Development of Marine Renewable Energy in the South West of England: The Wave Hub and PRIMaRE

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Abstract

The UK Government has committed to cut the UK's emissions of carbon dioxide by 20% below 1990 levels by 2010 and to increase the amount of electricity produced by renewable energy sources to 10% by 2010 and 15% by 2015. Wave and tidal energy are recognised as key renewable energy technologies for the UK, and the South West region in particular has the potential to generate substantial amounts of renewable energy from its wave and tidal stream resources. In recognition of the potential for the industry in the region, the South West of England Regional Development Agency (SWRDA) is supporting demonstration projects in marine energy through the Wave Hub project and PRIMaRE, the Peninsular Research Institute in Marine Renewable Energy.

Keywords: Marine renewable energy, Wave Hub, Wave energy array demonstration project.

1 The Wave Hub Project

The Wave Hub concept is to build an electrical grid connection point approximately 12 miles off Hayle in Cornwall into which arrays of wave energy devices would be connected [1]. The aim is to speed up the commercialisation of wave energy converters by reducing the risk for developers of the first pre-commercial wave machine arrays. Wave Hub will facilitate this by providing a well-defined and monitored site with electrical connection to the onshore electricity grid. The project received consent from the Department for Business, Enterprise & Regulatory Reform (BERR) and the Department for Environment, Food and Rural Affairs (DEFRA) in September 2007 and is scheduled to be commissioned in 2010.

Four developers are preparing for deployment at the Wave Hub: Ocean Prospect / E.ON are planning to install seven P750 Pelamis machines [2], each rated at 750kW; Ocean Power Technologies Inc. are planning a 5MW array of Powerbuoys [3]; Fred Olsen Ltd. plan to deploy three of their Buldra WECs [4], in which buoys oscillate in heave under a floating platform; and Orecon plan to deploy MRC multi-column oscillating water column devices [5].

2. PRIMaRE

The University of Plymouth and the University of Exeter are joint partners in the Peninsula Research Institute for Marine Renewable Energy (PRIMaRE) [6] which has been developed to meet the immediate needs of the emerging marine renewable energy sector in the South West, particularly associated with Wave Hub, and to address the wider considerations for marine renewable energy globally. The scope of the Wave Hub PRIMaRE research will span inter-linked challenges, such as device optimisation and mooring systems, characterisation of the wave energy resource, wave-current interaction, environmental impacts on marine biodiversity, impacts on the shoreline, beaches and wave climate, collision avoidance, and socio-economic considerations. The research methodologies will encompass field monitoring and testing, laboratory testing, the development of numerical models for predictive analysis and design and for improving survivability and performance of existing wave energy converters. The Wave Hub and associated research will be a unique demonstration project for the marine renewable sector and the knowledge gained will help to accelerate commercialisation of future wave farms. PRIMaRE's initial research strategy is to focus activity in support of the Wave Hub development in order to ensure that the SWRDA, local, regional and national Government and commercial stakeholders involved in

Wave Hub can be furnished with appropriate research data to inform future decision making.

3. Research Priority Areas

3.1 Marine Energy Resource Characterisation

Although measurement and numerical procedures have been applied to the determination of available resource, there still exists considerable debate on their application to understanding site specific resource. Of particular interest is the trade-off between point measurements, those produced by spatial average and estimates determined from numerical wave models. The classical method for wave monitoring is through the deployment of wave buoys and bottom mounted ADCP sensors, which provide single point measurements of the ocean directional wave spectra. These will be deployed around the Wave Hub site to aid understanding of the effect that spatial variations can make on energy conversion. These point measurements will be complemented by high frequency (HF) radar measurement techniques [7], which would enable the temporal and spatial distribution of waves surrounding the installation to be investigated. With the deployment of both single point and HF radar measuring devices at Wave Hub, PRIMaRE has the opportunity to examine the spatial characteristics of these measurements and to validate a convenient remote wave monitoring technique. The ADCPs will also provide current measurements through the water column at the Wave Hub site and some adjacent areas. These will be useful to device developers when considering mooring arrangements and provide inputs to wave-current interaction studies.

Measurement of the wave climate through wave buoys, ADCPs and HF radar will be further complemented by numerical modelling. The aim is to improve current numerical models, through comparison with measurements, and to develop models to provide a predictive capacity for the site. Nested wave models will be used to improve site specific wave climate assessment, to investigate wave farm effects on the wave climate and to investigate the downstream impacts of the wave farm on adjacent beaches [8]. The numerical wave modelling will provide a characterisation of the wave climate in terms of the probabilities of occurrence of different wave height, period and direction combinations. The models will also allow prediction of the wave climate and coastal impacts of a wave farm under various climate change scenarios.

3.2 Marine Operations

The current predictions of the high cost of offshore wave energy conversion compared with conventional methods for electricity generation and even other renewable sources [9] is partly due to the high cost of operations offshore. The survivability of devices in storm conditions is particularly challenging. The device may be de-tuned or decoupled to protect the power take off system, but nevertheless the mooring system must hold the structure in place in all weather conditions including extreme storms.

Furthermore, the dynamic response of some wave energy converters, WECs, in waves is significantly different from traditional offshore structures. This is mainly due to the fact that WEC structures have typically small length scales relative to the wavelength, whilst offshore oil and gas structures are relatively large in comparison with the wavelength. As a result, the top-end responses due to hydrodynamic loadings and their influence on the coupled system of structure and mooring system will be different for WECs from those for offshore oil and gas installations. In the case of a coupled moored system with non-linear mooring response, the behaviour of the mooring system itself can actively contribute to the dynamic motion characteristics of the top-end structure, contributing to peak loadings and large accelerations. The importance of the mooring contribution to a coupled moored WEC device is discussed by Johanning and Smith [10, 11, 12], who indicate the importance of peak line tensions associated with mooring line stiffness and damping. The operation of a device at close to peak wave loading is also a critical issue in determining design for survivability.

PRIMaRE research investigating the survivability of WECs and their mooring systems in extreme conditions as well as under normal production conditions encompasses numerical modelling, wave tank experiments and field tests. Numerical modelling for design of mooring systems and laboratory scale experiments to verify design loadings under controlled conditions are essential components of the mooring design process. Sophisticated numerical models [13, 14] are being developed to simulate the nonlinear coupled dynamic response of WEC and mooring system under the combined effects of waves, current and wind. These models incorporate high resolution free surface capturing and two-fluid flow simulation and the wave inlet boundary condition will be informed by the numerical wave prediction and monitoring.

A field site for testing moorings at half scale (referenced to the wave climate at the Wave Hub) is being established by PRIMaRE in order to assess and evaluate different mooring systems [15]. A buoy and mooring system will be fully instrumented to record the environmental climate (waves, wind, current), buoy response (six degrees of freedom) and loading on the mooring lines. The device and mooring response will be referenced to sea condition using two ADCP units to measure wave and current simultaneously. This facility is internationally unique and will provide accurate information on mooring line response under realistic conditions of wave, current and wind. These different research strands will be fully integrated by cross comparison of the numerical, wave tank and field test data and findings will be compared with traditional design methods for moorings in order to draw out

recommendations and guidelines for WEC mooring system design.

One aspect of WEC operation is tuning of the device, in which the dynamic characteristics of the WEC are matched to the prevailing sea conditions. Within PRIMaRE, the new subject of deterministic sea wave prediction [16, 17], which uses quiescent period prediction is being investigated. As with tuning, if deterministically predicted short term wave shape estimates are used to control shutdown on a wave by wave basis it is possible to obtain improvements in mean WEC output safely by many tens of percent [18, 19, 20].

Possible danger to shipping is an important consideration for planning of offshore renewable energy installations. Due to the near invisibility of some WEC designs to mariners, there is concern over the potential marine hazard introduced by wave farms. Work is being undertaken to examine risks to safe surface navigation in the vicinity of the Wave Hub. This includes the development of navigation scenarios to investigate the risks identified and the effectiveness of existing mitigation methodologies under development. As part of this, ship to structure collision risks and their mitigation and the factors affecting safe navigation in the vicinity where wave energy devices are deployed is under investigation.

3.3 Underwater and Surface Electrical Systems

Quite apart from the difficult issue of energy conversion and power take off system for an individual device, when installed as an array, the complexity of underwater electrical connections and compatibility of generation from different WECs needs to be considered. At the Wave Hub an underwater interconnector is connected through transformers to arrays of four different WEC devices. Research is underway to understand and investigate problems that may occur arising from the different electrical characteristics of each device and also to take into account the possibly intermittent nature of the power produced from each berth. Problems might occur in transient and dynamic stability and power quality, and these effects would feed through onto the power generated and delivered into the grid. In this research, new techniques for power conditioning are investigated that can overcome problems arising from faults within devices and sudden changes to their properties.

3.4 Legal Regimes and Socio-Economic Factors

The creation and operation of the Wave Hub as a demonstration project offers an unprecedented opportunity for investigation of the implications of marine renewable energy to the socio-economic systems of the UK in general and those around the South West region in particular. The introduction of the Wave Hub aims to produce benefits at the national and local levels in terms of environmental protection, security of energy supply, as well as job creation and infrastructure renewal. However, these positive impacts must be weighed against possible negative impacts of the project in terms of socio-economic and environmental impact on land and at sea and the potential limitations these place on the establishment and development of large-scale marine renewable energy projects.

A large infrastructural development like the Wave Hub presents a number of challenges on the existing economic, social, natural and cultural heritage of host areas. Conflicts are likely to emerge in the marine environment between different activities, users and purposes governed by a patchwork of common and private property rights, as well as customary and statutory rules and regulations. Essential sea uses other than energy generation must be accommodated within the concept of integrated coastal management. Also, maritime traffic in the vicinity of the Wave Hub must be recognized as an issue of significant concern. Safety, security and environmental protection measures must be designed pursuant to policy development taking account of legal and socio-economic perspectives. To address these issues, PRIMaRE research is being developed in four interrelated areas to ensure a holistic assessment of the Wave Hub. These are: the legal regimes, socio-economic sustainability, cost-benefit analysis and planning.

3.5 Environmental Impact

The environmental impact assessment is an essential feature of the planning process necessary for marine renewable energy installations. Benefiting from its involvement with the Wave Hub project at an early stage, PRIMaRE has a unique opportunity to perform thorough monitoring of marine biodiversity and physical changes at the site, before, during and after installation. The aim of this work is to gain a detailed understanding of key components of the marine ecosystem and physical processes at the wave energy test site and to assess its impact on these components; these impacts may be potentially either positive or negative.

Defining the baseline over a period of at least one year prior to construction is a vital aspect of this work and combined with regular longer-term monitoring and observation, this will allow the immediate effects during the construction and deployment phase to be investigated as well as the subsequent impact once the Wave Hub is up and running. Commercial wave farms will need to operate within a ‘marine safety zone', which will function as a *de facto* marine protected area (MPA), so part of this work will investigate whether this exclusion of other activity, such as fishing, acts as an MPA in providing refuge for commercial fishery species and increases marine biodiversity on the sea bed. Similarly, suitably engineered structures may provide valuable marine habitat if biodiversity enhancement is considered at the design stage [21].

Field measurement in the coastal area surrounding the Wave Hub site is underway to measure and assess any significant wave attenuation and changes in sedimentation attributable to the Wave Hub. The research team will monitor changes in coastal bathymetry, beach topography and beach state at key sites throughout the Wave Hub commissioning and operational phases. This field study will help to quantify the impact of Wave Hub, if any, on surfing and general recreational use of the beaches. Further measurements will be taken in the lee of the Wave Hub to identify and quantify the impact of energy extraction on the water column structure. This is likely to reduce the amount of turbulence near the sea surface and lead to a greater degree of vertical stratification, which has implications both for the physical environment and for the biological community.

4. Business Engagement

It is hoped that the Wave Hub will act as a catalyst and mechanism for development of the marine renewable energy and supply chain industry in the South West. The SWRDA are charged with raising the economic activity of the region and a second strategic aim is the development of a sustainable, low carbon community. The provision of renewable energy sources is a prime method of achieving this aim and the establishment of local expertise in the implementation or servicing this technology can achieve the aim of economic regeneration.

The region clearly has significant opportunities for the development of marine renewable energy, particularly wave energy, and provision of the Wave Hub subsea electrical connection will deliver a facility capable of attracting world-leading technologies to the South West. However this in itself may lead to relatively low level opportunities for the region in support of the device deployment and operational servicing of devices. To maximise opportunities for the region, an associated research activity was proposed, which would support the high level technical skills of the region and act as a generator of ideas and associated intellectual property. Further, the association with a higher education Institution would also provide opportunities for skills development and the generation of spin-out companies within the region.

PRIMaRE was developed to generate research output and knowledge in the area of marine renewables and to engage with commercial businesses and support development of the marine renewables and supply chain industry within the South West of England. The South West has considerable experience in marine construction and servicing, leading expertise in construction and manufacture and a number of very strong consultancies both in the marine and renewable energy industries. A challenge for Wave Hub and PRIMaRE is how to inform these diverse constituents as to the nature of the marine renewable challenge and opportunities and how to determine the degree to which they wish to and can become involved.

During the initial phase of its development, PRIMaRE has held Marine Renewable Energy Symposia, Business Information Days and Research Meetings to which local marine renewable energy and associated industries are invited. These events publicise the work of PRIMaRE within the business communities and enable research collaborations and collaborative relationships to be established. Implementation of the knowledge transfer strategy requires a highly proactive approach on the part of the institutional partners in the engagement of businesses. To support this aim, PRIMaRE will appoint knowledge transfer development staff in 2009 for a three year period to build capacity and expertise in this sector. The partner institutions knowledge transfer support infrastructure will provide additional and valuable support for PRIMaRE.

5. Conclusions

The Wave Hub will provide a significant opportunity to study the performance of devices deployed in wave farms. It will also provide an opportunity to observe and understand the cumulative environmental impact of multiple device deployment. Wave Hub will provide a test bed for impacts and planning issues particularly related to wave farm development and is ideally situated for this purpose on the north Cornish coast, which has as wide a range of stakeholders as any other potential marine energy location.

Through its association with Wave Hub, PRIMaRE has the unique benefit of relevant stakeholder involvement at all stages of the research including early scoping, thus ensuring its relevance and value to beneficiaries. PRIMaRE will take advantage of the potential for applied and pure research offered by Wave Hub. These will range from technology specific research to more broad-based environmental and socio-economic aspects that must be addressed. A full range of impact studies will be undertaken including base line surveys which are comprehensive both in time and spatial extent. These pioneering studies will without doubt form exemplars for other developments to follow. The programme of knowledge transfer, business engagement and engineering and environmental research support for the marine renewables and associated industry in the South West will benefit the region. The Wave Hub and associated research backed by stakeholder engagement will be an excellent demonstration project for the marine renewable sector and it is hoped that the knowledge gained will help to accelerate commercialisation of future wave farms in Europe and internationally.

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References

[1] http://www.wavehub.co.uk (accessed 07/04/09)

[2] http://www.pelamiswave.com (accessed 07/04/09)

[3] Ocean Power Technologies, Inc. http://www.oceanpowertechnologies.com/index.htm (accessed 07/04/09)

[4] http://www.orecon.com (accessed 07/04/09)

[5] http://www.fredolsen-renewables.com (accessed 07/04/09)

[6] http://www.primare.org (accessed 07/04/09)

[7] Wyatt, L.R., Thompson, S.P. and Burton, R.R. Evaluation of high frequency radar wave measurement, *Coastal Engineering* **37**, Issues 3-4, 259-282, (1999).

[8] D Millar, H C M Smith & D E Reeve: 'Modelling Studies of the Sensitivity of the Shoreline Wave Climate to the Proposed Wave Farm Development off the North Coast of Cornwall', Ocean Engineering, Vol 34 (5-6), p884-901, 2007.

[9] Parsons Brinkerhof Summary Report Powering the Nation March 2006 www.**pb**world.co.uk

[10] Johanning L., and Smith G.H.; Improved measurement technologies for floating WEC mooring arrangements, Int. Journal of the Society for Underwater Technology, special issue(OISI), Vol.27 (No.4), 2008, p.175-184

[11] Johanning L., and Smith G.H.; Station keeping study for WEC devices including compliant chain, compliant hybrid and taut arrangements, 27th Int. Conference on Offshore Mechanics and Arctic Engineering (OMAE), No. OMAE2006-57184, 15.-20.06.2008, Estoril, Portugal

[12] Johanning L.**,** Smith, G.H. and Wolfram J. "Measurements of static and dynamic mooring line damping and their importance for floating WEC devices" Ocean Engineering 1918–1934, Volume 34, 2007.

[13] Greaves, D.M. Simulation of viscous water column collapse using adapting hierarchical grids. *International Journal for Numerical Methods in Fluids* **50**, 693-711, (2005).

[14] Zhang, Y., Zou, Q., and Greaves, D.M. (2008) Numerical simulation of two phase flow using the level set method with global mass correction, submitted to *International Journal for Numerical Methods in Fluids*.

[15] Johanning L., Spargo, A.W., Parish, D; Large scale mooring test facility: A technical note, 2nd Int. conference on Ocean Eneergy 2008 (ICOE 2008), 15th to 17th October 2008, Brest , France

[16] E.L. Morris, H.K. Zienkiewicz, M.M.A. Purzanjani , J.O. Flower and M.R. Belmont.Techniques for Sea State Prediction. 2nd. Int. Conf. on Maneuvering and Control of Marine Craft, Southampton, pp 547-571, July 1992.

[17] M.M.A. Purzanjani, M.R. Belmont, H.K. Zienkiewicz and E.L. Morris.Applications of a Sea-Surface Estimator in Predictive Ship Control.2nd. Int. Conf., on Maneuvering and Control of Marine Craft, Southampton, pp 581-591, July 1992.

[18] E.L.Morris, H.K.Zienkiewicz and M.R.Belmont. Short term Forecasting of the Sea Surface Shape. Int. J. Shipbld. Prog. Vol. 45, No. 444, 381-400,1998.

[19] Korde U.A. Control System Applications in Wave Energy Conversion. Oceans Conference 2000. Proc.3, pp 1817-1824, 2000.

[20] Smith, G.H. and Venugopal, V. "A Generic Method for Determining WEC Power Conversion from a Random Sea 16th International Offshore and Polar Engineering Conference (ISOPE) 2006, San Francisco.

[21] Langhamer and Wilhelmsson, D. "Wave power devices as artificial reefs", Proceedings of the 7th European Wave and Tidal Energy Conference, 11 – 13 September 2007, Porto, Portugal.