynamic response and the effect this will have on energy production, turbine durability, tower fatigue and structural fatigue in the substructure in general. A challenge in this context has been to establish acceptance criteria both with respect to limitations of the design parameters and the dynamic response. Some of these acceptance criteria are related to maximum nacelle acceleration, maximum pitch angle, maximum excursions etc. A simplified CAD model has been established for illustrations and communication. The required degree of details in the CAD model has been considered in the course of the work. The Spread sheet model has been updated with weight estimates derived from the detailed CAD model and is accordingly very precise. An overview of the work flow for the concept design process is given in Figure 2.

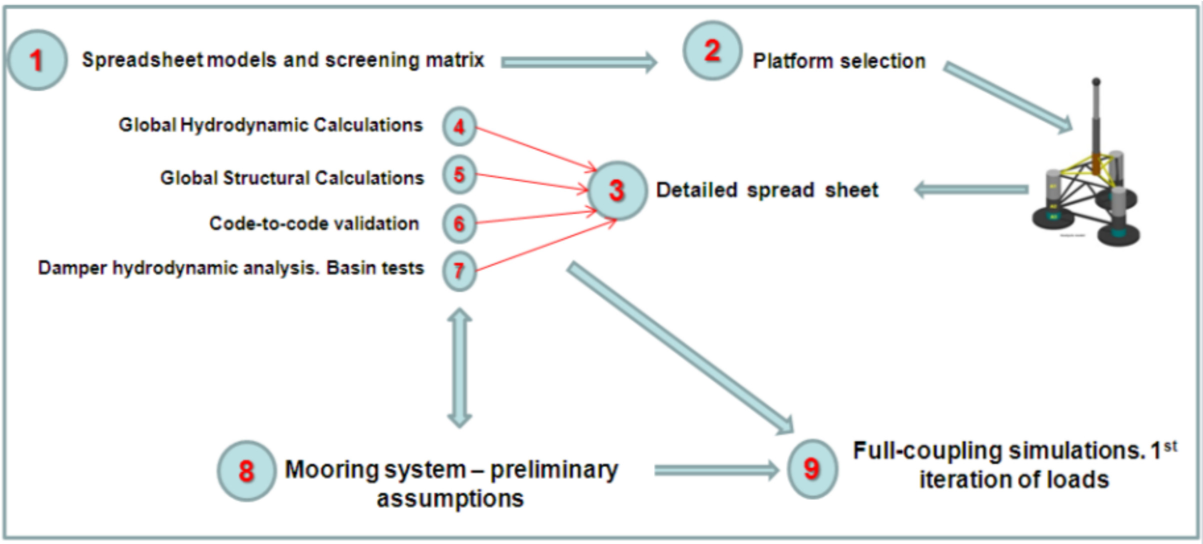

Figure 2: Schematic work flow of the concept design process

HiPRWind Deliverable 1.1. documents the conceptual design and describes the models, spreadsheet based tools and results used to develop and validate the design. More information about the floating wind turbine concept design can be found in public deliverables on the HiPRWind web site [1].

A full engineering design was completed and is documented in Deliverable 1.3. This report describes the final HiPRWind floater design in terms of:

- the structural design expanded to include relevant aspects from Met-ocean, Geophysical and Geotechnical conditions at the original site of deployment (Bimep),
- the Mooring, Transport, Sea-keeping and Stability,
- the Load-Out, Marine Operations, Turbine and Control analysis and their respective design implications.
- a fatigue analysis and the required testing of the welds of the structure to ensure the quality of the build was defined.
- the engineering design was then calculated and the construction drawings were created from the model.

2.2 Wind Turbine

The wind turbine model General Electric GE 1.5 has been selected to be installed at the HiPRWind floater. The use of this turbine required some “marinisation” modifications, which have been planned by project partner Ingeteam:

- **Electric component bottom arrangement:** transformer and associated switchgear should be emplaced outside the tower, while the control and power electronic cabinets should be maintained inside the tower structure; necessity of widening the diameter of the tower and the hatch dimensions.
- **Control of environmental conditions:** sensors, pressurization, special coating, sealants, modification of cooling system with filters and/or de-humidifier.
- **Floater access redundancy:** in some weather conditions it may be not possible to access the platform at a unique landing point, but may be possible if there were landing points at the three columns of the floater, or at least at two of them.
- **Lifting systems:** As jack-up vessels are unable to work in such water depths where floating wind turbines are expected to operate, more powerful cranes than usual will be needed both at the landing point in the floater and inside the nacelle, for a wider range of parts able to be installed/replaced.
- **Assembly basic procedure:** the most of the works & pre-commission must tasks be performed onshore. Assembly to be made at the deck and then towing the turbine on the floater into the sea.

Figure 3 visualises some of the above mentioned items.

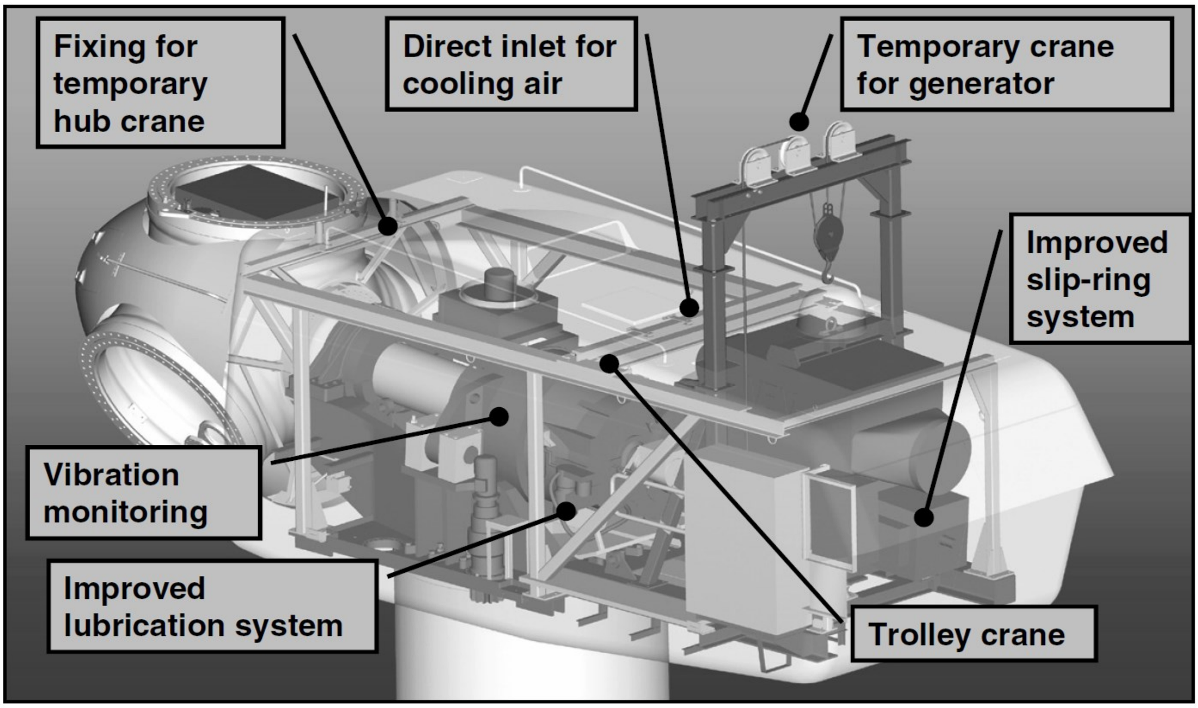

Figure 3: Some auxiliaries needed for "marinization" of a standard type wind turbine

2.3 Mooring arrangement and Anchor Design

Since the mooring arrangement and anchor design is strongly linked to a specific installation site, the following represents the status at project termination. This means that all information given are related to the original selected installation site of the HiPRWind floating wind turbine, the bimep test field at the coast of the Spanish Biscay (http://bimep.com). Nevertheless, the principle approach can be adapted to other sites as well.

Mooring Arrangement

As a basis for the dynamic response simulations performed with the floater model, a three line mooring arrangement has been selected as shown in Figure 4. Seabed conditions have been considered for the selection of the chain parameters as can be summarised as follows:

3 Mixed lines of 84 and 92 mm chain:

- Line A: 175,0m of 84mm + 380m of 92mm
- Line B: 172,5m of 84mm + 230m of 92mm
- Line C: 172,5m of 84mm + 380m of 92mm

Total chain weight: 250 tons

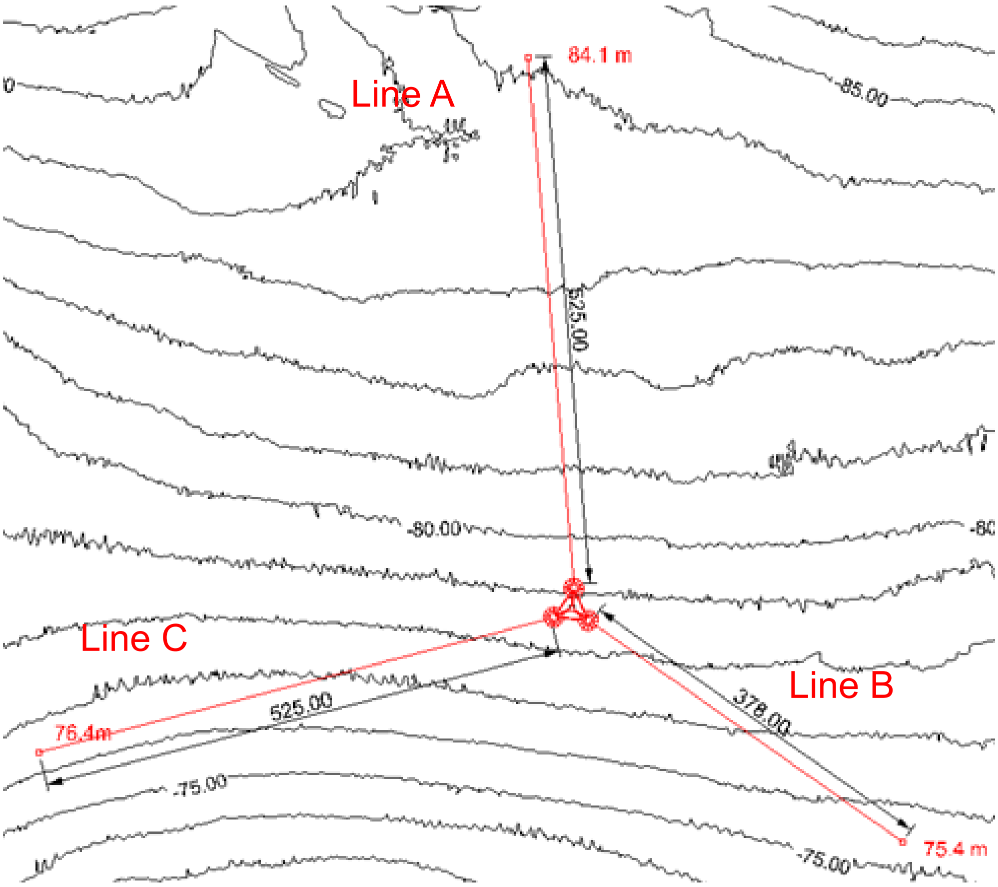

Figure 4: Proposed mooring arrangement for the bimep test site

Anchor design

The anchor design with the major parameters can be summarised as follows:

- Type of anchors: Drag embedment anchors
- Potential supplier: Vryhof (The Netherlands)
- Design to be done but based on MK5 Stevpris/Stevshark.
- Lines 1 & 3: 12 - ton anchors (5 m sediment thickness)
- Line 2: 18 - ton anchor (2/3 m sediment thickness)
- Manufacturing time: 8 weeks

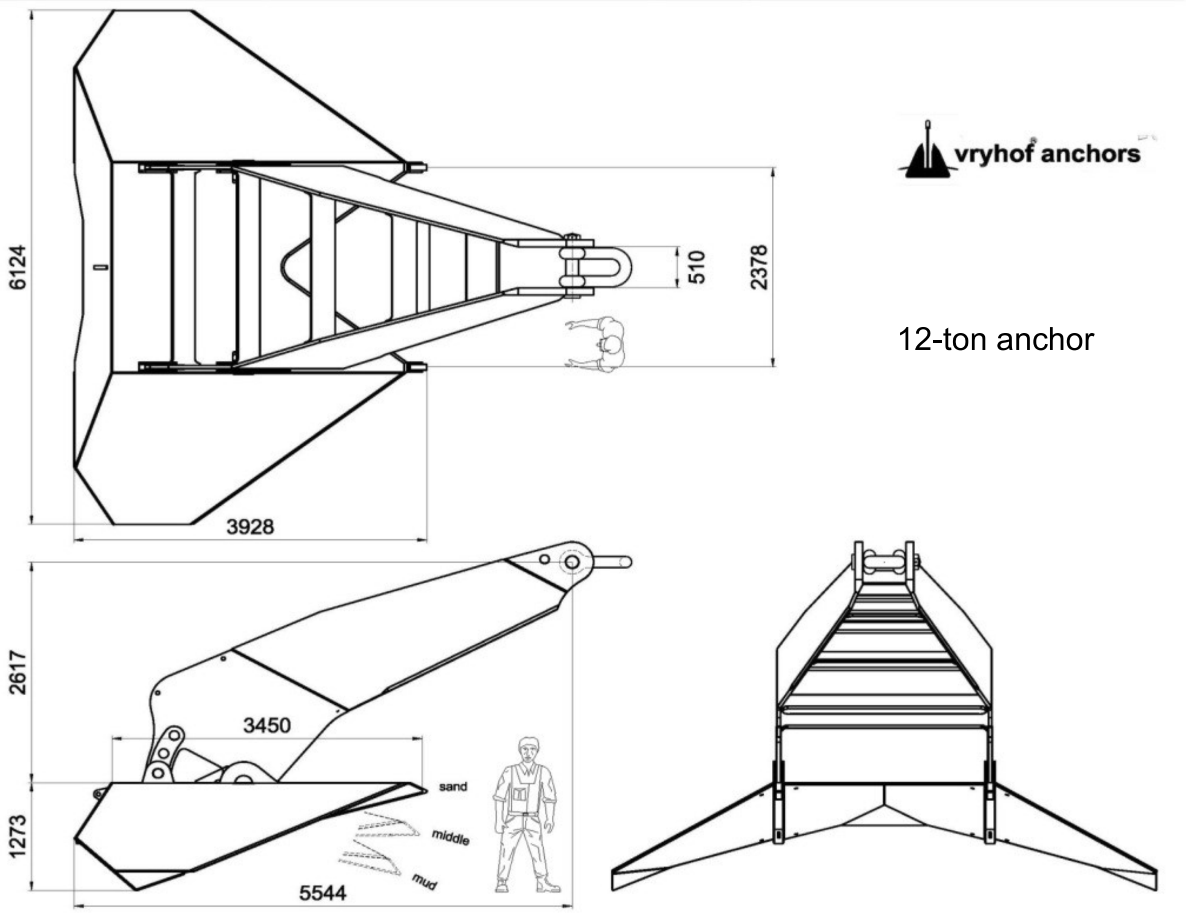

Figure 5: Proposed anchor design for the bimep test site

2.4 Aspects for integration into the electrical grid

With the introduction of floating wind turbines, the distance from the onshore connection point to the wind form collection point / converter station will be stretched more and more. This requires new power transmission approaches (e. g. HVDC). Figure 6 shows a typical scheme for the grid connection of far offshore wind farms, including also floating wind turbines. An example of a grid connection topology with multi-terminal HVDC transmission is shown in Figure 7.

All major aspects of offshore wind farms are discussed in detail in the HiPRWind public deliverable D5.2 “Report on deep offshore wind farm grid integration aspects including a case study”, to which here should be referred (see [1]).

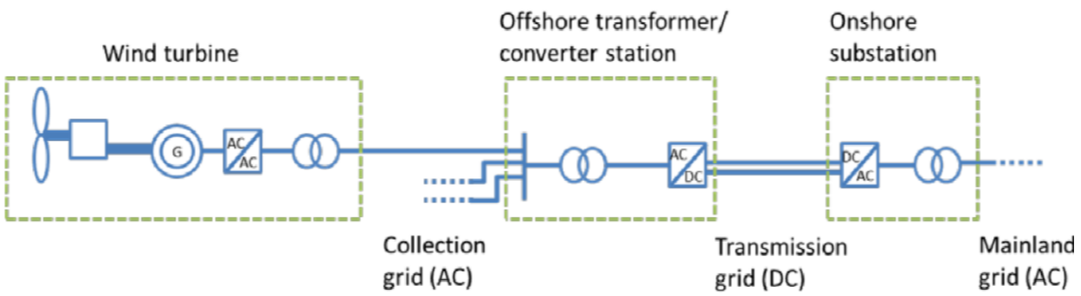

Figure 6: Grid connection scheme for far offshore wind farms

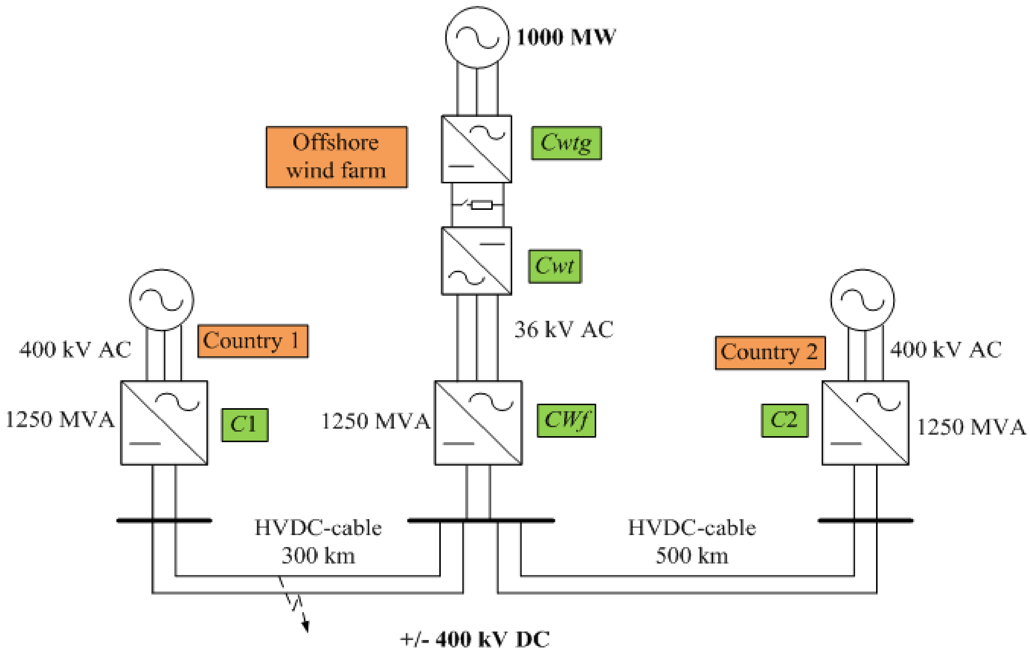

Figure 7: Wind Farm Grid Topology

3 Manufacturing of the HiPRWind Floater

The fabrication of the floating platform (buoyancy columns, braces and heave-compensation plates) had started at HiPRWInd partner IDESA's workshop according to a schedule that included assembly of the structure at the port of Aviles, Spain, during the summer 2013. The separate manufacturing of each part of the structure (floaters, heave-plates, braces, central tower, etc.) proceeded following this schedule. Just before suspension of the project in May 2013, the whole manufacturing process was 30% completed. Figure 8 shows some pre-assembled components.

Figure 8: Photographs of the inner columns at IDESA's facilities

In October 2014, the construction of the floating platform was restarted and a new planning was developed in order to meet the challenging deadlines included in the amended Document of Work. Due to the size of the HiPRWind structure, some parts of the platform had been stored in different places of Idesa´s facilities during the suspension period. So the first tasks after the re-start of the project were an in depth reconsideration of the manufacturing process and a complicated movement of heavy parts across the IDESA's workshops.

From October 2014 until the end of the period IDESA worked in parallel in the manufacturing of each main part of the structure. This approach complicates the logistic inside the workshop but it was the only way to meet the deadlines. The planning was to manufacture and paint each part of the structure at IDESA's facilities and then transport all of them to Aviles port (2 Km far from IDESA's work shop) where the final assembly would be performed next to the harbour bay. The construction could be completed up to approximately 50% till the decision was taken to terminate HiPRWind.

Figure 9: Images of the transport of large components (heave-plates) to the port of Avilés

4 Research on the HiPRWind Floating Turbine

The floating wind turbine to be developed in HiPRWind was meant to be used as a research platform, not only for the project partners itself, but for the European scientific community working on floating wind energy. Even if the turbine could not be constructed, the results in the HiPRWind project may be useful for future projects. In the following, some results of the work mentioned are described.

4.1 Structural Health Monitoring (SHM) System on the floating Wind Turbine

The most critical aspect of operation a floating wind turbine is the survivability of the entire structure under harsh sea conditions. Due to the movement of the floater under the influence of wind, waves and tidal currents, the wind turbines will be exposed to completely different structural load as when installed on solid ground. Therefore, an extensive structural health monitoring (SHM) system was supposed to be installed on the floating turbine. The system was designed and partly engineered. Figure 10 shows the type and position of the required sensor equipment.

The dimensions as well as the sea environment are setting strict requirements to the robustness of the sensors, cables, etc., to the electro-magnetic compatibility (EMC) and the resistance to salty air and humidity, lightning strikes, vibrations, etc.

The details of the SHM system is described in the HiPRWind deliverable D6.4 “Report on model based multimethod SHM for rotor blades”. Figure 10 below illustrates the sensor hardware designed for being installed on the platform

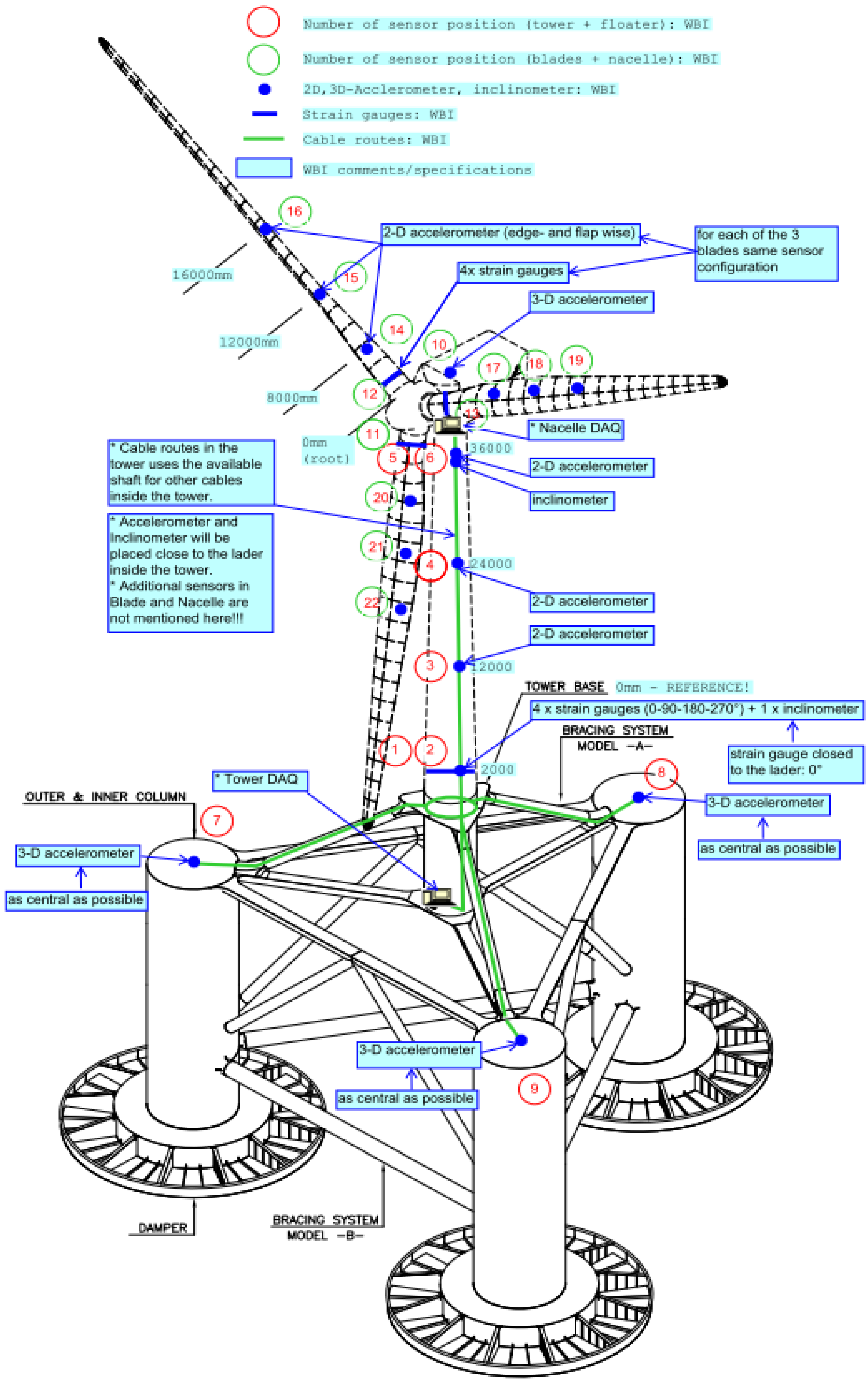

Figure 10: Sensor equipment for structural health monitoring (SHM)

4.2 Data Acquisition, Communication and Data base Concept

The definition of the data acquisition, data base and communication system remained valid even under the requirement to operate the floating platform at a different test site. The principle structure of the system is shown in the Figure 11 below.

One key issue of the data acquisition & communications system design was to have an exclusive path for the wind turbine's control system (Operating channel"), independent of the monitoring system path. This is important to guarantee the safe operation of the turbine even when a problem in the data acquisition communication may occur. In general, to minimise loss of data, a redundant channel using radio transmission, should be installed.

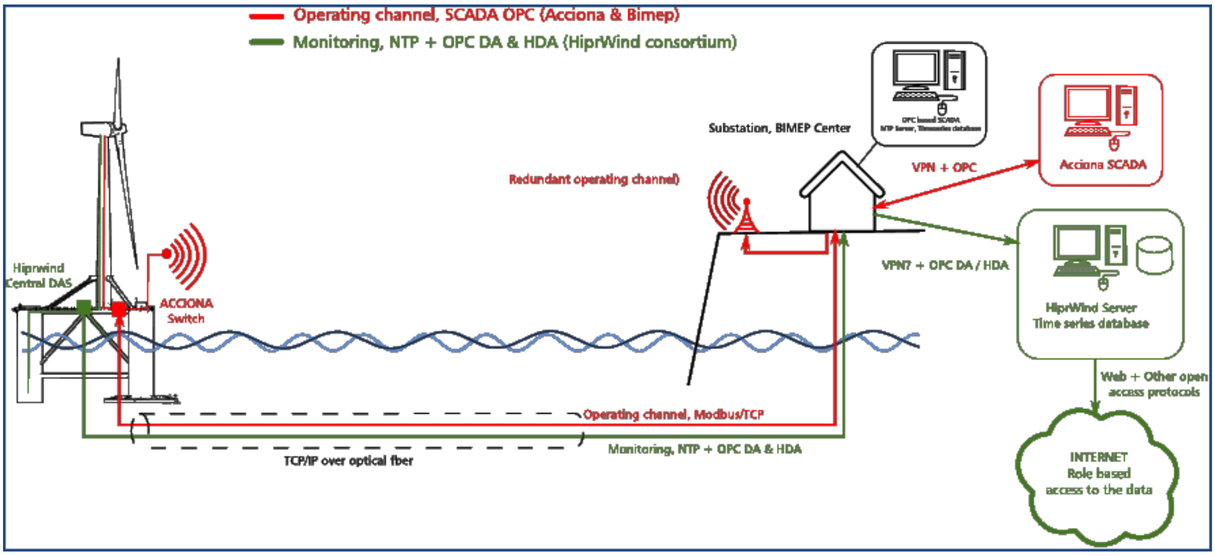

Figure 11: Structure of communication system

Detailed information to the above mentioned aspects of the data acquisition, storage and transfer can be found in the HiPRWind public deliverable report D3.3 "Database for data collection and communication system description" [1]

4.3 Platform Operation and Maintenance

The HiPRWind floating turbine would have required a comprehensive "Operation and Maintenance Protocol" if completed. Such a protocol has been defined in the public HiPRWind deliverable report D3.2, available on the public web site [1]. This report describes the proposed access hardware (boats, hatches, ladders, etc.) and procedures, incl. health & safety aspects. In addition, a tentative Cost analysis was implemented for the best identified solution.

5 Exploitation and Dissemination

HiPRWind has made significant achievements despite being unable to complete its platform and the research program it was designed for. Technical areas where exploitable project results have been achieved, are:

2. The platform design & engineering, which contains a number of technical innovations relative to the state-of-the-art in semi-submersible wind floaters. It allows reducing the amount of steel used by 40% compared to the original estimations. The design can be scaled to 5 and 10 MW and was fully engineered for the Bimep site. The platform was found to be transferable to the new intended site off the coast of Trøndelag (Norway).
3. The operational planning, including platform load-out, towing to the installation site, installation of mooring system, anchors and dynamic cable. The planning was almost fully completed for the original site (Bimep, off the Basque Country. Spain) and partly done for the Trøndelag site.
4. The multi-MW power converter. This has been fully developed in HiPRWind and is the basis for a next generation of products for large offshore turbines, being commercialised by ABB.
5. The floating turbine controller software, which has been defined, presented at a major industry conference and later published as a peer-reviewed article all within HiPRWind.
6. The study of grid stability of large VSC-HVDC connected GW-size offshore wind farms, which was fully developed and in a manner similar to item (4.) has been presented and subsequently published as a peer-reviewed paper.
7. The condition monitoring system, an SME-developed and IP-protected technology fully designed for the HiPRWind platform, featuring an unprecedented level of integration in the collection, analysis and interpretation of structural health data.
8. The Shared Data Access, a set of guidelines outlined in HiPRWind for offering access to field data without risking to compromise EU competitiveness, as might result from full public access that is open also to the competitors of European industry and R&D.

5.1 Heritage of the HiPRWind platform design & engineering

Positive impacts of HiPRWInd are already affecting other activities in European offshore wind R&D. HiPRWind partners are continuing to innovate and capitalising on the achievements of the project. Here we describe two examples of this "heritage", namely INFLOW and Nautilus.

The FP7 demonstration project INFLOW, focused on vertical axis floating turbines, started in June 2012. This €21.5m project was led by Technip, a HiPRWind consortium member. The design influence from the HiPRWind floater on the triangular semi-submersible carrying the INFLOW VAWT, is quite direct. Locating the powertrain and other heavy components at the tower base gives a favourable center of gravity compared to a conventional HAWT, resulting in numerous technical advantages for semi-submersible floaters in carrying a vertical axis turbine, if these would one day hit the market.

Tecnalia, also a HiPRWind consortium member, applies experience from HiPRWind in development of its floating platform NAUTILUS. A spin-off company, NAUTILUS Floating Solutions, is dedicated to the development of a floating platform for a 5MW wind turbine. This regional industrial venture is thereby benefiting from lessons learned and experience gained in HiPRWind. In particular, the experience has led to an optimized design of the NAUTILUS floater which has passed through several tank testing campaigns and verifications, and it has also been beneficial in clarifying the permission process for the demonstration at sea.

Outside of Europe, HiPRwind has had extensive interactions with Japanese floating wind developers in the Fukushima Forward consortium, including several bilateral and one EU meeting. Participants from Germany, Norway and Spain are focusing on Japan as a presumed early market for deep water wind solutions. While operational solutions for the Japanese projects are different, it is believed that the input from HiPRWind has been significant and will grow further, with expected substantial export opportunities in the years and decades to come.

5.2 Further steps to exploitation

The above two examples start from the design and engineering results in the HiPRWind Deliverables 1.1. and 1.3. Two further examples are in component-level innovations, in which power controllers for the offshore wind power sector is a fast growing market segment already worth billions of Euro per year whereas Structural Health Monitoring is a relatively newer market segment but also set to grow very large considering the potential cost savings in O&M.

To continue promoting exploitation of HiPRWind results, members of the HiPRWind consortium will continue to present information about HiPRWind and their role in it to industry and authorities, and to business partners with whom they are discussing new developments to establish new business in the emerging deepwater wind industry. As joint owners of the Foreground, HiPRWind partners enjoy full rights to use it. This is becoming more important as the interest in floating wind is rebounding.

Exploitation of the project results requires addressing the following five basic questions that each joint owner must consider based on their business model and priorities:

- What are the project results that can be exploited?
- Why? What is the aim of each partner’s individual exploitation effort?
- To whom? Which of our business partners are ideal partners? Together with these, we can identify target market(s), target groups and end users suitable for the exploitation.
- By whom? Are there project outcomes can be exploited by the Consortium as a whole, or by a smaller number of former HiPRWind participants working together?
- How? Which exploitation mechanisms are to be used for each type of exploitable result?

The ways and means of IP exploitation will necessarily have to be decided *ad* hoc in this situation. The HiPRWind participants have remained in collaboration until termination, are active in the same industry, and collaborating in many other funded projects, all of which bodes well for the future.

Consortium members will also integrate HiPRWind developments into their ongoing research, educational and commercial activities. The most important general considerations are:

- Economic impact resulting from industrial activity and commercialisation of products developed based on project results, future sales of derived products and/or services.
- Increase in development/operational efficiency for consortium members with regards to projects/operations deriving from HiPRWind to be developed in the future.
- Business allies/partners who can be helpful in exploitation: The Consortium Agreement allows full commercial use by HiPRWind participants of their jointly owned foreground.
- Use of new findings/technologies/innovations for further R&D and innovation.

5.3 Contribution to Certification and Standards

Whilst the platform was a one off R&D tool and not intended to be certified as such, the engineering was monitored by the certification company Bureau Veritas as a HiPRWind consortium partner. The HiPRWind work has informed a BV ”Guidance note on floating offshore wind turbines”, no. NI 572, published in 2011.

5.4 Dissemination of Results

The public web site www.hiprwind.eu has been kept updated throughout the duration of the project, including updates to the timeline, work scope and partner descriptions. Stories selected or written to give factual, constructive views of the HiPRWind progress towards achieving the goals were released. All public deliverables can be found under http://hiprwind.eu/?q=publications. The current planning is to keep the public web site alive for as long as possible after HiPRwind.

In addition to general information broadcast via the web site, the following dedicated dissemination materials have been published (these can also all be downloaded from www.hiprwind.eu):

- 8 conference presentations
- 2conference posters
- 4 scientific Journal Articles with review
- 7 presentations at meetings or events
  (including invited presentations and invitation only events)
- 5 industry or technical (but non specialist) magazine articles
- 3 general interest and mainstream press articles or similar coverage
- 3 other dissemination actions (brochures, flyers etc.)

6 Literature

[1] HiPRWind Public Deliverables http://www.hiprwind.eu/?q=publications

[2] Website Vryhof Anchors http://www.vryhof.com/