WP 4 – Performance Monitoring of Ocean Energy Systems

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DHI Water & Environment, DK

The Robert Gordon University, UK

Lancaster University, UK

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1. Introduction

As it is known the main objectives of the co-ordination action on Ocean Energy are "to develop of a common knowledge base necessary for coherent development R & D policies", "taking a coordinated approach within key areas of ocean research and development" and "to provide a forum for the longer term marketing of promising research deliverables".

To help to attain these objectives five workshops:

- Modelling of Ocean Energy Systems,
- Component Technology and Power Take-Off,
- System design, Construction, Reliability & Safety,
- Performance Monitoring of Ocean Energy Systems,
- Environmental, Economics, Development Policy and Promotion of Opportunities,

have been done. In Lisbon, workshop nº 4 "Performance Monitoring of Ocean Energy Systems" was held. This workshop was attained by more than eighty people from, developers, universities, research laboratories and others. Twenty four communications were presented and sixteen documents have been delivered.

This document intends to present a clear picture, based on the information collected during the workshop about:

- Monitoring and specification real sea performance data of wave power converters
- Monitoring and specification real sea performance data of tidal power converters
- Normalization of device performance.

2. Scope and Objective

The workshop held in Lisbon. "Performance Monitoring of Ocean Energy Sysytems" was divided into four different tasks. The first one "Incocean resource" aimed to present to the participants some of the work that Inco partners, namely Russia, have been undertaken. This task was not initially proposed in the project but was important to get acquaintance with the new Inco partners. The following task that was presented at the workshop was "Monitoring and specification real sea performance data of wave power converters". The aim of this task was to present data and methodologies used to acquire this data for wave power converters in order to be able to specify devices performance (in terms of several different areas of interest, power conversion, structural loads, etc) and thus get a picture about different data acquisition needs to be able to compare different devices performance. Different devices need different data acquisition systems, nevertheless, a correct estimate of the incident power, for example, knowing the sea state characteristics of devices locations, as well as a convenient system identification and data acquisition system enables to compute the device's efficiency for each step of the wave to wire power converting process. The wave power devices that were mentioned in this subtask and for which was collected some information were,

- Wave dragon,
- SSG wave energy converter,
- Wave rotor,
- OWC Pico plant,
- AWS,
- Waveplane,
- Pelamis.

Nevertheless, in general, real data about the performance of these devices was not presented.

The third task that was presented at the workshop was "Monitoring and specification real sea performance data of tidal power converters".

There is already some experience in the deployment and at-sea measurements of tidal power converters, and the need for a commonly accepted protocol is clear. Without a common datum, any performance claims are restricted to application within the developers own frameworks and across the board comparisons cannot be made. Procedures to characterize the local resource, the TEC (tidal energy converter) device performance envelope and the TEC operational status and annual energy production should be carried out as it is being done by the University of Edinburgh for DTI, UK. Delivered documents refer to:

- The production of a tidal current performance assessment protocol,

- Some lessons from tidal current and wave measurements at sea,
- Kobold turbine in the Strait of Messina. Performance monitoring,
- Performance monitoring of seaflow.

However, only few devices performance data was presented.

The underlying rationale of the task “Normalization of device performance” is to standardize the processing and presentation of data so that investors can get a clear picture of the performance of an Ocean Energy system. In “Status and Research and Development Priorities 2003: Wave and Marine Current Energy” (IEA-OES / DTI), Richard Boud writes: “It is essential that [marine energy] concepts are assessed fairly and objectively when allocating funding. A concept assessment methodology is therefore necessary. This methodology should use best available international experience and knowledge and be implemented fairly and credibly.” and “A sound approach to testing and certification would include widely recognised systems and methods. This means international agreement. Where such systems are developed they should involve contributions from a range of expertise and with an international perspective”. Much work has been completed in formulating an overarching framework within which marine energy systems may be assessed. Overall guidelines should be presented by both international and national consortia. Although agreement may be found in general terms, much research remains to be done in many areas of detail, especially for tidal energy systems. Aspects such as resource assessment, and accommodation of device variability in performance data portability, are areas within the general framework where research is ongoing. Delivered documents were:

- IEA-OES Annex II extension "Guidelines for development and testing of Ocean Energy Systems",
- The UK wave energy device performance protocol,
- Guidelines and methodology for wave energy resource assessment,
- Performance and the pathway to non-recourse project finance.

3. Conclusions

The monitoring and specification real sea performance data of wave power converters may be quite different from one converter to another converter. Indeed the concepts used by different devices are usually different. Nevertheless the developers bare in mind that a complete systems identification should be performed and that the understanding of all sub-processes involved into the overall process of wave-to-wire conversion power must be accomplish. Using results from monitoring together with developed software tools most of the developers aim to get performances, or efficiencies, for each of its device components and then get a clear picture of overall devices performance for different sea states. Monitoring is also important when defining the most suitable control strategies for the devices. The real-time display of data acquired by the data acquisition system may help to improve control strategies. The post-processing of the acquired data is fundamental and should fall upon time domain, statistical and spectral analysis, in order to get relevant device parameters as dynamic loads, flow rates, accelerations, velocities, displacements, etc.

The data acquired during these sea tests allowed the validation of wave basin tests and numerical software, and thus to predict with a certain level of confidence the performance of these devices under different operational conditions. When defining the overall devices performance it will be important to determine accurately the sea state characteristics for the location where the device is deployed.

Regarding the monitoring and specification of real sea performance data for tidal wave energy converters, there remains much work to be done in understanding the behaviour of the resource and the developers are (understandably) wary of releasing data that may give some benefit to their competitors and this difficulty is leading to multiple re-inventions of the wheel by many concerned.

Performance assessment protocols are to the benefit of all and care must be taken to develop comprehensive, robust and consistent procedures recognized and accepted by all concerned. Indeed, wave energy as well as a tidal current energy devices performance protocols must be accepted by all concerned.

4. Choice of methods

Under WP4 “Performance monitoring of ocean energy systems”, was held in Lisbon a workshop during 16th and 17th November. As it is possible to see from the program, twenty four communications were presented, divided in:

<u>INCocean Resource:</u>
Float wave electric power station
S. A. Temeev. Applied Technologies Company, RU

<u>Normalization of device performance:</u>
Comparable performance characteristics from different test sites
A.P. McCabe, G. Aggidis, T.J. Stallard. Lancaster Univ., UK

IEA-OES Annex II extension "Guidelines for development and testing of Ocean Energy Systems"
K. Nielsen. Ramboll, DK

The UK wave energy device performance protocol
J.Taylor, G. Smith. Univ. Edinburgh, UK

Guidelines and methodology for wave energy resource assessment
J-B. Saulnier, T. Pontes. INETI, PT

Performance and the pathway to non-recourse project finance
C. Day. CJDay Associates,

<u>Monitoring and specification real sea performance data of tidal power converters:</u>
Experience of ocean energy conversion systems
Alan Owen, G. T. Melville

Proposed methodology for the performance testing of tidal current energy devices
S. J. Couch, H. F. Jeffrey, I. G. Bryden. Univ. Edinburgh, UK

The production of a tidal current performance assessment protocol
H. F Jeffrey, S. J Couch, I. G. Bryden. Univ. of Edinburgh, UK

Some lessons from tidal current and wave measurments at sea
E. Gagnaire-Renou, M. Benoit, C.Buvat, C. Abonnel. Electricité de France, FR

Kobold turbine in the Strait of Messina. Performance monitoring
A. Fiorentino. Ponte di Archimede, IT

Tidal reservoir operated in two different reservoirs
G. Hiriart L.. National Autonomous University of Mexico, MX

<u>Monitoring and specification real sea performance data of wave power converters</u>

Introduction
M. Bryndum, DHI Water & Environment, DK

Three-years experience with energy production on the Nissum Bredning Wave Dragon proto type
P. Frigaard, J. Tedd, J.P. Kofoed. Aalborg University, E. Friss-Madsen. Wave Dragon, DK

Status and performance of the SSG wave energy converter
L. Margheritini, J. Peter Kofoed, P, Frigaard. Aalborg University, DK

OE Buoy: Performance monitoring
T. Lewis. UCC, IR

Wave Rotor scale model tests: sensors and data acquisition
E. Rossen. Eric Rossen (RIFA), DK

Performance monitoring of the Limpet wave energy device
J. Lees. Wavegen, C. Boake. QUBelfast, UK

Pico OWC power plant: refurbishement project, monitoring and performance
F. Neumann, A. Brito Melo. Wave Energy Centre, A. Sarmento. IST, PT

Performance monitoring of AWS systems
F. Gardner, M.Prado. Teamwork Technology, NL

Small is beautiful
E. Skaarup. Waveplane Production, DK

OPD Pelamis: Overview on the data processing tools
J. Cruz, R. Henderson, B. Dickens, T. Martins. OPD, UK

<u>Invited Speakers</u>

National Ocean Strategy
Miguel Sequeira. Ministry of Defense, PT

Remote on-line management of power systems: state of the art and current trends
F. Gomes. EFACEC, PT

It was set up an internet site, pmoes.ineti.pt, with information regarding the workshop. At pmoes.ineti.pt public can freely access the presentations in “pdf” format for download. As it is possible to see from the internet site almost all communications have a “pdf” document assigned. After the workshop some of the communication authors delivered a document with the information presented at the workshop. Sixteen documents were delivered and workshop participants or CA-OE partners can access these documents from the CA-OE internet site.

5. Results and conclusions

As already said the main tasks were, Monitoring and specification real sea performance data of wave power converters, Monitoring and specification real sea performance data of tidal power converters and Normalization of device performance. First is presented a summary of the results obtained for each of the contributions related to these tasks. Finally conclusions are drawn.

5.1 Monitoring and specification real sea performance data of wave power converters (Instituto Nacional de Engenharia, Tecnologia e Inovação)

Much work has been done under the development of wave energy devices. Some of the delivered documents describe laboratory tests (as it is the case of the document presented by AWS team) as well as the prototype monitoring in order to proceed to systems identification. Other documents make an overview of the data processing tools (as it is the case of the document presented by Pelamis team). The status and performance of some mew concepts (as it is the case of the SSG wave energy converter) is also presented. The Wave Dragon team exposed its experience obtained during 3 year tests of its device. The Wave Rotor team in its document presented fundamental equations and principles for the operation of the rotor as well as some acquired data obtained from a three week testing of a grid connected wave rotor prototype. Wave plane team presented a factual description of the tests performed with its device in wave basin and on site locations.

5.1.1 OPD Pelamis – Overview of the data processing tools

Ocean Power Delivery Ltd (OPD) continues to develop Pelamis. One of its activities has been the development of software tools to acquire and process data obtained from Pelamis machines. In order to achieve these goals OPD has been working with LABVIEW for real-time monitoring and MATLAB for the post-processing stage.

LABVIEW may be found as an important software tool to display semi-real time control data graphs that will allow not only to have an insight of the data related to the control strategy that is being applied but also to decide which will be the best control strategy that should be implemented in any given sea states. LABVIEW also manages a separate data acquisition system that logs data of interest but not specifically related to control. In addition to the LABVIEW tools, software written in MATLAB aim to post-processing data pointing out three different vectors: statistical, spectral and fatigue analysis. A wave analysis package was also developed, using as input data files data provided from Datawell Waverider buoys. Using this tool directional spectral analysis can be performed employing all the main stochastic and deterministic methods as:

-Truncated Fourier series decomposition method (TFSM),

-Direct Fourier transform method (DTFM),

-Extended Maximum Likelihood method (EMLM),

-Iterated Maximum Likelihood method (IMLM),

-Extended Maximum Entropy principle (EMEP),

-Bayesian Directional method (BDM),

-Single direction decomposition (SDD),

-Double direction decomposition (DDD).

It should be noted that this tool can be used for numerical simulation of a given sea state and thus allows to proceed with the optimization of control routines for a particular site.

5.1.2 Pico OWC power plant: Refurbishment project, monitoring and performance

For the Pico OWC power plant, device monitoring was done during the full-scale demonstration in September 2005 – October 2006. In order to allow a detailed analysis of device performance a data acquisition system was installed and collected data related to air pressure inside the pneumatic chamber, static and dynamic pressure in the turbine duct, upstream and downstream the turbine, dynamic pressure in each side of the turbine measured at three different radius. Further, the PLC that is installed in the plant provides essential data for the control and operation of the plant such as turbine rotational speed, control valve position and power delivered to the grid. Another variable that is important to be measured is the incident wave elevation, thus allowing to be known the amount of incident power that gets to the plant. Data should be collected for a range of, significant wave heights and energy periods. For the Pico power plant data was collected for wave heights between 1 and 3.5 meters and energy periods between 8 and 12 seconds. The acquired data allows to be checked the characteristic turbine curves obtained from experimental tests and numerical simulations. From Pico tests the following four remarks may be drawn:

-the turbine characteristic curves are close to wind tunnel experiment results and to those predicted by theoretical modeling.

-Control laws that were tested are viable and enable secure operation of the turbo-generator set.

-Relief valve allows increasing of power production and protects equipment.

-Simple taken measures during tests allowed reducing noise of relief valve and turbine.

5.1.3 AWS Ocean Energy Ltd

To characterize several device components performance system identification may be needed. According to AWS team, the main achievement got with the deployment of a full-scale unit off-coast of Portugal was to identify and validate the device capabilities to convert power.

There are many things that can not be done in real seas that could be done in the laboratory. Measuring the undisturbed wave for instance to characterize the wave force is, according to AWS team, impossible. Therefore numerical codes that have been checked for a long time were used to characterize the system. The undisturbed wave that has to be the input to the models and to the wave to wire energy conversion performance is therefore calculated from pressure, measured at different spots on the device setting up a transfer function that lead to the incident wave. The data acquisition system was based on a simple MS windows network. The network needed special care. The overall data acquisition rate depended on the amount of channels used to acquire data. A LABVIEW scada system was used to manage the overall data acquisition process. The LABVIEW scada was very flexible, real-time programming could be done. The scada system was able to present data on screen, thus allowing to cross-relate these data enabling the operational team to maintain instant control over the device at all time. Since the acquired data was available from different services, with different sampling rates, special care needed to be taken to synchronize all data available to compare. One important task was the signal noise filtering without loosing available data. During real sea tests an important task was to get accurate data measurements. It should be noted that each sensor had their own calibration and the effect of the tide was present in the data. The available data allowed to carry out system identification which may not be of interest for the end user but it is crucial for the developer since allows a full understanding of each component's dynamic behaviour.

5.1.4 Three years experience with energy production on the Nissum Brendning Wave Dragon Proto Type

A 1:45 Wave Dragon scale prototype has been sea tested for 20 months. Comparison between results from testing and earlier results from both laboratory model and computer simulation gives the optimal operating point (in terms of device's control) and the expected power of the device. The Wave Dragon is a floating offshore wave energy converter of the overtopping type. The prototype has all the features of an operational power plant:

- wave reflectors to focus the incident wave energy towards the ramp,
- pneumatic system to adjust the floating level of the platform,
- propeller turbines mounted with permanent magnet generators,
- inverter system to control rotational speed of the turbines,
- calibrated dummy turbines to process overtopping flow rates that exceed the capacity of the propeller turbines.

A data acquisition system allowed to be obtained the water flow overtopping the ramp and the hydraulic power which passes through the turbines. Laboratory tests allowed to be compared these prototype results with those obtained at laboratory. The electric power generated by the device is also recorded. It is computed the electric power that the device would supply to the grid if the dummy turbines had been replaced by propeller turbines and if the rotational speed control of the PM generators had been working optimally. Wave Dragon team defines overtopping flow as the flow which passes through the turbines, if there was no water spilling from the reservoir back to the sea. To compute the individual turbine flow it is needed to know the head and turbines rotational speed. Pressure transducers in the reservoir measured the head. By defining the hydraulic power as the water power available to the turbines, the hydraulic efficiency will be defined as the ratio of the average power of the water through the turbines to the theoretical incoming wave power across a width equal to the Wave Dragon ramp width. Production efficiency is defined as the ratio of the average electric power by the incident wave power. Both of these quantities, hydraulic efficiency and production efficiency, were computed by the Wave Dragon team. Although an enormous quantity of data had been recorded, many has not yet been fully analysed, however the work done until now suggests that predicted performance for the device based on wave tank testing and turbine model will be achieved in a full scale prototype.

5.1.5 Status and performance of the SSG wave energy converter

The Seawave Slot-Cone Generator (SSG) is a overtopping wave energy converter. There are not yet results for prototype testes since its construction is foreseen for summer of 2007. This prototype will include turbines, generator, control system and connection to the public grid. It will have an installed power of 150 kW. Wave basin tests have been done and data related to the performance of several geometries have been collected. The development of a power simulation software tool has been carried out. For this software input parameters are the results of physical model test, reservoir size, turbine characteristics and control strategy for the turbines. The outputs are:

-flow in each reservoir,

-flow in each turbine,

-spilled volume of water when the reservoirs are full,

-produced energy,

-average power,

-overtopping efficiency,
-turbines efficiency,
-overall efficiency.

The SSG team aims to achieve partial efficiencies for the different steps that are involved in the wave-to-wire power conversion process, and thus get overall device efficiency. The overall efficiency is expected to be approximately 22%.

It should also be mention that the wave data at the pilot plant location has been exhaustively collected. Relevant results as scatter diagrams for wave heights, periods and direction have been obtained. It is also expected that the power production of one module of the SSG wave energy converter (10m width) will be around 320 MWh/y.

5.1.6 Green electricity from the Wave Rotor

There have been some tests of a grid connected Wave Rotor prototype. The tests aimed to get captured and converted wave energy to the public grid, to gather data from different transducers, sampled once every second. Results for mechanical shaft power and torque have been obtained. Measures of rotational speed were also performed. At the moment there are no more available data regarding the monitoring and specification of real sea performance data of this device.

5.1.7 WavePlane sea trials

Not all the wave energy devices aim to produce energy. This is the case of the WavePlane device. The WavePlane aims to operate as a sea water pump to allow water circulation in areas where no circulation, i.e., stagnation is found. Several experiments had been conducted in Denmark as well as in Japanese waters. Data has been collected regarding the performance of the WavePlane in terms of output water flow for monochromatic and polychromatic sea waves. In Japan the effect of adding a damping plate to the device was studied. It was observed that the performance of the device was improved in the longer wave excitations.

5.2 Monitoring and specification real sea performance data of tidal power converters (The Robert Gordon University)

Of all the developers within the field, only The Robert Gordon University and Ponte di Archimede S.p.A. were prepared to offer their at-sea experience for discussion and scrutiny by the workshop attendees and an opportunity for greater collaboration was not explored by the wider developer community.

5.2.1 Experience of ocean energy conversion systems

Alan Owen of the Robert Gordon University presented material from available sources with regard to the complete process of deployment including administration, design, installation, operation and retrieval. The example of the failed designed recovery of the Sea Snail was used to illustrate the unforeseen difficulties inherent within any project. Questions from the floor were raised regarding data acquisition sampling and averaging periods appropriate for tidal current data measurements.

5.2.2 Proposed methodology for the performance testing of tidal current energy devices

Scott Couch of the University of Edinburgh proposed a testing methodology that would inform an assessment protocol at some future date. The methodology would comprise a specified field data process; subsequently analysed using an agreed and accepted data analysis methodology and the results would be presented in a standardised report format. Questions from the floor inquired as to how would the protocol define the theoretical, technical and practical power available from a site? Also, after harmonic analysis of the data from a given site, how would the residual values be accommodated in the structure of the protocol?

5.2.3 The production of a tidal current performance assessment protocol

Henry Jeffrey, also of the University of Edinburgh extended from Scott Couch's presentation and discussed the production of a tidal current performance assessment protocol, how such a document would benefit the developer community and what the current limitations are on producing such a document. Whilst the protocol is being developed at the behest of the UK Department of Trade and Industry (DTi) the methodology and consultation process was international in its enactment. The protocol is designed to ensure that the performance of different devices is assessed on a consistent basis that is broadly acceptable to all developers, and that funding bodies can expect a realistic standardised result from any projects funded by themselves and other support mechanisms. Questions from the floor inquired as to who were the collaborators within the protocol development process, and who were the likely beneficiaries of the eventual protocol?

5.2.4 Some lessons from tidal current and wave measurements at sea

Elodie Gagnaire-Renou from the research and development division of EDF presented a very interesting paper on measurement of tidal currents and their interaction with surface wave action using ADCP acquired data from the Raz de Barfleur (Normandy). The work was designed to develop a greater fundamental understanding of the basic tidal current resource and how meteorological events could affect the resource magnitude and exploitability. Questions from the floor were directed at how does the presence of the free surface affect the ADCP measurements and how does the depth of water at the site affect the results averaging due to the increase in bin size. In addition, comments were made regarding the difference between the instantaneous dynamic current and the average current, i.e. large scale turbulence. It was also noted that the orbital nature of waves would tend to retard the current velocity in regions proximate to the free surface.

5.2.5 Kobold turbine in the Strait of Messina. Performance monitoring

Antonio Fioretino presenting data from the Kobold turbine in the Strait of Messina made the point that the need for a device testing protocol also placed an obligation on developers to release certain details of their devices. It was also acknowledged that, under present circumstances, few were likely to do so and that development may be hampered by this reluctance. Investors were possibly being starved of the comparative data required to make commercial decisions and that this should be a concern for all developers. Questions were primarily directed at technical detail such as start-up flow speed and generation frequency.

5.2.6 Tidal reservoir operated in two different reservoirs

The possible benefits of generation from two reservoirs emptying into one basin were presented by Gerardo Hiriart of the National Autonomous University of Mexico. A basic simulation using the Gulf of California was presented showing how the various permutations could be used to extend the operational period. Power generation was considered secondary to the need for desalinated water supplies, prompting a question from the floor that perhaps solar energy would be better suited to the end-use?

5.3 Normalization of device performance (Lancaster University)

Much work has been completed in formulating an overarching framework within which marine energy systems may be assessed. Overall guidelines are presented here by both international and national consortia, in sections 4.3.1 and 4.3.2, respectively. Although agreement may be found in general terms, much research remains to be done in many areas of detail, especially for tidal energy systems. Aspects such as resource assessment, section 4.3.3, and accommodation of device variability in performance data portability, section 4.3.4, highlight areas within the general framework where research is ongoing. The final contributor, in section 4.3.5, draws attention to an often neglected assessment of performance, a financial one, without which no marine energy project could hope to reach fruition.

5.3.1. IEA-OES ANNEX II – Guidelines for the Development and Testing of Ocean Energy Systems

In this document K. Nielsen presents a recommended series of experiments for testing wave power converters, in an extensive international development context, to ensure that the results presented for different types of wave energy converters are comparable. The guidelines are intended as the least amount of material required to evaluate performance. Although it is assumed that full-scale operation will take place in the North Sea, the principles may, with a number of modifications, be applied to a larger selection of ocean sites. The guidelines aspire to supply realistic parameters for wave conditions for the evaluation of energy production and design loads.

Experiments are advocated for the testing of wave power converters a set of standardised generic wave conditions, addressing the need for the preparation of the wave data and measurements regarding the device. Proposals for the presentation of the measured sea states, in terms of scatter diagrams, directional description, and ocean currents are made. Specified duration and sampling frequency of and intervals between measurement periods are stipulated, as well as the required accuracy and documentation formats. The performance assessment should take account of the electric energy production, the energy absorbed over a year, the rated power of the device and its power take-off system, and the unit and capital costs. Optimisation of power production is dealt with using tests on the power take-off systems in terms of force and speed (or torque and rotation) measurement. Design and survival testing, and accommodation of environmental concerns are also covered. Special consideration is given, where necessary, to oscillating water column and overtopping systems, and distinctions made where shoreline and offshore wave energy systems differ in application.

5.3.2: The UK Wave Energy Device Performance Protocol

In these documents J. Taylor and G. Smith present daft protocol documents aimed at developers of wave and tidal energy generation facilities participating in the UK DTI (Department of Trade and Industry) Wave and Tidal-stream Energy Demonstration Scheme. As such the protocols stipulate the requirements of participants for the provision of information, collection and recording of data, and the submission of data and performance summaries during the project.

The wave energy device protocol outlines information that needs to be supplied before a project is commissioned, such as the topography of the project location, the arrangement of multiple devices and monitoring instrumentation, and the connection to the power network. Procedures for the measurement of the wave resource using suitable continuously-deployed instrumentation are stipulated. Measurements are to be taken over half-hour averaging periods to produce wave records in the form of time-series data and frequency-domain spectra. Similarly, conditions for the quantification of device performance during each half-hour period are laid down. The main measurement of performance is the average electric power from each device, excluding losses due to external transmission arrangements, along with the identification of the operational status of devices so that such conditions may be considered in the device performance assessment. An important test of the utility of the combined device power measurements is provided by the measurement of the metered electricity exported into the network, taking account of the operational status of the connection to the network.

The tidal current energy device performance protocol draws attention to the need for a clearly-defined set of tests in an area where there is, at present, a lack of universality in performance assessment. The protocol addresses this need, whilst recognizing considerable ‘grey’ areas in the knowledge base, which constrain the development of a strict method for performance testing, in comparison with more mature technologies. Procedures for the best practice in the characterisation of the tidal current resource at a selected site, and to evaluate the device performance envelope using a measured power curve, are outlined. Again, the net annual electric power production and the operational status of both device and network connection are required performance data. Both wave and tidal energy device protocols propose standardized reporting formats for the required data.

5.3.3: Guidelines for Wave Energy Resource Assessment and Standard Wave Climate

In this paper J. Saulnier and M. Pontes draw attention to the need for standard wave climate and energy resource statistics, to enable the true comparison of wave energy converter performance either by numerical modelling or tank testing. A proposal of a methodology for wave energy resource characterization is made based on the usual wave height, period, direction and power parameters. In addition, other spectral wave parameters relating to spectral width and wave grouping are used namely to select a representative sample of sea states. Initially, the traditional wave height, period, power and direction parameters, and the statistics used for resource assessment are presented, completed by spectral width and wave grouping parameters. Subsequently, a wave energy resource based on long-term buoy data off Portugal north-western coast is proposed as a standard having in view allowing the comparison of performance of different wave systems. Finally, a methodology for selecting representative sea states from a data set, based on wave height, period and power statistics as well as on the proposed spectral width and grouping parameters, is described. In a first attempt, this selection has been performed by considering twelve homogeneous zones of the (Hs,Te) scatter table in terms of power level, P, and spectral width, $\varepsilon 0$. In each zone, the selection of sea conditions that differ in terms of spectral width and wave groupiness is based on the analysis of the joint distribution of $\varepsilon 0$ and the wave correlation parameter, κ.

5.3.4: Comparable Performance Characteristics from Different Test Sites

In this paper, A. McCabe, G. Aggidis, and T. Stallard present an investigation into the transferability of the power capture matrix of a ‘tuned’ wave energy converter, so that data obtained from one site can be employed to predict performance at other sites. The performance of all devices is dependent on the characteristics of the incident wave-field. Standard testing procedures look to define the performance of a device by its annual power capture. Typically, this is estimated as the overall product of two matrices: a wave-field occurrence matrix and a power capture matrix. The wave field matrix is site-specific and describes the probability that a wave-field with given significant wave height and zero crossing period will occur at a random instant. A power capture matrix is device-specific and describes the mean power generated by the device in a wave-field characterized by a given combination of significant wave height and zero crossing period. Draft guidelines for the measurement of wave energy device performance suggest that the power capture stated for a given pair of characteristics should be the mean of that measured in at least six statistically similar wave-fields. Such criteria have been met by few device developers and so it is important to note that, whilst power capture matrices have been published by several device developers, there is little publicly-available evidence from offshore tests to support the figures stated.

Although the power capture measured at one site can provide an estimate of the power capture at other sites which exhibit similar sea-states, estimates of power capture at sites with a different distribution of wave conditions can be inaccurate. Thus, in some situations, it is useful to improve the transferability of a measured power capture matrix. A method for achieving this is presented. The method takes account of site-specific tuning of a point absorber by normalization of the power capture matrix and is demonstrated using a simulated site-tuned point absorber. The 'tuning' characteristics of the device at a designated 'test' site are eradicated to produce the normalized data set for the device. Performance at a new site is then extrapolated from the normalized power data and compared to the results that would have been obtained with the device model itself. This approach shows significant improvement in the accuracy with which power capture may be predicted at sites where the 'tuning' characteristics of the device differs noticeably from those at the test site.

To avoid compromising the intellectual property of companies developing devices, simplified models are used to predict the performance of a device at a number of sites around the UK. Linear mathematical models are used to describe the characteristics of point-absorber wave power device whose performance approaches the theoretical limit of a point absorber in regular waves. The site-specific wave data was provided by the UK Met-Office (UKMO) numerical weather prediction model, a hindcast wave model which calculates the wave conditions from forecast wind conditions. Seven locations within the UK waters wave model and one taken from the North-Western European waters model provide a wide range of sea states for performance comparison.

5.3.5: Performance and the pathway to non-recourse project finance

In this paper C. Day presents an exploration of the outcome at the point where projects are bankable for non-recourse project finance. The question is raised about the measured outcome – "performing to do what and for whom". The question is directed to the responses needed for non-recourse project finance (Nrpf). The security for this finance is only in the revenue, not the balance sheet of a parent or start-up company. Hence the evaluation of the technology and its reliability has a high profile. Projects have a start and finish, defined resources and time frame and specific inputs and outputs. Non – recourse project finance relies on the quality and reliability of the revenue. Transaction costs (inputs) are also different on the competition for research funding and project finance. Qualities sought for research (a very targeted output) may not be sought for finance. This polemic discusses project and corporate finance; but corporate finance in this business is a "project – driven company". The unit of development is again the project. Aim or other junior markets funding the sector fund projects. All corporate finance (source of funds) is eventually for projects (use of funds). The project controls both delivery of government policy and delivery of corporate finance.

Projects must be bankable (finance-able) if policy is to be delivered not as technology or grid–connected power but as revenue. Some pathways imply continued support for capital spend. Projects must deliver revenue and with an annual and annualised total to finance projects. The pathway with its triggers and constraints is examined and the pathway followed over the last few years by biomass power plants in the UK is compared with the pathway being currently followed by marine energy. The paper argues for support which is directed towards projects with clear identification of support which is for research. The requirements of non-recourse project finance are explored in contrast with the outcomes from R and D. The risks in technology, power generation and distribution, power purchase agreement and environmental compliance must be guaranteed by the players and with bankable long term contracts. Performance may not be bankable without considerable early stage work at high cost. For finance of multiple projects through a company a market must be in place. The market will not accept political risk and will not rely on policy objectives to define future markets. Corporate finance will require market fundamentals such as the price of gas to underpin the investment.

Case histories are presented for the non-performing, early policy stages of biomass power in the UK and the recent strong project-lead market. Historic policy and project stages for biomass are compared with the current policy and research stages for marine energy. The feed–in support mechanism can be contrasted with the capital grant approach. The influence of non-technical externalities is also highlighted with project examples.

5.4 Conclusions

The monitoring and specification real sea performance data of wave power converters may be quite different from one converter to another converter. Indeed the concepts used by different devices are usually different. Nevertheless the developers bare in mind that a complete systems identification should be performed and that the understanding of all sub-processes involved into the overall process of wave-to-wire conversion power must be accomplish. Using results from monitoring together with developed software tools most of the developers aim to get performances, or efficiencies, for each of its device components and then get a clear picture of overall devices performance for different sea states. Monitoring is also important when defining the most suitable control strategies for the devices. As it is known control plays a crucial roll in the improvement of devices efficiency. The real-time display of data acquired by the data acquisition system may help to improve control strategies. The post-processing of the acquired data is fundamental and should fall upon time domain, statistical and spectral analysis, in order to get relevant device parameters as dynamic loads, flow rates, accelerations, velocities, displacements, etc. The quality of measured data is crucial, post-processing tools must be used to remove noise from the signal without loosing data.

Most of the prototype sea tests didn't attend to get a larger electric power production so far. However these tests have been considered of capital importance since allowed several teams to gain experience in the deployment and operation of the devices. The data acquired during these sea tests allowed the validation of wave basin tests and numerical software, and thus to be able to predict with a certain level of confidence the performance of these devices under different operational conditions.

While the overall performance of a WEC may be regarded as average electric power production over wave incident power, the performance of each step of the wave-to-wire power conversion process is different for distinct concepts. When defining the overall performance it will be important to determine accurately the sea state characteristics for the location where the device is deployed. There is work being done attempting to define which sea state characteristics should be used. IEA-OES Annex II presents guidelines for the development and testing of Ocean Energy Systems to ensure that results can be compared for different wave energy converters. The guidelines aspire to supply realistic parameters for wave conditions for the evaluation of the energy production and design loads. Proposals for a wave energy resource evaluation methodology have been already suggested.

Regarding the monitoring and specification of real sea performance data for tidal wave energy converters, there remains much work to be done in understanding the behaviour of the resource and the developers are (understandably) wary of releasing data that may give some benefit to their competitors and this difficulty is leading to multiple re-inventions of the wheel by many concerned.

A performance assessment protocol is to the benefit of all and care must be taken to develop a comprehensive, robust and consistent procedure recognized and accepted by all concerned. Indeed, wave energy as well as a tidal current energy devices performance protocols must be accepted by all concerned.

DTI, Heriot-Watt University and the University of Edinburgh have been developing a wave energy protocol which focuses the information that is needed to be supplied before commissioning, procedures for the measurement of wave resource, as well as procedures for the device performance measurement. For tidal current energy, DTI and University of Edinburgh have been defining standards for local resource characterization, procedures to characterize TEC device performance envelope and procedures for reporting the operational status and annual energy production. It is proposed by both protocols standardized reporting formats for the required data.

6. Recommendations for future work

It will be necessary to get experience with the deployment and operation of wave energy and tidal power converters to be able to set up standards for assessment of plants performance. Although there is already in public domain drafts for tidal and wave energy devices performance protocol for the UK, EU protocols could be looked for in a not too long time frame.

Another area of future research that may be considered is the set up of a European sea states data base that could be used for the performance evaluation of different devices. This data base would help end-users and others to compare different developers' devices.

From monitoring is possible to understand that devices control is crucial to the system power production capability. As it is known optimal control for wave energy devices is not causal (it will depend on future values of several parameters devices). Sub-optimal strategies need to be improved. Research in this area would be helpful.

For tidal power converters as IT Power Limited states in its paper ("Performance Monitoring of Seaflow") "there is insufficient knowledge relating turbulence in flows typical of potential tidal power sites to be able to know what the correct averaging period should be and how much variation exists between different tidal sites. This is an area of research which could have great potential benefit to the development of tidal energy conversion".