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COMMITTEE V.4

OFFSHORE RENEWABLE ENERGY

COMMITTEE MANDATE

Concern for load analysis and structural design of offshore renewable energy devices. Attention shall be given to the interaction between the load and structural response of fixed and floating installations, taking due consideration of the stochastic nature of the ocean environment.

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18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

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CONTENTS

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

1 DISCUSSION

1.1 Official Discussion by Finn Gunnar Nielsen

1.1.1 Introduction

Let me first congratulate the committee with an extensive and well written report. The development within offshore renewable energy is rapid, in particular within offshore wind. The report gives a very good overview of the latest developments in this area.

Last year IPCC issued the special report on Renewable Energy Sources and Climate Change Mitigation (IPCC, SRREN, Arvizu et al. 2011). Here Ocean Energy is defined as "...energy derived from technologies utilizing seawater as their motive power or harness the water's chemical or heat potential." The six distinct energy sources are by IPCC listed as: Wave energy, Tidal range (rise and fall), Tidal currents, Ocean currents, Ocean thermal energy conversion and Salinity gradients. Wind energy is treated as a separate source of renewable energy, including both on- and offshore wind turbines. From a technical point of view the differences in terminology between IPCC and ISSC should not be a problem, but may cause some confusion, in particular when discussing the energy potential. According to IPPC, SRREN 2011 Ocean energy and wind energy in 2008 contributed with 0.002% and 0.2% respectively to the global primary energy supply. (Coal, oil and gas contributed with about 85% of the primary energy supply). Despite these almost negligible contributions from ocean and wind energy, the estimates on technical potential show that wind energy alone can supply almost an order of magnitude more electricity than the present global demand. The estimates on the technical potential of electrical energy from near shore and shallow water offshore wind alone ranges from 15 EJ/year to 130 EJ/year as compared to the present (2008) global demand of electrical energy of 61 EJ/year. The estimates on the technical potential for ocean energy show an even wider span. This is mainly due to the immature status of the technologies. The estimates range from 7 EJ/year to 331 EJ/year. So independent of which estimates to rely upon it may be concluded that ocean energy and offshore wind may supply a very significant portion of the global electrical energy demand. To make this happen, however, the cost per produced kWh must be significantly reduced. Here the competence of the ISSC community can provide significant contributions. However, even if the ocean environment is the same for ships and offshore structures as for offshore renewable energy devices and the basic physics is the same; we have to rethink our approaches in design and computational methods.The committee has very well addressed some of these challenges, as will be commented upon in the following.

1.1.2 General

The committee has in the present report decided to focus on the status and challenges related to offshore wind as this technology presently is the most mature and of greatest commercial interest. I support this prioritizing as there still are several severe challenges to be addressed to make large scale deployment of offshore wind farms a commercial success. It could however be argued that there are even larger challenges related to the various ocean energies. Thus the research community should help finding the path forward towards commercial deployment of these technologies. Also, as e.g. is the case for wave power, there are very many proposed technologies. It is unlikely that all of these may have a future commercial potential. Based upon physical insight and engineering experience, the ISSC community could consider more actively help sorting out which technologies that have the potential for success, not only comment upon the technology applied for the proposed concepts.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

The committee has devoted much of the report to give an update on current activities with respect to concept developments, testing and analysis. This is useful, however, I would recommend that future reports puts more effort on the discussion of various challenges related to dynamic analysis and testing of the structures. If possible also specific recommendations should be provided.

1.1.3 Offshore Wind Turbines

The offshore wind market is still only a small fraction of the total wind energy market. Within EU only 4% of the installed wind power in 2011 was installed offshore (EWEA, 2012). In a global perspective this fraction is even lower. A key challenge is thus to secure that the special requirements related to the offshore environment are taken care of in the design of standardized wind turbine products. The special requirements relates to materials (salt and humid atmosphere), dynamic loading, reduced access opportunities (requires better reliability), installation as well as replacement of major components. These challenges are partly outside the mandate of the committee, but have certainly implications on the design of offshore wind turbines.

The offshore wind industry has developed from a land based industry, via very shallow water to increasing water depth. Thus the wind industry is following some of the same path as the oil industry went down about 60 years ago. The oil industry initially used jacket foundations, a very logical solution for shallow water, but the technology was extrapolated to deep water and, one may argue, beyond reasonable limits to more than 400 m water depth. This trend was broken by the introduction of floating platforms. We now see an extrapolation trend also in the offshore wind industry. The water depth limits for monopoles as well as jacket foundations are pushed.We must contribute with solutions that are optimum from a total cost perspective, i.e. construction, installation and operation. The committee addresses some of the design challenges related to the various substructures, but also point on the problem of limited experience with most of the newer designs.

Most offshore foundations, fixed or floating, are designed to carry an almost standard wind turbine tower.We must think of the complete support structure as one unit that shall carry the nacelle- rotor assembly, i.e. not only design a foundation that can be used as support for a standard tower. Such an integrated design approach will challenge the wind turbine and tower manufacturers.

With respect to the future size of turbines we now see a discouraging trend: The weight per MW is higher for the larger turbines than the smaller ones (Verhagen, 2011). This combined with higher nacelle level for large turbines challenges the design of offshore support structures. Thus we may see an increase in expenses for the support structures that may be greater than the benefit of using fewer units. One should also keep in mind that on a given area of an offshore wind park, the total installed power is approximately independent of the turbine size. This is under the assumption that the ratio between of the distance between turbines to the turbine diameter is constant.

Various alternative turbine concepts to the 3 bladed horizontal axes solutions are discussed. It would have been useful to address which challenges these solutions imply to the foundation design and analysis, e.g. the implications of the large dynamic variations in horizontal thrust that may be experienced by a vertical axis turbine.

In the discussion of costs of offshore wind turbines it is observed that generally the cost per ton of steel for the substructure is considerable higher than for the tower. It seems like here is a potential for significant cost reduction. The reasons are probably both related to design and market issues.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

Among the concepts discussed are the downwind turbines on a floating foundation. One of the basic ideas behind these concepts is the weather-vaning capability, i.e. a forced yaw control should not be needed. One should however be aware that the weather-vaning capabilities downwind turbines may be dubious.Neither is the turbine necessarily directional stable, nor does it always align with the wind direction, see e.g. Verelst and Larsen (2010), Corrigan and Viterna (1982).

The report does not discuss issues related to installation of offshore wind turbines. Present installation techniques are highly weather sensitive and costly. In the evaluation of concepts one has to consider the "as-installed" costs. The installation costs are highly dependent upon number of units considered. If very many similar structures are to be installed, special purpose installation vessels may be justified, thus reducing the marginal costs of the marine operations significantly. Maybe future reports should look more into the marine operation issues.

Analysis tools

As the committee states, there are several numerical codes available for analyzing offshore wind turbines. A trend is observed that the traditional wind power community have advanced turbine models on which they add simplified wave load models. Similar the offshore community makes simplified aerodynamic load models and couple them to the state of art wave load computer codes. Such simplified modeling of either the wind loads or the wave loads can be justified in some cases. However, if new concepts are to be studied, and new and maybe unexpected phenomena revealed, we should encourage the use of fully coupled aero-hydro-servo-elastic simulation tools, at least for verification of the more simplistic approaches.

Validation techniques

The committee refers several concepts that have been developed to various technical maturity levels and being tested. It is observed that testing of concepts may have several objectives and take place at various levels of concept maturity. We see testing at very small scales at an early idea stage, model testing with fairly advanced models and controlled environment as well as open sea tests at reduced or full scale. It would be useful to address these test options in more detail and discuss at which development stages the various tests are relevant, the challenges related to scaling, control of environment as well as the information that can be expected to be extracted from such testing.

The discussion of testing and validation should reflect the findings from numerical analysis of the concepts. E.g. if the wind forces are the most important forces to the dynamic response of a foundation, it has no meaning to make a combined wind and wave scale testing with great simplifications in the modeling of wind forces. Likewise for floaters that can be sensitive to negative damping induced by the turbine control algorithm, scale testing without this effect properly modeled will be of limited value or even misleading.Performing model scale tests, scale effects on the loads are always a concern and should be considered carefully. However, the advantage of model testing is the excellent control of the test conditions. Also model testing is well suited for testing extreme events rarely occurring in real life. Full scale tests on the other hand will reveal the "correct response" without scale effects. However, accurate assessment of the environmental conditions during the tests is always a major challenge, and one has to wait long for the extreme events to happen. The costs of full scale tests might be prohibitive.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

1.1.3.1 Details, fixed structures

For the fixed foundations there is a challenge related to assess the natural periods of the elastic bending modes. I particular the first bending mode is sensitive to the soil properties.One may raise the question if state of art methods both with respect to soil testing and implementation in integrated numerical models are sufficient to accurately represent the restoring, damping and inertia effects of the soil. Also the change of properties over time may be a challenge. These are areas where the experiences from the offshore oil and gas industry are important, but may be not sufficient.The committee's viewpoints of these issues are welcomed.

It is observed that for most engineering applications the beam element momentum (BEM) method is used for computing the aerodynamic loads. This method is well established, but relies heavily upon several correction factors, as the Glauert correction for large induction factors, Prandtl's tip loss correction, correction for skewed flow, and e.g. a Beddoes-Leishman type dynamic stall model. The various BEM implementations should thus not be expected always to give similar results for the aerodynamic loads. Frequently CFD computations based upon Navier-Stoke's equations are considered to be the alternative to the BEM method. However, it would be nice to hear the committee's viewpoint on other methods as e.g. vortex sheet methods. Such methods account directly for most of the effects added as corrections in the BEM approach and are much faster than most CFD methods.

With respect to hydrodynamic loading, most codes use a Morison equation approach. This is an approach with long tradition in the offshore oil and gas industry. Most oil and gas platforms are located in deeper water than wind turbines. Care should therefore be taken when using the same Morison equation approach to offshore wind turbines as for the offshore oil and gas platforms. Some of the important phenomena that should be considered carefully are:

- Effect of shallow water.
  - Steep waves, non-linear wave kinematics, more frequent breaking waves, intensified by interaction with strong ocean currents.
  - Non-linear loading, e.g. slamming.
- Small draft to wave height ratio.
  - Nonlinear wave loads due to variation in submerged volume, "water entry" effects.
- Large diameter structures (monopoles)
  - Diffraction effects may be important.

A more comprehensive discussion of these effects would be welcomed as the implementations of some of these effects in standard engineering tools seem to be very simplistic.

In the report the committee refers to Veldkamp and van der Tempel (2004) that concludes that linear wave kinematics with Wheeler stretching is sufficient for fatigue calculations. High and steep waves may contribute significantly to the fatigue damage. Based upon the results by Johannessen (2010) one may thus question if the simple use of Wheeler stretching is sufficient. Johannessen claims that to obtain correct estimates of the kinematics in the wave, one has to ensure that the spectrum used for the wave elevation contains linear components only.The velocity profile is obtained by including second order terms in the potential and an exponential profile above the mean free surface, and using a truncation criterion to exclude the contribution from the shortest waves. I assume that accurate modelling of the wave kinematic close to the free surface

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

is more important to the assessment of fatigue loading on wind turbine substructures than on most oil and gas platforms. Thus I support the committee's recommendation on more work on these issues, and in particular to implement the effect in integrated analysis tools. The statistical properties of the wave kinematics and loading must also be considered.

The use of response surfaces and contour line approaches are discussed to establish the ULS response for wind turbine. I agree on the warning the committee issues with respect to use of the contour line method for wind turbines. The method assumes that the most severe responses are to be expected along the contour of the most severe environmental conditions.Wind turbine maximum loads under operation occur at rated wind speed and the most severe structural wave loads may have significant contributions from resonant response, thus violating the inherent assumptions in the contour line approach. However, it would be worthwhile to investigate more carefully the applicability of this method for wind turbine design.

In the discussion of coupled versus decoupled fatigue analyses the committee seems to advocate the use of coupled time domain analyses. I support that recommendation. At the same time, quick, early phase engineering tools are always useful in concept screenings etc.A recommendation on how to use coupled or decoupled frequency domain analyses for such applications would be useful. In the coupled analyses the aerodynamic loads will contribute to damping of structural resonant response. But do we know if the most common implementations of the BEM model give correct damping estimates? This may be an important issue as the resonant response becomes more important in deeper water and higher waves.

The wind industry has used 10 minute simulation time as standard in their time domain analysis. When wave loads becomes important this is far too short to establish reliable extreme value estimates. The offshore oil and gas industry has typical used 3 hours simulations. Even this is too short when highly non-linear events control the extremes. More reliable procedures for extreme value estimates for combined wind and wave induced loads should therefore be an area for further investigation.

1.1.3.2 Details, floating structures

As mentioned in the report, most of the floating foundations suggested for the wind industry are well known from the offshore oil and gas industry.However, one should not underestimate the new challenges related to smaller sizes, need for mass production and low costs, and a very different load pattern. An example is the TLP design. An offshore oil and gas TLP has large deck area and are carrying large weights. The environmental loads are dominated by waves. The large horizontal distance between the tethers combined with the wave loads acting at a low level, results in relatively small dynamic variations in the tether loads. For TLP wind turbines the situation is different.Large static and dynamic wind loads are acting at nacelle level, causing large pitch moments. To counteract these moments the distance between the tethers should be as large as possible to avoid too large dynamic variation in tether tension. However, most TLP wind turbines have fairly small horizontal distance between the tethers. Thus the wind turbine TLP is a very different design than a TLP for oil production.Similar consideration can be made for the other concepts.

In the report, the wave induced heave response for different concepts is presented. One should rather present pitch/roll motion responses and accelerations as these are the quantities most important to the fatigue of the tower.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

As stated in the report, the longest natural periods for most floaters are much longer than the wave periods, in the order 25 seconds and more. At the same time the elastic modes have similar natural periods as for fixed structures. Thus the challenges related to time domain simulations, fatigue assessment and extreme value estimates mentioned above for fixed foundations becomes even larger for the floating structures.

The importance of coupled analyses was commented upon above. This is even more important for floaters. Here the interaction between e.g. nacelle motions and thrust forces, gyro effects, nonlinear restoring and damping forces due to mooring lines etc. all interact.

I miss a discussion of the applicability of the various floater concepts with respect to water depth. The draft of each structure obviously constitutes a limit. But the cost related to mooring in shallow water seems to be underestimated by many designers. The mooring system shall have both sufficient strength and compliance yet not being too expensive. Also the power off-take cables must have sufficient compliance. These factors may call for a certain minimum water depth depending upon the site specific wave climate.

1.1.4 Wave Energy

A nice update on the most recent activities within development and testing of wave energy devices is given. The overview demonstrates that still it seems to be a way to go before commercial scale wave power devices are deployed. Any convergence in technology, as for the wind turbines, has not yet taken place.

A lot of new ideas and inventions of wave energy devices have been presented during the last decades. Not all are based upon a firm theoretical insight in the basic principles for capturing wave energy. The book by Falnes (2002) and his review article (2007) are useful references where the basic principles are formulated.Falnes and Budal (1978) formulate the basic requirement to a wave power device: *"In order for an oscillating system to be a good wave absorber it should be a good wave generator".*

For most wave power devices it is not possible to distinguish between the power off-take system and the support structure. Thus, analysis to assess fatigue end extreme loads must also consider the power off-take. With respect to analysis of wave power devices, two critical issues seem to be important; handling of non-linear resonant response and inclusion of proper control algorithms. This calls for advanced non-linear analysis. The use of linear analysis may help in understanding the system properties and behavior, but can hardly provide exact estimates on power take-off or extreme loads. A more in-depth discussion of the applicability of the various numerical tools available and the most important effects to include in the computations would be welcomed. Similar the role of scale testing would deserve a thorough discussion as the design of tests obviously depends upon what purpose the tests is to serve, e.g. demonstration of principle,validation of computational tools, assessment of power off-take, extreme load estimation or optimization of geometry and control system.

A problem that frequently occurs is that each new wave power device requires modifications of existing computational tools or tailor made programs to be analysed. This makes evaluation of the concepts costly and time consuming. A module based computational system for analysing various basic systems for wave energy conversion would thus be very welcomed.

Testing wave power devices in small scales implies not only challenges related to hydrodynamic scale effects, but even more so challenges related to scaling of the power off-take system. The power off-take system should provide the correct system damping to be able to study the system performance.

In the description of the Penguin concept there seems to be a printing error.It does not capture the rotational energy, but converts wave energy into rotational motion, as most wave power devices attempt to do.

1.1.5 Tidal, Ocean Current and Ocean Thermal

The report gives a good review of various concepts for tidal current and ocean current energy conversion.The ultimate wish is to be able to utilize the energy in low speed currents at a reasonable cost. In the discussion of the new ideas that aim at solving this challenge, it would be useful to look upon the ideas in view of the basic principles, considering limits on available energy. From such considerations and rough estimates on the size of the structures involved, one may obtain a first impression of the proposed concept likelihood of success.As stated in the report, the resources are very site dependent. So will most of the support structures be. As a consequence the cost of energy will be very site dependent.

It is nice that the committee includes a discussion of ocean thermal energy converters in the report. They give a brief review of some of the conversion principles. However, I am missing a more thorough discussion of the load challenges, e.g. by deploying large diameter vertical pipes of several hundred meter length in an ocean environment with waves and current.

1.1.6 Summary and Conclusions

The committee summarizes very well the status and challenges within offshore renewable energy.

The basic principles for energy conversion are well known and several practical concepts exist. To make offshore renewable energy realized at a commercial scale, the cost of produced energy must be reduced. This must realized by combining increased efficiency, high reliability and low costs.

I will encourage future committees to, in addition to describe principles and concepts, also discuss how the various concepts address the fundamental challenges related to both energy conversion, support structures , analysis and testing. Thus the report could to a large extent provide a guideline for the professional community with respect to promising concepts as well as analytical and experimental challenges.

1.1.7 References

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18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

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1.2 Floor and Written Discussions

1.2.1 Ivan Ćatipović

Since the wind turbine blades are very flexible associated natural frequencies are low. Moreover, complete structure of fixed wind turbine also has low natural frequencies. This information can be found in ISSC (2012) Committee Report V.4, chapter 2.2.3 along with example form Jonkman et al. (2009). Mentioned author states that the lowest natural frequency of the tower plus the rotor is about 0.32 *Hz*, while the blade natural frequency ranges from 0.67 to 2.02 *Hz*. So, corresponding natural periods are: 3.1 *s* (tower plus rotor), from 0.5 to 1.5 *s*(blade).

According to API-RP-2A-LRFD (2003), in seismically active areas, fixed offshore structures are to be designed to resist earth ground motions. To describe ground acceleration amplitude API recommends normalized design spectra such as Figure 1 for use in structural design.

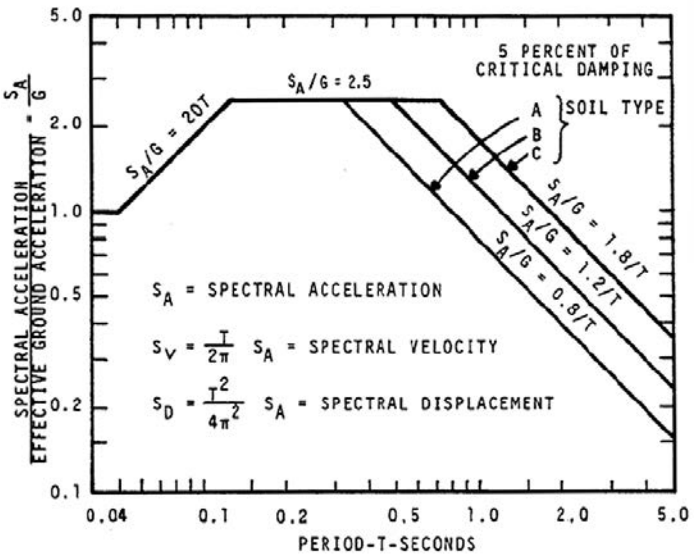

Figure 1: Normalized (response) spectral function of ground acceleration

As can be seen on Figure 1, natural periods of turbine blades (0.5-1.5 *s*) are partly overlapping with peak of spectral function of ground acceleration during earthquake. Also, natural period of the tower plus the rotor (3.1 *s*) is very near to the peak. Therefore, the occurrence of resonance can be expected. Part of this problem is low overall damping of fixed wind turbines; see ISSC (2012) Committee Report V.4, chapter 2.2.3.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

Since DNV (2011) in "Design of Offshore Wind Turbine Structures" considers earthquake as environmental load, this topic should be considered in the future work of the committee to fully cover design problems of fixed wind turbines.

1.2.2 Rachel Nicholls-Lee

1. During the presentation wave and tidal energy were said to be "less important" than wind. Surely this is very location specific as many countries have both environmental (national parks, protected areas etc.) and political problems with wind energy and cannot implement it. We are very interested in wave/tidal/river/current energy!

2. In the report, wave is said to be less important than wind due to the steady progression of wind from onshore to offshore. Surely this is not the main reason – the extreme environment WEC's operation is usually avoided by most industries and creates huge issues with regard to through-life-design and reliability!

3. Section 3.2.2 and 4.1.5 would be useful to reference the development of Marine Renewables Road maps. Recommended reference: Johnstone, C.M.; McConkes, T.; Bahaj, A.S., Myers, L.E.; Holmes, B.; Koefoed, J.P.; Bittencourt, C. (2011): "EquiMar: development of best practices for the engineering performance appraisal of wave and tidal energy converters". In the 9^{th} European Wave and Tidal Energy Conference, Southampton, UK, 5^{th} – 9^{th} Sept. 2011.

4. Comment was made in the conclusions regarding the prohibitively high CAPEX costs relating to installation of tidal energy devices. This is correct, however it is being addressed in the industry and academia currently with several TSB and EU projects funded to develop methods of installation and bespoke installation vessels.

5. While the tidal section was short, I feel it would be enhanced by mention of TGLs tripod, gravity base installation and also the quick and relatively quiet method used by MCT of pre-installation of pin piles.

6. Section 4.1.4: Environmental modeling of tidal flow and the effect of tidal turbines is being undertaken. There are several papers by Ross Vennell, Otago University, NZ, on the subject as well as Turnock at al. (University of Southampton).

1.2.3 Pengfei Liu

1. Informal update on organizational structure of *National Research Council Canada* (NRC) and *Institute of Ocean Technology* (NRC-IOT)

I am glad to see that IOT has been mentioned/acknowledged during the talks and several places during the presentation of the committee. However, since April 1, 2012, NRC-IOT does no longer exist. I felt that I should give an update on this.

1. NRC is undergoing a restructuring/reform: it has been changed from institutional-based to portfolio-based management. For example, NRC-IOT has combined with Canadian Hydraulic Centre (NRC-CHC) into *Ocean, Coastal and River Engineering Portfolio* (NRC-OCRE). NRC-IOT now is called NRC OCRE St. John's or NRC St. John's for short and IRC-CHC is called NRC OCRE M32 or NRC M32 for short.
2. NRC OCRE currently consists of several programs: Marine Vehicles, Marine Safety, Arctic, Marine Infrastructure, Inland Waterway Resources and Marine Renewable Energy.
3. Programs are not permanent: Current programs may be discontinued and new programs may be deployed.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

2. Questions to V.4, Offshore Renewable Energy Committee Report

Congratulations to the Committee for its excellent work and contribution to the renewable energy community.

1. Among the three technology areas waves, tidal and river hydro-kinetic energy systems, which one has been or will be the technology of highest priority (of course all three energy resources are assumed equally available)?
2. For renewable energy technology development, for these two aspects: 1) technology development and 2) project (site) development, which one should be given more effort, concentration or focus?
3. River turbine technology development was not seen to be discussed in the committee report. Is there any reason for this – is it out of the scope/mandate of the report, or is it not important enough to be considered/included? Canada is placing strong emphasis on the development of river turbine technologies – would you expect it to have a reasonable or a large global market opportunity?

1.2.4 Wim de Boom

The committee has reported from published research that costs of offshore wind have to come down considerably to make the industry survive.

At conferences several times statements have been made "if we do not half the cost of offshore wind this industry will be dead". The reality is that costs have shown an upward trend the last couple of years, rather than going down.

Has the committee, from reviewing many publications, got any feel for where the desired significant cost reduction could come from?

1.2.5 Spyros Hirdaris

From the presentations it becomes obvious that in this area technology is extremely important. My question is:What do you believe is the role and associated responsibilities of independent assurance bodies' with respect to the implementation and assurance of technologies in the area of offshore renewable systems?

Would the process be the same as for oil and gas? Do you see any dangers if the industry proceeds with self-certification? Do you see immediate scope in clustering technology providers/manufacturers class societies with detailed rule making or certification via implementing existing standards is adequate?

Congratulations for the presentations and the excellent report.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

The Committee appreciates Prof. Gunnar Neilsen's valuable contribution to this Specialist Report and in particular his broad and balanced perspective of the subject matter. The committee is obviously pleased with the general conclusions made. Prof. Gunnar Neilson adds a very valuable commentary on the relationship between IPCC and ISSC.

The main points of the Official Discussion as we see it and where we agree entirely are:

- That our report was correct to focus on Offshore Wind;
- That cost reduction is the primary driver for Offshore Renewable energy;
- There is a fundamental need to consider integrated solutions;

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

http://www.stg-online.org

- There is a pressing need for appropriate Standards and Guidance;
- Future committees should expand the mandate to include consideration of installation, access, inspection and repair in addition to describing principles and concepts.

Specific remarks made to the committee to be addressed are as follows:

Prof. Gunnar Neilsen'sstates that it would have been useful to address the challenges of Novel solutions e.g. VAWTs on foundation design and analysis. The view the committee took was that it needed to be careful not to inadvertently stray into areas which might be commercially sensitive and that the committee doesn't have the wherewithal to research ripple effects in two-bladed turbines and compare to three bladed configurations or to study HAWT versus VAWT for that matter. We reported as objectively as possible the peer reviewed literature concerning these concepts without conjecture. Having said this, there is a good point to be made here and that is that by taking a systems or integrated design approach including the turbine with the foundation as a single structural solution then the structural advantages or otherwise of certain configurations on the structure should become apparent;

That the report does not discuss issues related to installation of offshore wind turbines and making the observation that present installation techniques are highly weather sensitive and costly. We agree with the Official Discusser's observations in this regard and that installation might be dealt with by the new committee;

Prof. Gunnar Neilsen advocates a need for fully coupled aero-hydro-servo-elastic simulation tools to study new wind power concepts. The committee agrees particularly for the development of floating wind concepts however expresses caution in encouraging development of numerical and analytical tools in the absence of an empirical knowledgebase for verification and validation of these new tools. Dimensional similarity is very difficult if not impossible to achieve through model tests and once information starts to become available from field tests on large/full-scale devices then is the time to encourage refinement of such methods. The next point leads well from this;

The Official Discussion devotes significant time to discussing the merits and difficulties in full/large-Scale Testing. The committee agrees that not only is this important for the reasons expressed above (i.e. combined aero-hydroelastic aspects) but also for structural integrity purposes including the effects of corrosion, residual stresses and size effects on the fatigue performance of steel foundation structures;

The question is posed whether or not Soil-Structure interaction models developed for Oil & Gas are sufficient? The committee response is that they are not and that it is well documented the difficulties encountered in extrapolating small diameter pile models to those currently used in monopile wind foundations. The industry is exploring "heavyweight" monopiles up to nine metres in diameter and these certainly will require a new understanding of pile-soil interaction.

Prof. Gunnar Neilsenmakes the observation that in the report the wave induced heave response for different concepts is presented and explains that it is better to present pitch/roll motion responses and accelerations as these are the quantities most important to the fatigue of the tower. The committee agrees and included the Heave Figure for illustrative purposes.

Finally Prof. Gunnar Neilsen poses the question at what point do floating Wind Turbines become more economical and makes the observation that many academics and concept studies underestimate the cost of moorings in shallow water. The committee agrees that shallow water moorings can be complex and expensive. It would add that the depth of water is not the only parameter but also the size of the turbine needs to be significant to offset the size of the floater.

2.2 Reply to Floor and Written Discussions

2.2.1 Ivan Ćatipović

The committee thanks Dr. Ćatipović for his contribution and agrees that seismic effects need to be considered in certain parts of the world and that the new committee may see fit to investigate this further.

2.2.2 Rachel Nicholls-Lee

The committee is grateful to Dr. Nicholls-Lee for her comments. Taking these in turn:

1. It is not the view of the committee that Marine energy is less important than offshore wind but that at this time there is by far more economic activity and technical research and development work focused on Offshore Wind applications and therefore this needed to take priority and our report and presentation reflected this. The committee agrees that Marine Energy has enormous potential and is certainly site specific;
2. Again there was no suggestion that Wave Energy is less important than wind. The committee agrees that the manner in which wave energy is imparted to a WEC structure is in the main more severe than for Wind and Tidal and WECs subjected to impact loading need to be designed very carefully;
3. We agree this is an important reference and are grateful for its inclusion in these proceedings;
4. It is encouraging that these projects are underway to help reduce costs, certainly it should be possible to greatly reduce installation costs;
5. The committee is restricted to reporting peer reviewed publications and whereas members are aware of such developments we could not find any public domain objective publications to detail these concepts; ISSC must remain independent and the committee was careful not to be drawn into stating an opinion that might be used by one developer over another for commercial advantage;
6. Again this is a useful contribution to these proceedings.

2.2.3 Pengfei Liu

The committee is grateful to Dr. Liu for his update concerning the Canadian NRC and its former IOT. Responding in turn to the questions posed:

1. The committee would point to the discussion above with Dr. Nicholls-Lee and stress that each technology needs to be considered in detail given the local resources available. No one technology will always be better than another and the performance or otherwise will be site specific;
2. Again this is an interesting question and one without a definitive answer. Many island and distributed communities would be quite happy with a 1 - 2 MW single turbine and therefore an appropriate technology will be the primary focus; for large arrays (or parks) generating several hundred megawatts or greater, then site development and array design becomes more important than the component turbine technologies;
3. River Turbines like Hydroelectric Power is important but deemed to fall outside the mandate of ISSC.

2.2.4 Wim de Boom

The committee thanks Mr. de Boom for his insightful question. The Committee believes that so far despite the growth in Offshore Wind the sector has not yet benefited from the economies of scale largely due to the fact that an offshore wind turbine is still manufactured and installed in the same way be it a single installation or part of a wind array. The cost reduction must come from greater automation in manufacturing and special purpose installation vessels that allow installation without competing with Oil & Gas and other users of the sea.

2.2.5 Spyros Hirdaris

Dr. Hirdaris poses a number of very important questions concerning the roles of Classification Authorities in this developing sector. We believe the role and associated responsibilities of independent assurance bodies' with respect to the implementation and assurance of technologies in the area of offshore renewable systems is one of partnership with the developers. No one has been here before and all of us are learning as we research and develop such technologies. It is important for developers and their investors to appreciate this and not to expect independent assurance bodies to be able to provide cost-efficient solutions to new technological solutions but to provide a guiding framework to allow the design and testing of new systems in a safe in manageable manner. We expect the process to be largely the same as for Oil & Gas however the risks of unmanned installations are far less and should allow for a greater tolerance of adventure. Risks associated with self-certification would be to fragment the healthy friendly criticism that often exists between developers and certification bodies and developers would stand to lose access to the immense body of knowledge available through these relationships. It certainly makes sense to cluster technology providers/manufacturers and class societies with detailed rule-making as incremental development of implementing existing standards brings with it baggage that may not be appropriate for this industry.

2.3 References

API (2003). API-RP-2A-LRFD: Planning, Designing and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design. American Petroleum Institute.

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