7th European Wave and Tidal Energy Conference

Eng. António de Almeida Foundation Conference Centre, Porto, Portugal,
11-13 September 2007

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Local organization

- Instituto Superior Técnico, Lisbon, Portugal
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Foreword

This is the seventh of a series of European conferences on Wave Energy, that started in 1993 in Edinburgh, and, since 2005, have also included Tidal Energy. For the second time the conference is taking place in Portugal (the second conference was held in Lisbon in 1995).

The growing interest in wave and tidal energy is evident from the increasing number of papers presented at these conferences. About 150 abstracts were submitted to the present conference, from which 103 were selected for presentation and inclusion in the proceedings.

For the first time in this conference series, the selection of the papers was based on peer review of the full paper, and, also for the first time, the proceedings will be available to the participants at the beginning of the conference. This was a heavy task for the Technical Committee, for other reviewers and for the local organizing committee. I want to thank all of them for the excellent job they did.

António Falcão
Chairman of the Technical and Organizing Committees

Technical Programme

Session 1
Plenary Session 1, Room 1, Tuesday, 11th September, 11:00-12:40

North American ocean energy status – March 2007, Roger Bedar, Mirko Previsic, George Hagerman, Brian Polagye, Walt Musial, Justin Klure, Annette von Jouanne, Uday Mathur, Craig Collar, Charles Hopper and Scott Amsden

The UKERC Marine Renewable Energy Technology Roadmap, M.A. Mueller, H. Jeffrey, A.R. Wallace

The Strategy for the Next Five Years – International Energy Agency's Ocean Energy Systems (IEA-OES) Implementing Agreement, G. S. Bhuyan and A. Brito-Melo

Update on EMEC activities, resource description, and characterisation of wave-induced velocities in a tidal flow, J.V. Norris and E. Droniou

Environmental management recommendations for the wave energy Portuguese Pilot Zone, C.Huertas-Olivares, F. Neumann and A. Sarmento

Session 2
Plenary Session 2, Room 1, Tuesday, 11th September, 14:00-15:40

Update on the modelling of a 1:33 scale model of a modified Edinburgh duck WEC, Jorge Lucas, Joao Cruz; Stephen Salter, Jamie Taylor and Ian Bryden

The development of Oyster – A shallow water surging wave energy converter, Trevor Whittaker, David Collier, Matt Folley, Max Osterried, Alan Henry and Michael Crowley

Development of the ANACONDA all-rubber WEC, J.R.Chaplin, F.J.M.Farley, M.E.Prentice, R.C.T.Rainey, S.J.Rimmer and A.T.Roach

Pico OWC Recovery Project: Recent Activities and Performance Data, F. Neumann, A. Brito-Melo, E. Didier and A. Sarmento

Optimal Power Takeoff System Layout for the Seawave Slot-Cone Generator Kvitsøy Pilot Plant, Wilfried Knapp, Bernd Mayr, Matthias Faust and Rudolf Schilling

Session 3
Plenary Session 3, Room 1, Tuesday, 11th September, 16:10-17:50

Considering Mooring Cables for Offshore Wave Energy Converters, John Fitzgerald and Lars Bergdahl

Geo-Spatial Multi-criteria Analysis for Wave Energy System Deployment, Ana Nobre, Miguel Pacheco, Raquel Jorge, M. F. P. Lopes and L. M. C. Gato

Direct generation wave energy converters for optimized electrical power production, H. Lendenmann, K-C. Strømsem, M. Dai Pre, W. Arshad, A. Leirbukt, G. Tjensvoll and T. Gulli

The Ocean Energy Development Strategy for Ireland, Tony Lewis, Eoin Sweeney and Graham Brennan

Characterising the wake of horizontal axis marine current turbines, A.S.Bahaj, L.E.Myers, M.D. Thomson and N. Jorge

Session 4
Wave Energy Resource 1, Room 1, Wednesday, 12th September, 8:50-10:30

Advances in Wave Resource Estimation: Measurements and Data Processing, J. Cruz, E. Mackay and T. Martins

Influence of Sea-States Description on Wave Energy Production Assessment, M-A. Kerbiriou,M. Prevosto, C. Maisondieu, A.Clément and A.Babarit

Comparison of linear and nonlinear energy and energy flux calculations for bi-chromatic long-crested surface water waves, W. Parsons and R.E. Baddour

Sea & Swell Spectra, Brian Holmes and Sean Barrett

Spectral Bandwidth and WEC Performance Assessment, J.-B. Saulnier, P. Ricci, M. T. Pontes and A. F. de O. Falcão

Session 5
Wave Power Take-off, Room 2, Wednesday, 12th September, 8:50-10:30

Offshore experiments on a direct-driven Wave Energy Converter, J. Engström, R. Waters, M. Stålberg, E. Strömstedt, M. Eriksson, J. Isberg, U. Henfridsson, K. Bergman, J. Asmussen, and M. Leijon

The Power Takeoff System of the Multi-MW Wave Dragon Wave Energy Converter, Marek Jasinski, Wilfried Knapp, Matthias Faust and Erik Fris-Madsen

Linear generator systems for wave energy conversion, H. Polinder, M.A. Mueller, M. Scuotto and M. Goden de Sousa Prado

AquaBuOY Hose-Pumps – theory and experimental results, Alla Weinstein, Kim Nielsen, Kam Biaz Zandiyeh and Johnathan Bensted

A Novel Lightweight Permanent Magnet Generator for Direct Drive Power Take Off in Marine Renewable Energy Converters, Markus Mueller, Alasdair McDonald, Kenneth Ochije and John Jeffrey

Session 6
Wave Energy Converter Arrays, Room 3, Wednesday, 12th September, 8:50-10:30

A preliminary study on the optimal formation of an array of wave power devices, Colm Fitzgerald and Gareth Thomas

Interaction of waves with an array of floating wave energy devices, B. F. M. Child and V. Venugopal

Wave climate investigation for an array of wave power devices, V.Venugopal and G.H.Smith

Power Smoothing by Aggregation of Wave Energy Converters for Minimizing Electrical Energy Storage Requirements, M. Molina, O.Skjervheim, B. Sørby, P. Andreasen, S. Lundber and T. Undeland

Session 7
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Diffraction Effects near Foz do Douro Breakwater, H. Martins-Rivas and C.C. Mei

A linearized model of OWC devices with additional vertical ducts, S. M. Camporeale and P. Filianoti

Performance analysis of a model of OWC energy converter in non-linear waves, A.C. Mendes and W.M.L. Monteiro

A Physical and Numerical Study of a Fixed Cylindrical OWC of Finite Wall Thickness, R. K. Sykes, A. W. Lewis and G. P. Thomas

Experimental and numerical analysis of the oscillating water column inside a surface-piercing vertical cylinder in regular waves, M.F.P. Lopes, Pierpaolo Ricci, L.M.C. Gato and A. F. de O. Falcão

Session 8
Environmental Impact and Consent Process, Room 2, Wednesday, 12th September, 11:00-12:40

Environmental Impact and Appraisal – Gaining Planning Consent for the South West of England Wave Hub, Nick Harrington and Inma Andina-Pendás

Wave power devices as artificial reefs, Olivia Langhamer and Dan Wilhelmsson

Wave Dragon : Results From UK EIA and Consenting Process, Iain Russell and Hans Chr. Sorensen

Regulatory Interventions in Support of Marine Energy Deployments in New Zealand, J.A. Huckerby

Impact of Santoña WEC installation on the littoral processes, César Vidal, Fernando J. Méndez, Gabriel Díaz and Roberto Legaz

Session 9
Tidal Energy Resource and New Concepts, Room 3, Wednesday, 12th September, 11:00-12:40

Effects of tidal energy extraction at Portland Bill, southern UK predicted from a numerical model, L. S. Blunden and A. S. Bahaj

The power potential of tidal streams including a case study for Masset Sound, J. Blanchfield, A. Rowe, P. Wild, and C. Garrett

Tidal currents assessment in the Tagus estuary, A. Mendonça and A. Trigo Teixeira

Development of a floating tidal energy system suitable for use in shallow water, S.R. Turnock, G. Muller, R. F. Nicholls-Lee, S. Denchfield, S. Hindley, R. Shelmerdine, and S. Stevens

Empirical Modelling of Low Speed Flow over LAR Hydrofoils, A.Owen

Session 10
Wave Energy Converter Hydrodynamic Modelling 2, Room 1, Wednesday, 12th September, 14:00-15:40

Friction for a floating body heaving along a fixed vertical guiding strut, Torkel Bjarte-Larsson

Point-absorber arrays: a configuration study off the Portuguese West-Coast, Pierpaolo Ricci, Jean-Baptiste Saulnier and António F. de O. Falcão

Energy Converters under First- and Second-order Wave Loads, S.A. Mavrakos, G.M. Katsaounis and I.K. Chatjigeorgiou

Modelling and Simulation of Sea Wave Power Conversion Systems, Hallvard Engja and Jorgen Hals

Frequency-domain and stochastic model for an articulated wave power device, J. Cândido and P.A.P. Justino

Session 11
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Design of a baffle-plate for an OWC-WEC equipped with vertical-axis air-turbines: Numerical study of the air-flow, J. M. Paixão Conde and L. M. C. Gato

The Development of a Turbo-Generation System for Application in OWC Breakwaters, T.V. Heath

Advances in Oscillating Water Column Air Turbine Development, W.K. Tease, J. Lees and A. Hall

Numerical Analysis of a Variable Pitch Reversible Flow Air Turbine for Oscillating Water Column Wave Energy Systems, P. Cooper and A. Gareev

Dynamic System Modeling of an Oscillating Water Column Wave Power Plant based on Characteristic Curves obtained by Computational Fluid Dynamics to enhance Engineered Reliability, R.G.H. Arlitt, K. Tease, R. Starzmann and J. Lees

Session 12
Tidal Energy Device Modelling 1, Room 3, Wednesday, 12th September, 14:00-15:40

Modelling of free surface proximity and wave induced velocities around a horizontal axis tidal stream turbine, J. Whelan, M. Thomson, J. M. R. Graham and J. Peiró

Towards realistic marine flow conditions for tidal stream turbines, I. Masters, J.A.C. Orme and J. Chapman

Numerical and Experimental Investigation of a Ducted Vertical Axis Tidal Current Turbine, V.R. Klaptocz, G.W. Rawlings, Y. Nabavi, M. Alidadi, Y. Li and S.M. Calisal

Tidal current turbine fatigue loading sensitivity to waves and turbulence – a parametric study, G.N.McCann

An innovative modelling approach to optimize the design configurations of marine (river) cross-flow current energy converters' farm, T. Maitre, S. Antheaume, C. Buvat, C. Corre and J.L. Achard

Session 13
Wave Energy New Concepts, Room 1, Wednesday, 12th September, 16:10-17:50

Hydrodynamic Optimization of a Wave Energy Converter Using a Heave Motion Buoy, Marco Alves, Huw Traylor and António Sarmento

Hydraulic characteristics of seawave slot-cone generator pilot plant at Kvitsøy (Norway), L. Margheritini, D. Vicinanza and J. P. Kofoed

CETO, a Carbon Free Wave Power Energy Provider of the Future, L.D Mann, A.R. Burns and M.E.Ottaviano

Non-linear methods for next wave estimation, A.A.E. Price and A.R. Wallace

Session 14
Air Turbines 2, Room 2, Wednesday, 12th September, 16:10-17:50

A New Test Facility for evaluating turbines for use in OWC power plants, S. J. Herring and G. Laird

Experimental and numerical investigation on the performance of a Wells turbine prototype, M. Torresi, S. M. Camporeale and G. Pascazio

A small scale field experiment on a Wells turbine model, P. Filianoti and S. M. Camporeale

Viscous flow analysis in a radial impulse turbine for OWC wave energy systems, F. Castro, A. el Marjani, M. A. Rodriguez and T. Parra

Session 15
Strategy and Economics, Room 3, Wednesday, 12th September, 16:10-17:50

The Hawaii Wave Energy Opportunity, M.H. Kaya, M. Anderson and A.T. Gill

Internationalization within the ocean energy industry - a remedy for entrepreneurial challenges?, N. Løvdal, A. Sarmento and F. Neumann

An assessment of growth scenarios and implications for ocean energy industries in Europe, W.M.J. Batten and A.S. Bahaj

Wave energy: going down the tube?, P.M.Connor

Session 16
Wave Energy Converter Control, Room 1, Thursday, 13th September, 8:50-10:30

Advanced Control Techniques for WEC Wave Dragon, J. Tedd, J.P. Kofoed, M. Jasinski, A. Morris, E. Friis-Madsen, R. Wisniewski and J.D. Bendtsen

Dynamics of a force-compensated two-body wave energy converter in heave with hydraulic power take-off subject to phase control, Jørgen Hals, Reza Taghipour and Torgeir Moan

Phase control through load control of oscillating-body wave energy converters with hydraulic PTO system, António F. de O. Falcão

Control of the Archimedes Wave Swing using Neural Networks, Pedro Beirão, Mário J. G. C. Mendes, Duarte Valério and José Sá da Costa

A Frequency Converter Control Strategy for a MW Wave Energy Take-off System, Zhongfu Zhou, H. Ch. Sørensen, M. Jasinski, M. Malinowski, W. Knapp, J. MacEnri, E. Friis-Madsen, L. Christiansen, I. Masters and Petar Igic

Session 17
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Integrating Offshore Wind and Wave Resource Assessment, M. T. Pontes, AM. Sempreviva, R. Barthelmie, G. Giebel, P. Costa, A. Sood

Wave energy resource in the North Sea, C. Beels, J.C.C. Henriques, J. De Rouck, M.T. Pontes, G. De Backer and H. Verhaeghe

Wave climate and energy off the Catalan coast, X. Gironella, A. Sanchez-Arcilla, D. Gonzalez-Marco, J. Gomez, R. Bolaños and J. Sospedra

Scalability of a Benign Wave Energy Test Site, S. Barrett, B. Holmes, A.W. Lewis

Session 18
Wave Energy Converter Hydrodynamic Modelling 3, Room 1, Thursday, 13th September, 11:00-12:40

Experimental validation of the performances of the SEAREV wave energy converter with real time latching control, M. Durand, A. Babarit, B. Pettinotti, O. Quillard, J.L. Toularastel and A.H. Clément

Performance of a point absorber heaving with respect to a floating platform, G. De Backer, M. Vantorre, R. Banasiak, J. De Rouck, C. Beels and H. Verhaeghe

The design of small seabed-mounted bottom-hinged wave energy converters, M. Folley, T.J.T. Whittaker and J. van´t Hoff

WRASPA, Wave Interactions and Control in a new Pitching-Surge Point-Absorber Wave Energy Converter, Robert V. Chaplin and George A. Aggidis

Modelling of Multibody Marine Systems with Application to Wave-Energy Devices, Mícheál Ó'Cáthain, Bernt J. Leira and John V. Ringwood

Session 19
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Specific Kinetic Wave Energy Definition, Raquel Silva and Francisco Taveira-Pinto

Short TermWave Energy Variability off the West Coast of Ireland, G. Nolan, J.V. Ringwood and B. Holmes

A methodology to evaluate wave energy resources in shallow waters, Paula Camus, César Vidal, Fernando J. Méndez, Antonio Espejo, Cristina Izaguirre, Jose Manuel Gutiérrez, Antonio Cofiño, Daniel San-Martín and Raúl Medina

Providing Sea Surface Elevations for Marine Energy Converters using a Novel Optical Fibre Sensor: Progress in the Flume, Brian G. Sellar, Tom Bruce and Robin Wallace

Generalisation of wave farm impact assessment on inshore wave climate, H.C.M. Smith, D.L. Millar and D.E. Reeve

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Facilities for marine current energy converter characterization, G. Germain, A.S. Bahaj, C. Huxley-Reynard and P. Roberts

Close Coupled Tandem Oscillating Hydrofoil Tidal Stream Generator, M. Y. Paish, H. Traylor and J. O'Nians

Aspects of mathematical modelling of a prototype scale vertical-axis turbine, Gareth I. Gretton and Tom Bruce

A direct drive generator for marine current energy conversion - first experimental results, K. Nilsson, M. Grabbe, K. Yuen and M. Leijon

Development of a Contra-Rotating Tidal Current Turbine and Analysis of Performance, J.A. Clarke, G.Connor, A.D. Grant, C.M. Johnstone and D. Mackenzie

Session 21
Wave Energy Converter Hydrodynamic Modelling 4, Room 1, Thursday, 13th September, 14:00-15:20

Representation of non-linear aero-thermodynamic effects during small scale physical modelling of OWC WECs, J. Weber

The Effect of Wavelength on the Response of Floating Ocean Wave-Energy Conversion Devices, D.R.B. Kraemer

Oscillating Water Column (OWC) wave power caisson breakwaters – the present status, the need for new developments, the problems, K.Thiruvenkatasamy and Michio Sato

A modular graphical user interface for WAMIT, Grégory S. Payne

Session 22
Future Guidelines, Room 2, Thursday, 13th September, 14:00-15:20

Wave Energy Development & Evaluation Protocol, B. Holmes, K. Nielsen, S. Barrett

Small scale physical model tests of floating wave energy converters, J.-M. Forestier, B. Holmes, S. Barrett and A. W. Lewis

Wave energy and the Pacific Islands market, Barbara Vlaeminck

An investigation of the Knowledge Base of the UK Marine Renewable Sector, Henry F Jeffrey, Markus Mueller and George Smith

Session 1

Plenary Session 1

Room 1, Tuesday, 11th September, 11:00-12:40

Chair: David Ingram, University of Edinburgh, UK
Co-Chair: Ana Brito Melo, Wave Energy Centre, Portugal

North American ocean energy status – March 2007

Roger Bedard[1], Mirko Previsic[2], George Hagerman[3], Brian Polagye[4], Walt Musial[5], Justin Klure[6], Annette von Jouanne[7], Uday Mathur[8], Craig Collar[9], Charles Hopper[10] and Scott Amsden[11]

[1]Electric Power Research Institute (EPRI), USA, [2]Revision Consulting, Sacramento, USA, [3] Virginia Tech, USA, [4]University of Washington, USA, [5]National Renewable Energy Laboratory, USA, [6] Oregon Department of Energy, USA, [7] Oregon State Universities, USA, [8] Pacific Gas and Electric Company, USA, [9] Snohomish Public Utility District, USA, [10]Nova Scotia Power Inc, Canada, [11] Tacoma Power , USA

Abstract

Ocean energy resources are attractive renewable supply alternatives for North America because good wave, tidal and river energy resources are found in close proximity to population centers. The Electric Power Research Institute (EPRI) established two North American collaborative programs to demonstrate ocean energy conversion in North America. The two collaborative programs bring together the resources and knowledge of 10 State Agencies, 2 Federal Agencies, 17 Electric Power Utilities, 3 Universities and over 30 Technology Developers. This paper summarizes key findings of these collaborative programs and provides the current status of the North American wave, tidal in-stream and river in-stream programs. Ocean energy accomplishments in North America to date include: (i) The first two tidal in-stream demonstration plants began operation in late 2006. (ii) Approximately 30 preliminary permits applications for tidal plants have been filed by private investors with the Federal Energy Regulatory Commission (FERC). (iii) Nova Scotia Power has announced a multi million dollar tidal in- stream pilot demonstration plant. (iv) Approximately 10 preliminary permits applications for wave plants have been filed with FERC. (v) The first full license application for a wave plant was filed with FERC in November, 2006. (vi) A river in-stream energy conversion feasibility study is underway.

The UKERC Marine Renewable Energy Technology Roadmap

M.A. Mueller, H. Jeffrey and A.R. Wallace
The University of Edinburgh, UK

Abstract

This paper summarises UKERC roadmapping activity in the last 12 to 18 months. A summary of previous activity is provided since the start in April 2005, to put the current status in context. Results of questionnaires and discussion summaries are presented in the paper, which shows that UKERC has adopted a consultative and consensus based approach to developing a technology road-map. As well as reinforcing the approach being adopted, constructive criticism was provided in the discussions at the Oxford workshop to assist in the development of the road-map. All the data collected since the start of the road-map is being collated and analysed to develop one road-map for the international marine renewable community. This paper provides a sample of some of that data.

The Strategy for the Next Five Years – International Energy Agency's Ocean Energy Systems (IEA-OES) Implementing Agreement

G. S. Bhuyan[1] and A. Brito-Melo[2]
[1]Powertech Labs Inc., Canada, [2]Wave Energy Centre, Portugal

Abstract

The work program for the first five-year term of the IEA-OES Implementing Agreement has been completed recently. The IEA-OES's strategy for the next 5-years has been approved by the Renewable Working Party (REWP) and the Committee on Energy Research and Technology (CERT) of the International Energy Agency as well as by the Executive Committee of the implementing agreement. This paper presents the scope of activities, strategic objectives and key collaborative actions targeted for the years 2007 to 2011.

Update on EMEC activities, resource description, and characterisation of wave-induced velocities in a tidal flow

J.V. Norris and E. Droniou
The European Marine Energy Centre (EMEC) Ltd, UK

Abstract

The European Marine Energy Centre (EMEC) has been established in the UK as an open-sea grid-connected test facility for wave and tidal devices. Developers receive detailed site information regarding the resource available, environmental characteristics, and meteorological data. There is a range of additional support, including assistance with legislation and consenting, as well as technical and operational matters. Whilst being primarily an operational test centre serving individual device developers, there is additional scope at EMEC for investigation of a range of unknown issues which need to be addressed by the wave and tidal industries in general as they develop to commercial viability. In addition to providing an update on the current situation at EMEC, this paper also discusses some of the work being undertaken at the centre on data provision and interpretation, in particular regard to the tidal test site. For its tidal test site, EMEC is currently developing Acoustic Doppler Current Profiler (ADCP) survey methodologies in order to address developers' needs for an appropriate picture of the raw energy. The tidal flow is not homogeneous. It is therefore necessary to capture waveinduced velocities which can be particularly important during high sea states and turbulence, especially within the seabed boundary layer. Progress in this ongoing work is also presented.

Environmental management recommendations for the wave energy Portuguese Pilot Zone

C.Huertas-Olivares[1], F. Neumann[1] and A. Sarmento[1,2]
[1]Wave Energy Centre, Portugal, [2]Instituto Superior Técnico, Portugal

Abstract

The Portuguese Government is developing legislation and regulations to create a Pilot Zone to support the deployment of offshore wave energy prototypes and farms. The Pilot Zone will be designed to support both the initial phase of the demonstration and the pre-commercial and commercial phases of wave energy utilization, up to a few hundreds of megawatts of installed power. It is of great importance that Portugal intends to address the environmental issues in a way that can be later considered as "Best-practice". The future reputation of this industry may partly depend on the success of this demonstration zone. This paper aims to give advice on an environmental management and monitoring strategy for the Portuguese Pilot zone taking into account former related projects, like the offshore wind farm experience in Denmark and the WaveHub.

Session 2

Plenary Session 2

Room 1, Tuesday, 11th September, 14:00-15:40

Chair: Lars Bergdahl, Chalmers University of Technology, Sweden
Co-Chair: Gregory Payne, University of Edinburgh, UK

Update on the modelling of a 1:33 scale model of a modified Edinburgh duck WEC

Jorge Lucas[1], Joao Cruz[1,2]; Stephen Salter[1], Jamie Taylor[1] and Ian Bryden[1]
[1]University of Edinburgh, UK, [2]Instituto Superior Técnico, Portugal

Abstract
A modified version of the Edinburgh duck wave energy converter has been studied recently at the University of Edinburgh. From the design point of view the key innovation was a modification of the wetted profile. Wave energy is converted into useful work by the same pitching motion as in the original duck, but by means of a circular cylinder with an off centred axis of rotation. This recent study was focused on a duck version designed for vapour compression desalination rather than electricity production. The duck was partially filled with water and the motion of the water inside provided the necessary pump effect for the vapour compression. The inner water behaves as an inertial reference as well as a double-acting piston. Under the assumptions taken, the results can be applied also to the electricity production version. WAMIT was used to predict the hydrodynamic coefficients and to select a set of configurations. A 1:33 scale model was tested at the Edinburgh curved tank to validate the numerical predictions. This paper extends the already published numerical predictions and experimental results obtained with this model, and reports on the new experimental tests and features. The relative capture width of the device that resulted from the measurements is presented, as well as the measured mooring forces in regular waves. Finally, the behaviour of a linear damper used to model the power-take-off mechanism is analysed.

The development of Oyster – A shallow water surging wave energy converter

Trevor Whittaker[1,2], David Collier[2], Matt Folley[1], Max Osterried[1], Alan Henry[1] and Michael Crowley[2]
[1]Queen`s University Belfast, UK, [2]Aquamarine Power Limited, UK

Abstract
In 2005 Aquamarine Power Ltd. was formed to develop Oyster, a near shore flap which is hinge connected to the sea bed. With a combination of private equity and grant aid a 350kW Oyster module has been designed and it is planned to install a prototype module at the EMEC test site in Orkney when the nearshore test berth is available. In this version of Oyster high pressure sea water will be pumped ashore to drive a Pelton wheel. Ultimately it is envisaged that Oyster units will be arranged in clusters feeding power to a power take off unit of between 3.5 and 5 MW capacity. Arrays of clusters will form power stations of 20 to 100 MW capacity.
An extensive research and development programme has produced a very efficient structural form, which gives Oyster one of the highest power to weight ratios of all current technologies combined with high capture factors in the most commonly occurring seas. The sea bed foundations and installation technique developed enables Oyster to be easily removed and reinstalled for major maintenance when required. This is a feature normally associated with moored devices. Although there are other bottom-hinged flap devices, Oyster is different in several ways and occupies a different part of the design space. For example, unlike the other systems it completely penetrates the water column from the water surface to the sea bed. Although it might be considered that such a system would be vulnerable in extreme seas, extensive wave tank modelling has shown that the flap intrinsically decouples from the wave as the oscillation increases and that the wave loads experienced are manageable in the three operational modes; generating, undamped and parked on the sea bed. However, model tests show that Oyster can remain generating in all sea-states including plunging breakers. This paper charts the evolution of Oyster presenting some of the research that has led to the current design. An outline of the impending sea trials of a prototype demonstration unit is given along with the projected outcomes.

Development of the ANACONDA all-rubber WEC

J.R.Chaplin[1], F.J.M.Farley[2], M.E.Prentice[3], R.C.T.Rainey[4], S.J.Rimmer[5] and A.T.Roach[3]
[1]Southampton University, UK, [2]Maritime Energy Developments Ltd, France, [3]Avon Fabrications LLP, UK,
[4]Atkins Consultants Ltd, UK, [5]SJR Consulting Ltd., UK

Abstract
The ANACONDA all-rubber WEC operates in a completely new way, capturing water waves as "bulge waves" in a giant water-filled rubber tube, aligned head-tosea. It offers new possibilities for low capital and operational costs, based on the unique durability of rubber, and the single moving part (a conventional medium-head unidirectional water turbine). See www.bulgewave.com. Avon Fabrications LLP have recently taken an exclusive license to manufacture the device, which has been selected by the Carbon Trust for the Marine Energy Accelerator programme. Initial model tests show good capture width and wide bandwidth. The economics of the device depend on the price of the rubber, per unit of elastic energy stored in it over its lifetime, in p/kWh. This must be less than the selling price of the electricity produced over the device lifetime, again measured in p/kWh. On this basis the economics of ANACODA are very promising.

Pico OWC Recovery Project: Recent Activities and Performance Data

F. Neumann[1], A. Brito-Melo[1], E. Didier[1] and A. Sarmento[1,2]
[1]Wave Energy Centre, Portugal, [2]Instituto Superior Técnico, Portugal

Abstract
The 400 kW Pico OWC plant was built in 1995-1998 with support from the European Commission and co-funding from EDP (Electricidade de Portugal) and EDA (Electricidade dos Açores), respectively the national and regional utilities. Instituto Superior Técnico (IST), Lisbon was responsible for the conception and basic engineering studies of this plant and co-ordinated the project. The plant is a bottom-mounted shoreline structure, equipped with a Wells turbine with guide vanes. In 2004-2006 a set of relevant repair works under the co-ordination of the Wave Energy Centre, in the scope of a national funding scheme, lead to the successful recovery and commissioning of the plant included a monitoring program indicating reasonable performance. Relevant data has been recorded, such as instantaneous values of the water free surface elevation inside the pneumatic chamber, the air pressure in the chamber, the air pressure (static and dynamic) in the turbine duct, the rotational speed of the turbine and the electrical power output delivered to the grid. Due to necessary modifications of the support structure of the turbo-generation unit, the tests have been discontinued in late 2006. Excessive vibrations at higher turbine speeds inherited from the original mechanical project presently the focus of ongoing efforts until end of August 2007.

Optimal Power Takeoff System Layout for the Seawave Slot-Cone Generator Kvitsøy Pilot Plant

Wilfried Knapp, Bernd Mayr, Matthias Faust and Rudolf Schilling
Technische Universität München, Germany

Abstract
WaveSSG is a novel wave energy converter in which the waves are running up a ramp, overtopping into three reservoirs situated at different heights above the mean sea level. The potential energy of the water in the reservoirs is converted into electrical energy by low-head hydro turbines in each reservoir. A full scale pilot plant of the WaveSSG with an installed capacity of 190 kW will be built on the Norwegian island of Kvitsøy; the deployment is scheduled for summer 2008. In order to find an optimum turbine configuration, a power simulation software program has been written, modelling the energy conversion process in the time domain. With this software, the system performance with different layouts of the power train has been evaluated. For each layout variant, optimum control parameters have been determined. Furthermore, the effect of changes in reservoir size has been investigated. The paper describes the simulation software, the modelling it is based on and the main findings from the parameter studies. A second aspect covered is the realisation of the turbine control. Different concepts including adjustable guide vanes, cylinder gates, butterfly and knife gate valves have been studied and compared. Finally, the turbine and control solution chosen after evaluation of overall efficiency, reliability, purchase cost, maintenance requirements and controllability is described.

Session 3

Plenary Session 3

Room 1, Tuesday, 11th September, 16:10-17:50

Chair: Trevor Whittaker, Queen's University of Belfast, UK
Co-Chair: Miguel Bessa Pacheco, Instituto Hidrográfico, Portugal

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Considering Mooring Cables for Offshore Wave Energy Converters

John Fitzgerald and Lars Bergdahl
Chalmers University of Technology, Sweden

Abstract

Wave energy developers have additional concerns to the survivability issue which is predominant in the mooring of conventional offshore structures in exposed areas. These include the role moorings will play in the deployment of farms of devices or the manner in which moorings might influence the motion of individual devices and their corresponding effect on power capture. These issues are discussed in the context of assessing 5 mooring cable types, each sized for the same extreme load requirements. This extreme load was chosen to be the load associated with a 40m/s wind and 1.03m/s current load applied collinearly on a cylindrical floater of diameter 15m. In addition, a wave induced orbital motion of radius 6m is applied to the cable's attachment point in order to represent the extreme wave induced load. A shallow water depth of 50m is assumed. The 5 cable types are then compared in terms of: overall weight and cost required to react the baseline extreme loads; mechanical impedance of the mooring cable at the attachment point and its likely influence on the motion of the floater; the seabed footprint and horizontal movement at the surface due to steady or slowly varying loads and its likely influence on array efficiency; deployment considerations, required bollard pull for anchor embedding, etc. The results highlight the potential of introducing elasticity and buoyancy in the cable. The introduction of modern efficient vertically loaded anchors in combination with flexible synthetic cables may mean that tension legs have the potential to provide very efficient mooring solutions in the future.

Geo-Spatial Multi-criteria Analysis for Wave Energy System Deployment

Ana Nobre[1], Miguel Pacheco[1], Raquel Jorge[2], M. F. P. Lopes[2] and L. M. C. Gato[2]
[1]Instituto Hidrográfico, Portugal, [2]Instituto Superior Técnico, Portugal

Abstract

The growing requirements for renewable energy production lead to the development of a new series of systems, including wave energy conversion systems. Due to their sensitivity and the impact of the aggressive marine environment, the selection of the most adequate location for these systems is a major and very important task. Several factors, such as technological limitations, environmental conditions, administrative and logistic conditions, have to be taken into account in order to support the decision for best location. This paper describes a geo-spatial multi-criteria analysis methodology, based on geographic information systems technology, for selection of the best location to deploy a wave energy farm. This methodology is not conversion system dependent and therefore can be easily customized for different systems and conditions. Selection factors can include, for example, ocean depth, bottom type, underwater cables, marine protected areas, ports location, shoreline, power grid location, military exercise areas, climatology of wave significant height, period and direction. A case study demonstrating this methodology is presented, for an area offshore the Portuguese southwest coast. The system output allows a clear identification of the best spots for a wave energy farm. It is not just a simple Boolean result showing valid and invalid locations, but a layer with a graded suitability for farm deployment.

Direct generation wave energy converters for optimized electrical power production

H. Lendenmann[1], K-C. Strømsem[2], M. Dai Pre[3], W. Arshad[1], A. Leirbukt[4], G. Tjensvoll[5] and T. Gulli[5]

[1]ABB Corporate Research, Sweden, [2]Intelligent Decisions AS, Norway, [3]University of Padova, Italy, [4]ABB AS, Power Technologies, Norway, [5]Fred Olsen Ltd, Norway

Abstract

New concepts for the direct conversion of the movement of a vertical heaving buoy point absorber to electricity are presented. The low loss direct conversion and generation system without intermediate hydraulic system permits hereto unprecedented speed and force control flexibility of the buoy movement. Three solutions are compared: an induction generator with a rack-pinion linear to rotary motion conversion and a step-up gear, a high pole application-specific permanent magnet (PM) generator with a belt-pulley linear to rotary conversion, and a linear PM generator mounted directly on the guide of the buoy. The linear generator is the least robust and most challenging in design, while the induction generator solution is found best due to its cost and maintenance advantages. The PM rotating generator solution shows the highest efficiency. Control strategies considering practical limitations (motor size, inverter rating) are explored and compared to linear damping and latching control. The peak power handling capability is optimized while diminishing the annual energy take-off only marginally. Simulations for irregular wave traces and the efficiency consequences are discussed. A 1:5 scaled test system using this direct conversion was installed at shore in real sea waves. Experimentally measured energy capture widths for wave-to-electricity in the range of 25% are reported.

The Ocean Energy Development Strategy for Ireland

Tony Lewis[1], Eoin Sweeney[2] and Graham Brennan[3]

[1]University College Cork, Ireland, [2]Marine Institute, Galway, Ireland, [3]Sustainable Energy Ireland

Abstract

This paper presents the current situation regarding the national policy for the development of ocean energy in Ireland. There are four Phases envisaged within this policy to encourage indigenous developers to progress commercial projects to prototype stage. The driving force behind the strategy is the large wave energy resource available at the Irish west coast compared with the electrical energy requirement of the country. The potential for commercial development is also recognized in this nascent industry where Irish developers are amongst the leading contenders worldwide. The first Phase of this strategy has been implemented with the establishment of a Centre of Excellence for R&D. The intermediate scale test site has been established in Galway Bay and two devices have been deployed there. A tidal stream device has also been demonstrated. The second Phase is currently being implemented with the establishment of the open sea test site where grid connected prototypes can be tested.

Characterising the wake of horizontal axis marine current turbines

A.S.Bahaj[1], L.E.Myers[1], M.D. Thomson[2] and N. Jorge[3]

[1]University of Southampton, UK, . [2]Garrad Hassan and Partners Limited, UK, [3]Garrad Hassan, Portugal

Abstract

This paper presents a discussion on the characterisation of the wake of horizontal axis marine current turbines. Understanding the effect devices have on the flow is critical in determining how one device may modify both the performance of and loading experienced by another device in a farm or array. It is the aim of this work to identify and investigate the parameters which govern the wake structure and its recovery to the free-stream velocity profile. An experimental and theoretical investigation of the flow field around small-scale mesh disc rotor simulators is presented. Wake characteristics of the rotor simulators have been measured in the 21m tilting flume at the Chilworth hydraulics laboratory, University of Southampton. The experimental results are at present being used to develop a numerical wake model for Marine Current Energy Converter (MCEC) devices. Based on an industry standard wind turbine wake model, developed by Garrad Hassan over the last 15 years, an eddy-viscosity model is presently being developed to model device wakes. This work has been conducted as part of a DTI-funded project to develop a tool which will assist in the layout design of arrays, ensuring they are optimally spaced and arranged to achieve the maximum possible energy yield at a given tidal energy site.

Session 4

Wave Energy Resource 1

Room 1, Wednesday, 12th September, 8:50-10:30

Chair: Maria Teresa Pontes, INETI, Portugal
Co-Chair: Brian Holmes, University College Cork, Ireland

Advances in Wave Resource Estimation: Measurements and Data Processing

J Cruz[1], E Mackay[2] and T Martins[1]

[1] Ocean Power Delivery Ltd, UK, [2]University of Southampton, UK

Abstract

New software has been developed by Ocean Power Delivery to process data from directional Waverider buoys. The software improves on existing packages by providing robust quality checking of the input time series, user definable options for spectral analysis and several advanced methods of directional analysis. Significant differences in parameters important to Wave Energy Converter (WEC) performance were noted when compared to the conventional processing. If not addressed, these differences can lead to inaccuracies when calculating WEC performance. The use of satellite altimeter data for long term resource prediction is also discussed. A new algorithm for estimating the wave period from altimeter data has been developed jointly by Ocean Power Delivery and the National Oceanography Centre, Southampton (NOCS). The algorithm is a significant improvement on previous models which were unable to properly reproduce the joint distribution of wave height and period, a necessity when estimating device response. The new algorithm enables mean monthly and annual Pelamis power output to be calculated to a high accuracy at any location in the world.

Influence of Sea-States Description on Wave Energy Production Assessment

M-A. Kerbiriou[1],M. Prevosto[1], C. Maisondieu[1], A.Clément[2] and A.Babarit[2]

[1]IFREMER, France, [2]Ecole Centrale de Nantes, France

Abstract

Sea-states are usually described by a single set of 5 parameters, no matter the actual number of wave systems they contain. We present an original numerical method to extract from directional spectra the significant systems constituting of a complex sea-state. An accurate description of the energy distribution is then given by multiple sets of parameters. We use these results to assess the wave climatology in the Bay of Biscay and to estimate the power harnessable in this area by a particular Wave Energy Converter, the SEAREV. Results show that the fine description of sea-states yields a better assessment of the instantaneous device response. The discrepancy between the classical and multi-sets descriptions shows that the new one is preferable for the assessment of harnessable power and for device design.

Comparison of linear and nonlinear energy and energy flux calculations for bi-chromatic long-crested surface water waves

W. Parsons[1] and R.E. Baddour[2]
[1]Consultant, Canada, [2]National Research Council of Canada, Institute for Ocean Technology, Canada

Abstract

We employ a fully nonlinear numerical model to generate and propagate long-crested gravity waves in a tank containing an incompressible invicid homogeneous fluid, initially at rest, with a horizontal free surface of finite extent and of finite depth. A non-orthogonal curvilinear coordinate system is constructed which follows the free surface and is "fitted" to the bottom topography of the tank and therefore tracks the entire fluid domain at all times. A waveform relaxation algorithm provides an efficient iterative method to solve the resulting discrete Laplace equation, and the full nonlinear kinematic and dynamic free surface boundary conditions are employed to propagate the solution. In addition, a bi-chromatic deterministic theoretical wave-maker, employing a Dirichlet type boundary condition, and a suitably tuned numerical beach are utilized in the numerical model. Using our fully nonlinear model, we calculate the energy and energy flux for both small steepness bi-chromatic waves and for larger steepness bi-chromatic waves and compare these results with the results from linear theory. In particular, this paper evaluates the validity of the superposition principle inherent in linear estimations of energy and energy flux calculations for bi-chromatic and, in general, multi-chromatic waves. Special attention is given to the phenomenon of the nonlinear interaction of the "higher order components", especially near resonance situations, and its effect on energy and energy flux.

Sea & Swell Spectra

Brian Holmes, Sean Barrett
University College Cork, Ireland

Abstract

The Hydraulics & Maritime Research Centre (HMRC) is currently investigating the spectral composition of seaways that occur off the western seaboard of Ireland. This level of detail is important to wave energy development since most devices proposed to date have resonant responses, so the exact excitation frequencies forcing the machines must be known to accurately predict the performance. Typically a device's annual production would be estimated from a scatter diagram for any sea area and a corresponding power matrix. However, within the occurrence of a certain wave height and period the spectral shape can vary from the classical shapes such as Bretschneider and JONSWAP traditionally employed in both physical and mathematical modelling programmes. The validity for this assumption relative to the sea areas where WEC will be deployed will be validated by a number of means such as plotting the bivariate scatter plot against another temporal statistic, where the amount of deviation from a classical spectrum can be seen. The primary data source is a full year's archive of Waverider buoy records from a 60m station just over one nautical mile from the coast. This information will be extended by additional shorter duration measurements over the coming year at similar type sites. A secondary investigation is being conducted into the fidelity of computer predicted spectra and whether this information can be relied upon for device evaluation. Simultaneous predicted records from a Regional WAM program run by Met Éireann, are being obtained and checked against the measured records. These are provided in the form of a full 3-dimensional energy flux table of 30 frequencies and 24 directions output every 6 hours (with a 48 hourly forecast). A previous contract had verified the accuracy of the summary seaway statistics but this is the first time the spectral profiles have been investigated. This paper will present the findings from the study, with particular interest in the results from the analysis of a number of large storm occurrences during December 2006.

Spectral Bandwidth and WEC Performance Assessment

J.-B. Saulnier[1], P. Ricci[2], M. T. Pontes[2] and A. F. de O. Falcão[1]
[1]Instituto Nacional de Engenharia, Tecnologia e Inovação, Portugal, [2]Instituto Superior Técnico, Portugal

Abstract

This paper investigates the dependency of wave energy conversion on the spectral bandwidth of sea-states. To this aim, the performance of an axisymmetrical Wave Energy Converter is assessed in the frequency domain by using a stochastic model in two far different wave climates (Portugal and North Sea) both represented by more than 23000 energy spectral densities obtained from measurements. The correlation between the performance and various bandwidth parameters found in the literature is observed. Then, refined methods for predicting the long-term converted wave energy based on wave statistics including spectral bandwidth are compared to more common procedures and conclusions are drawn.

Session 5

Wave Power Take-off

Room 2, Wednesday, 12th September, 8:50-10:30

Chair: Henk Polinder, Delft University of Technology, The Netherlands,
Co-Chair: Frank Neumann, Wave Energy Centre, Portugal

Offshore experiments on a direct-driven Wave Energy Converter

J. Engström[1], R. Waters[1], M. Stålberg[1], E. Strömstedt[1], M. Eriksson[1], J. Isberg[1], U. Henfridsson[2], K. Bergman[3], J. Asmussen[3], and M. Leijon[1]

[1]Uppsala University, Sweden, [2]Vattenfall Research & Development, Sweden, [3]Vattenfall AB, Sweden

Abstract

The direct-driven linear generator wave power plant being developed at the Swedish Centre for Renewable Electric Energy Conversion at Uppsala University was launched in the spring of 2006 and has during more than two months been tested in real ocean wave conditions. This first prototype was built mainly to test the overall concept in terms of survivability and energy extraction. The full scale prototype Wave Energy Converter has been connected to a 2.9 km long sea cable and, during 2 months, power has been delivered to a resistive load placed on the island Gullholmen situated at the Swedish west coast. The load resistance is adjustable which has allowed the testing of power absorption for different resistive loads. By European standards, the wave climate on the test site is poor, and during the test period the mean energy flux was slightly less than 1.4 kW/m. The output voltage shows great variation in amplitude and frequency. It is indicated that the optimum resistive load to achieve high power absorption is independent on wave climate. The relative power absorption for this configuration is shown to be higher in the lower range of the wave spectrum.

The Power Takeoff System of the Multi-MW Wave Dragon Wave Energy Converter

Marek Jasinski[1], Wilfried Knapp[2], Matthias Faust[2] and Erik Fris-Madsen[3]

[1]Warsaw University of Technology, Poland, [2]Technische Universität München, Germany, [3]WaveDragon ApS, Denmark

Abstract

Wave Dragon is a wave energy converter of the overtopping type. The waves are focused onto a ramp by two reflector arms and overtop into a reservoir above the mean sea level. The potential energy of the water in the reservoir is converted into electrical energy by a set of lowhead hydro turbines and generators. Wave Dragon will be built next winter as a full scale pre-commercial demonstrator device offshore the Welsh coast with a power output of 7 MW, called the *Wave Dragon MW*. After its deployment in 2008 it will be the world's largest wave energy converter. The complete power train from the hydro turbines to the electricity feed into the grid will be described, and the main design approaches for the components will be discussed. For a reliable and cost optimal solution a number of different turbine/generator arrangements have been investigated, taking layouts with direct driven permanent magnet generators into consideration as well as induction generators combined with gearboxes. For controlling the generator and feeding the electric energy into the grid a number of options like full back-toback AC/DC/AC converter (transistors based LSC and GSC) or transistor based LSC with step-up chopper (DC/DC converter) and diode rectifier have been evaluated. The main objective of this paper is to discuss the control methodology of the power electronics. Results found in simulations and in experimental investigations are shown. Finally, based on these results a recommendation for an optimal power takeoff train in terms of control accuracy, overall efficiency, reliability, purchase cost, maintenance requirements and power quality is given.

Linear generator systems for wave energy conversion

H. Polinder[1], M.A. Mueller[2], M. Scuotto[1] and M. Goden de Sousa Prado[1,3]

[1]Delft University of Technology, The Netherlands, [2]The University of Edinburgh, UK, [3]Teamwork Technology, The Netherlands

Abstract

The objective of this paper is to review linear generator systems for wave energy conversion and the research issues related to this. The paper starts with a short review of wave energy conversion, indicating that the different wave energy conversion systems that have been presented in literature have very different generator systems. Next, a few state-of-the-art linear generator systems are discussed, such as the linear generator of the Archimedes Wave Swing (AWS) and the linear generator developed in Uppsala. Subsequently, some remaining problems and possible solutions that need further research are listed. The paper concludes with some sensible directions for further research, such as investigating an increase of the speed of the linear motion of the wave energy converter, investigating other generator types with higher force densities and possibly better efficiencies (for example, transverse flux permanent magnet machines) and investigating generator constructions that result in cheaper generators.

AquaBuOY Hose-Pumps – theory and experimental results

Alla Weinstein[1], Kim Nielsen[2], Kam Biaz Zandiyeh[3] and Johnathan Bensted[4]

[1]Finavera Renewables Ocean Energy (Europe), Ltd, UK, [2]Ramboll, Virum, Denmark, [3]Dunlop, Grimsby, UK, [4]Renewable Power Consulting Ltd, UK

Abstract

Hose-pumps, produced from reinforced rubber hoses, have been incorporated in the IPS buoy system to form the central part of the power take off system of the AquaBuOY. As part of the development of AquaBuOY, the performance of the hose pumps has been verified through dynamic testing. The paper presents the theory behind the Hose-Pump, explains the working principles and presents experimental results from static and dynamic testing compared to theoretical predictions. A number of scale hose-pump samples were built and tested in a test rig to characterize the hose-pump performance, to determine and verify its operational conversion efficiency and to validate the expected life-cycle. The measured data have been used to validate hose-pump numerical models and to compare its operation to the test results from testing performed in Sweden in the beginning of the 1980's. The present experimental results have confirmed the theoretical relations for a number of different angles of hose-pump reinforcement under static and dynamic performance conditions. The basic theory is shown to be in good agreement with test results. Dynamic testing has validated the conversion efficiency to be in the 70-80% range.

A Novel Lightweight Permanent Magnet Generator for Direct Drive Power Take Off in Marine Renewable Energy Converters

Markus Mueller, Alasdair McDonald, Kenneth Ochije and John Jeffrey

The University of Edinburgh, UK

Abstract

The evolution of a novel permanent magnet (PM) generator topology is described in the paper. It has the significant potential to be lighter than conventional PM machine topologies, making it attractive for direct drive applications in wind, wave and tidal current generators. The philosophy of the generator concept is based upon reducing the structural mass by eliminating large unwanted magnetic attraction forces that exist in all conventional iron-cored electrical machines. A comparison with an existing commercially available rotary PM generator for a 100kW turbine is presented to show the potential of the new topology.

Session 6

Wave Energy Converter Arrays

Room 3, Wednesday, 12th September, 8:50-10:30

Chair: Spyros Mavrakos, National Technical University of Athens, Greece,
Co-Chair: Paulo Justino, INETI, Portugal

A preliminary study on the optimal formation of an array of wave power devices.

Colm Fitzgerald[1] and Gareth Thomas[2]
[1]Loughborough University, UK, [2]University College Cork, Ireland.

Abstract
This paper describes a preliminary study into the optimal formation of an array of heaving semi-submerged spheres. A small body approximation is employed and an important new consistency condition for the interaction factor q is presented. With attention directed towards a five-member array, the results from a numerical optimisation study are presented and identify optimal behaviour in both symmetric and non-symmetric configurations.

Interaction of waves with an array of floating wave energy devices

B. F. M. Child and V. Venugopal
The University of Edinburgh, UK

Abstract
A method is presented to analyse wave interactions with an array of simplified wave energy devices. The problem is formulated in terms of a group of heaving vertical circular cylinders floating in the ocean, whose motion is damped by their power take-off mechanisms. Under the assumptions of linear wave theory, an exact analytical solution is derived in order to compute wave and body motion amplitudes. From these, the hydrodynamic heave exciting force, the added mass and damping coefficients, and the power extracted by each element of the array are calculated and presented as functions of incident wave number. The numerical implementation proved particularly efficient and the results compare very well with other theoretical and experimental work.

Wave climate investigation for an array of wave power devices

V.Venugopal[1] and G.H.Smith[2]
[1]University of Edinburgh, UK, [2]University of Exeter, UK

Abstract
This paper presents the results of a study carried out to determine the change in wave climate around an array of hypothetical wave devices. The main objective of this work is to investigate the change in wave height in the upstream and downstream of the devices for different levels of wave absorption. This is achieved by modeling the wave devices as porous structures with different porosity levels, with the inclusion of partial reflection and partial transmission. The MIKE 21 suite wave models, (i) Spectral wave and (ii) Boussinesq wave are used for this purpose. The former wave model is employed for the estimation of various phase averaged wave parameters for the Orkney Islands. These wave parameters are then used as input to the Boussinesq model to study wave-device array interactions. The results are presented in the form of wave disturbance coefficients defined as a ratio of the significant wave height at a particular location relative to the incoming or input significant wave height. This study illustrates how the variations in wave absorption by the devices affect the degree of wave reflection and transmission around the devices.

Power Smoothing by Aggregation of Wave Energy Converters for Minimizing Electrical Energy Storage Requirements

M. Molinas[1], O.Skjervheim[1], B. Sørby[2], P. Andreasen[1], S. Lundberg and T. Undeland[3]

[1]Norwegian University of Science and Technology, Norway, [2]Norwegian University of Life Sciences, Norway,

[3]Chalmers University of Technology, Sweden

Abstract

The degree of reduction of required electrical energy storage for smoothing the power output in a wave farm is investigated by considering spatial power smoothing by a particular choice of aggregation of wave energy converters (WEC). Several possible arrays are analyzed considering that no energy storage is provided locally at each WEC unit and that all energy storage required will be electrical and provided at the point of connection to the electrical network. This paper focuses on a case study of direct drive WEC for near shore devices and the power output data implemented in the study derives from a linear hydrodynamic model developed in Matlab with input forces obtained by solving the radiation problem with the finite element simulation tool Comsol. The results from simulations indicate that there is a significant smoothing effect for sinusoidal waves and quite a good short term smoothing effect is achieved in an irregular sea.

Session 7

Wave Energy Converter Hydrodynamic Modelling 1

Room 1, Wednesday, 12th September, 11:00-12:40

Chair: Johannes Falnes, Norwegian University of Science and Technology, Norway
Co-Chair: João Cruz, Ocean Power Delivery, UK

Diffraction Effects near Foz do Douro Breakwater

H. Martins-Rivas and C.C. Mei
Massachusetts Institute of Technology, USA

Abstract
In order to determine the response inside an OWC pneumatic chamber situated at the head of a breakwater to incident waves and assess the possible effects of the breakwater geometry, we have developed a threedimensional numerical model based on the linear theory. In the model the hybrid element method is applied. The thickness of the remote part of the long breakwater is ignored. Numerical results are obtained for a skeletal geometry of the the Foz do Douro breakwater. The high response in the chamber suggests the need for further account of separation losses at the opening. The strategy is outlined.

A linearized model of OWC devices with additional vertical ducts

S. M. Camporeale[1] and P. Filianoti[2]
[1]Politechnic University of Bari, Italy, [2]University Mediterranean of Reggio Calabria, Italy

Abstract
Under the hypothesis of random sea waves with Gaussian distribution, the paper proposes an original methodology for linearizing the differential equations governing the dynamics of a REWEC plant. This device can be easily embodied in a caisson breakwater, and consists of an OWC with an additional vertical duct in the wave-beaten side of the breakwater. The methodology is applied to a plant with given geometry and turbine shape. The obtained average performance are compared with the results obtained by integrating in the time domain non-linear differential equations. The stochastic approach proves to be effective to estimate average power output, even at highest values of wave heights attacking the breakwater.

Performance analysis of a model of OWC energy converter in non-linear waves

A.C. Mendes and W.M.L. Monteiro
Universidade da Beira Interior, Portugal

Abstract
This paper evaluates the impact of hydraulic losses on the overall performance of oscillating-water-column wave power converters. A review on energy loss in OWC's is firstly presented, within the scope of shoreline systems. In order to assess the efficiency of the power conversion process a series of wave-tank experiments were conducted with a physical model, in regular waves. Different wave conditions and power take-off constraints were imposed on the model, for which the amplification factor, the energy absorption efficiency, the internal efficiency and the overall conversion performance of the system were determined. In parallel, a sequence of video-frames of the flow in the water column helped us to uncover the physics of energy dissipation in the system.

A Physical and Numerical Study of a Fixed Cylindrical OWC of Finite Wall Thickness

R. K. Sykes, A. W. Lewis and G. P. Thomas
University College Cork, Ireland

Abstract

An investigation is undertaken into the hydrodynamic behaviour of a thick-walled fixed vertical Oscillating Water Column (OWC) in finite depth. This is facilitated through numerical modelling with the Boundary Element Method (BEM) code WAMIT and the use of this code is verified by comparison with an eigen-function expansion method by Mavrakos, specifically for this geometry. Comparisons of numerical predictions of pressure are made with measurements from a dedicated experimental programme. These validate the code and demonstrate the variation of hydrodynamic pressure in an OWC.

Experimental and numerical analysis of the oscillating water column inside a surface-piercing vertical cylinder in regular waves

M.F.P. Lopes, Pierpaolo Ricci, L.M.C. Gato and A. F. de O. Falcão
Instituto Superior Técnico, Portugal

Abstract

The movement of the free surface inside a surface piercing cylindrical duct, simulating a floating OWC in regular waves, was analysed experimentally and by numerical simulation, and the results were compared with an analytically obtained solution. This provided insight into the influence of each of the terms in the equations that govern the dynamics of the system, especially the hydrodynamic and damping coefficients. The experimental values show that the viscous damping due to real fluid effects is important, at least at the scale of the model. The prediction of the natural frequencies was found to be accurate. The measured dynamic response of the system agreed fairly well with the predictions. A detailed analysis of the free surface shape for different resonant frequencies showed that the sloshing modes are present and their shape can be determined from numerical simulation. However, they are significant for frequency much higher than the range of frequencies of interest for the OWC applications where the column is narrow with respect to the width. The consideration of the wall thickness, water depth and the order of the numerical solution has significant importance in the radiation damping.

Session 8

Environmental Impact and Consent Process

Room 2, Wednesday, 12th September, 11:00-12:40

Chair: Georgios Lemonis, Greece,
Co-Chair: Marc Hadden, Martifer, Portugal

Environmental Impact and Appraisal – Gaining Planning Consent for the South West of England Wave Hub

Nick Harrington[1] and Inma Andina-Pendás[2]

[1]South West of England Regional Development Agency, UK, [2]Halcrow Group Limited, UK

Abstract

Wave Hub is an innovative demonstration site for generation of wave energy located in the South West of England. In simple terms Wave Hub consists of an offshore electrical "socket" to connect arrays of wave energy converters to the national grid via under-sea cables, allowing technology developers to demonstrate and monitor the operation of their devices in real sea conditions. A key element in the development of the proposed Wave Hub is to gain consent from the relevant UK regulatory bodies. This paper describes the process for the consent application followed and highlights the main issues encountered during the preparation of the environmental studies to support the application.

Wave power devices as artificial reefs

Olivia Langhamer and Dan Wilhelmsson

Uppsala University, Sweden

Abstract

Offshore energy installations, such as wave power parks have large area demands. Little is known about their effects on the marine environment, and early studies may minimize environmental risks and enhance potential positive effects on the marine environment. The Islandsberg project is a wave power park located on the Swedish west coast under construction since 2005. Here, buoys acting as point absorbers are connected to generators anchored on concrete foundations on the seabed. Most likely, biofouling has the potential to be an engineering concern but at the same time, these structures can be considered as artificial reefs. In the present study the colonisation of foundations by invertebrates and fish was investigated. The influences of holes in and on the surface of the foundations on colonisation and species composition were examined and a succession in colonisation over time is shown. Structural heterogeneity may enhance the colonisation of macrobenthic organisms. This pilot study is the first contribution to what constitutes an important research topic based on different ideas of an effective and purposeful reef design integrating wave power devices and their development.

Wave Dragon : Results From UK EIA and Consenting Process

Iain Russell[1] and Hans Chr. Sorensen[2]
[1]Wave Dragon Ltd, UK, [2]Spok ApS and Wave Dragon ApS, Denmark

Abstract

After nearly two decades of development and over 20,000 hours of real-sea 1:4.5 scale testing, Wave Dragon have encountered and solved a considerable number of issues and learned to optimise the control of our device in a vast range of situations and conditions. The next stage of realisation is to deploy a full scale (7MW) unit in UK Waters; the application for formal consents were made on the 27th of April 2007. A full Environmental Impact Assessment (EIA) has been conducted assessing all the information on biological, physical and human factors that the consenting authorities may consider pertinent. An EIA must also consider how these factors interrelate with each other and with other issues such as public perception, socio-economic factors, risk assessment and safety. The EIA and Consents processes are often where technology meets policy, practice and the public for the first time; and the process itself can be complex. This paper will present Wave Dragons actual experiences of the EIA and Consent application process in the UK from Initial Consultations, EIA process, through to consent submission to responsible authorities. This paper details the initial discussions with Consenting bodies and the initial geophysical / navigational work. The paper will then present how this information was taken, assessed and, in conjunction with Consenting bodies, how it was used to formulate a full survey assessment of the deployment site and land fall areas. The Paper will also present the findings of these surveys and how this information was utilised in the Environmental Statement and Consents.

Regulatory Interventions in Support of Marine Energy Deployments in New Zealand

J.A. Huckerby
Power Projects Limited, New Zealand

Abstract

The immense potential marine energy resources of New Zealand have been recognized for many years but development of marine energy projects has lagged behind European and North American developments. Happily the gap is beginning to close for a number of reasons: (i) Increasing energy supply/demand imbalances. (ii) Increased costs for imported, internationally traded energy products. (iii) Need to meet greenhouse gas emissions reductions targets. (iv) Potential incentives for new renewable generation. Nonetheless, it will be some time before marine energy will be commercially competitive with other renewable and fossil fuel forms of generation. It is therefore appropriate and necessary for the New Zealand Government to offer legislative and regulatory support for marine energy projects, not only R&D but also for establishment of demonstration and commercial projects. In December 2006 the New Zealand Government published a number of draft energy and climate change strategy documents for consultation, a process that closed on 30 March 2007. Implementation of legislation or regulations to give effect to the Government's strategic objectives is anticipated in the second half of 2007. Proposed initiatives to promote marine energy include a '*marine energy deployment fund*', potential for a revenue support mechanisms, such as a '*feed-in tariff*' and a "*Renewables Obligation*" and priorities for R&D funding. New Zealand will provide an interesting case study for other countries, contemplating how to accelerate and promote uptake of marine energy.

Impact of Santoña WEC installation on the littoral processes

César Vidal[1], Fernando J. Méndez[1], Gabriel Díaz[1] and Roberto Legaz[2]
[1]Universidad de Cantabria, Spain, [2]Iberdrola Energías Renovables, Spain

Abstract

Iberdrola Energías Marinas de Cantabria is installing a Wave Energy Conversion (furthermore referred to as WEC) plant 4 Km northeast of Berria beach in Santoña, northern Spain. The buoy field will occupy a rectangular area of 800 by 600 m with the long side oriented towards the dominant wave direction. This paper analyses the impact of the plant in the nearshore dynamics. After an approximate evaluation of the WEC plant wave transmission, the available wave data base has been propagated to the coast with and without the presence of the WEC plant and the differences on wave height and direction, wave-driven currents and nearshore transport have also been evaluated and analysed. After the analysis of results, the impact of the plant on the nearshore dynamics has been found to be negligible. The methodology developed for this study can be applied to bigger WEC implementations where the impact on the coast's morphodynamics could be noticeable.

Session 9

Tidal Energy Resource and New Concepts

Room 3, Wednesday, 12th September, 11:00-12:40

Chair: AbuBakr Bahaj, University of Southampton, UK,
Co-Chair: António Trigo Teixeira, Instituto Superior Técnico, Portugal

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Effects of tidal energy extraction at Portland Bill, southern UK predicted from a numerical model

L. S. Blunden and A. S. Bahaj
University of Southampton, UK

Abstract

An array of tidal stream generators situated off Portland Bill headland (English Channel coast, Southern UK) was simulated using a two-dimensional finite element model developed with the T´EL´EMAC hydrodynamic modelling system. The effect of energy extraction was parameterized as a stress proportional to the square of flow speed, linearly interpolated in space across affected elements within the mesh. Different resolution finite element meshes were used to indicate the degree of mesh-independence of the simulation. For each run, one month of simulation results were analyzed in terms of harmonic constituents using T TIDE. The distributions of cubed speeds over 18.6 years were then compared for cases with and without energy extraction, in order to quantify the difference in predicted input power to the generator array. It was found that in the bin that was closest to the rated speed chosen for the array, 15–16 $(m/s)^3$, there was a reduction in available energy of approximately one third. This implies that there could be a large impact upon individual generator design criteria in this case, subject to future validation of this method of simulating energy extraction, through experimental results.

The power potential of tidal streams including a case study for Masset Sound

J. Blanchfield, A. Rowe, P. Wild and C. Garrett
University of Victoria, Canada

Abstract

Interest is growing among utility companies and governments of maritime countries in assessing the power potential of tidal streams. While the latest assessment for Canadian coastlines estimates a resource of approximately 42 GW, these results are based on the average kinetic energy flux in the undisturbed state through the most constricted cross-section of a channel. It has been shown, however, that this method cannot be used to obtain the maximum extractable power for electricity generation. This work presents an updated theory for the extractable power from a tidal stream in a channel linking a bay to the open ocean. A mathematical model is developed for one-dimensional, non-steady flow through a channel of varying cross-sectional area, and includes flow acceleration, bottom surface drag, and exit separation effects in the dynamical balance. The model is applied to Masset Sound in Haida Gwaii, a remote island region, to determine the extractable power and its associated impacts to the tidal amplitude and flow rate through the channel.

Tidal currents assessment in the Tagus estuary

A. Mendonça and A. Trigo Teixeira
Instituto Superior Técnico, Portugal

Abstract
The authors present in this paper the results of an initial assessment of the potential of tidal currents to generate energy in the Tagus estuary. The work is divided into three phases. The first phase comprises the setting up and calibration of a detailed finite element model for the estuary starting in the ocean boundary. The model was calibrated and verified using water levels and current velocities for several measuring stations within the estuary. The measuring campaign took place in 1987 and was performed by Instituto Hidrográfico of the Portuguese Navy. The records are of good quality and cover a period of spring and neap tides. The model give clear indication about the flow pattern within the estuary showing the places were high current velocities are likely to occur. Calculation of the tidal power on selected locations was made. The second phase consisted on the study of the requirements of tidal turbines in terms of site conditions: mainly the minimum water depth and current velocity required for installation. In addition a review was made to understand the development of tidal turbine tech for the site, which usually are associated with moderate current velocity. The third and final phase was the study of the estuary "map-use" trough the construction of a GIS system that allows the identification of locations of potential conflict.

Development of a floating tidal energy system suitable for use in shallow water

S.R. Turnock, G. Muller, R. F. Nicholls-Lee, S. Denchfield, S. Hindley, R. Shelmerdine and S. Stevens
University of Southampton, UK

Abstract
A proposal is made for the use of a traditional stream waterwheel suspended between two floating catamaran NPL series demi-hulls as means of generating electrical power. Two prototype devices, of lengths 1.6m and 4.5m, have been developed, constructed and tested. It was found that the concept is sound although greater investment is required with regards to the materials and both hydrodynamic and aerodynamic design of the waterwheel to ensure an economically viable system. The work presented concentrates on practical aspects associated with design, construction and trial testing in Southampton water of the 4.5m prototype. The relatively low cost, ease of deployment, and the fact that conventional boat mooring systems are effective, combine to make this an attractive alternative energy solution for remote communities.

Empirical Modelling of Low Speed Flow over LAR Hydrofoils

A.Owen
The Robert Gordon University, UK

Abstract
Low aspect ratio hydrofoils have a variety of potential uses in tidal current energy for harnessing or directing the moving flow relative to a stationary body. Such a body is the Sea Snail, a purpose-built support structure for tidal turbines and other related plant, that utilises an array of six hydrofoils to harness the pressure energy within the flow thereby enhancing the devices inherent submerged weight. This paper shows the empirical testing of the array at $1/7^{th}$ scale within a river environment.

Session 10

Wave Energy Converter Hydrodynamic Modelling 2

Room 1, Wednesday, 12th September, 14:00-15:40

Chair: Alain Clément, Ecole Centrale de Nantes, France,
Co-Chair: António Carlos Mendes, Universidade da Beira Interior, Portugal

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Friction for a floating body heaving along a fixed vertical guiding strut

Torkel Bjarte-Larsson
Norwegian University of Science and Technology, Norway

Abstract
The investigated floating body heaving along a fixed vertical guiding strut is a part of a wave-energy converter, which is an axisymmetric point absorber, utilises the relative heave motion between a float and a body submerged beneath the float. In order to analyse the amount of produced useful wave power from a given incident wave, not only quantitative information on the hydrodynamic parameters of the two-body wave-absorbing system is needed, but also on the friction parameters. In the present work these friction parameters are experimentally determined for three frequencies. Also computed results for hydrodynamic parameters are presented.

Point-absorber arrays: a configuration study off the Portuguese West-Coast

Pierpaolo Ricci[1], Jean-Baptiste Saulnier[2] and António F. de O. Falcão[1]
[1]Instituto Superior Técnico, Portugal, [2]INETI, Portugal

Abstract
The geometry of a wave energy converter (WEC) has a major influence on the power it can theoretically absorb. One of the first steps in the WEC design is the optimization of its geometry. If large power levels are to be attained, the individual WECs must be incorporated into "wave farms", consisting in one or more arrays of devices, each device having its own PTO equipment. It is then important to understand how the different oscillators interact with each other and how their relative positions and distances affect the performance of the system. A simple WEC consisting of a single axisymmetric oscillating body equipped with a linear PTO mechanism is considered first. The dependence, on geometry and size, of the power absorption from irregular waves is investigated, based on a stochastic model. This is followed by a study on the hydrodynamics of arrays of different configurations, and their performance in irregular waves. It is expected that the analysis developed here may be applied to a wide variety of wave WECs.

Energy Converters under First- and Second-order Wave Loads

S.A. Mavrakos, G.M. Katsaounis and I.K. Chatjigeorgiou
National Technical University of Athens, Greece

Abstract
The paper deals with the presentation of a numerical model to predict performance characteristics of tight moored vertical axisymmetric wave energy converters that are allowed to move in the heave, pitch and sway modes of motion. The first-order hydrodynamic characteristics of the floater, i.e. exciting wave forces and hydrodynamic parameters, are evaluated using a linearized diffraction –radiation semi-analytical method of analysis that is suited for the type of bodies under consideration. The floating WEC is connected to an underwater piston that feeds a hydraulic system with pressurized oil. The performance of the system under the combined excitation of both first- and second-order wave loads is here analyzed. To this end, the diffraction forces originated from the second-order wave potentials are computed using a semi-analytical formulation which, by extension of the associated first-order solution, is based on matched axisymmetric eigenfunction expansions.

Modelling and Simulation of Sea Wave Power Conversion Systems

Hallvard Engja and Jorgen Hals
Norwegian University of Science and Technology, Norway

Abstract

Ocean energy conversion has been of interest for many years. Recent developments such as concern over global warming have renewed interest in the topic. Wave energy converters are complex and expensive to develop, and for this reason is this paper introducing the use of mathematical models and computer simulation as an important tool in system development. The computational capabilities are not a problem any longer, but model construction still seems to be a hurdle. A method well established as a valuable aid in constructing models of physical systems is the method of bond graphs. It is a multi-domain concise pictorial representation of the energy exchange in a system. In this paper we discuss issues related to physical system modelling and an outline of the bond graph language. A complete mathematical model of a floating buoy and semi-submersible platform with downstream hydraulic system is presented in addition to simulation results.

Frequency-domain and stochastic model for an articulated wave power device

J. Cândido and P.A.P. Justino
INETI, Portugal

Abstract

To have the first look into device performance, analytical and numerical tools must be used. Assuming that the wave power system hydrodynamics has a linear behaviour, diffraction and radiation coefficients can be computed. If the power take-off equipment may be, for the first approach, regarded as holding a linear behaviour then overall (i.e. hydrodynamic plus mechanical) device performance can be studied for regular waves. In this study a frequency-domain model describes the articulated system behaviour for regular waves. For this paper a stochastic model is found for an articulated wave power device, and probability density functions are defined for the relevant parameters that characterize the wave power system behaviour. For these parameters and for different sea states the probability density functions are found. The articulated system is characterized by these probability density functions. Also, average values for capture width are obtained for these sea state conditions.

Session 11

Air Turbines 1

Room 2, Wednesday, 12th September, 14:00-15:40

Chair: Luís Gato, Instituto Superior Técnico, Portugal
Co-Chair: Tom Heath, Wavegen, UK

Design of a baffle-plate for an OWC-WEC equipped with vertical-axis air-turbines: Numerical study of the air-flow

J. M. Paixão Conde[1] and L. M. C. Gato[2]
[1]New University of Lisbon, Portugal, [2]Instituto Superior Técnico, Portugal

Abstract
The paper presents a numerical study of the air-flow in a typical pneumatic chamber geometry of an oscillating water column (OWC) type wave energy converter (WEC), equipped with two vertical-axis air turbines, asymmetrically placed on the top of the chamber. Outwards and inwards air-flow calculations were performed to investigate the flow distribution at the turbine inlet section, as well as the properties of the air-jet impinging on the water free-surface. The numerical study was performed using the FLUENT code. Steady and periodic flow conditions were assumed in the calculations. The original design of the OWC is likely to be harmful for the operation of the turbines due to the possible air-jet produced water-spray at the water free-surface subsequently ingested by the turbine. A geometry modification of the air chamber, using a horizontal baffle-plate to deflect the air from the turbines, is proposed to reduce the risk of water-spray production from the inwards flow. The influence of three different baffle-plate geometries was studied and two of them proved to be very effective. The flow distribution at the turbine inlet section for the outwards flow was found to be fairly uniform for the geometries considered, providing good inlet flow conditions for the turbines. Steady flow was found to be an acceptable model to study the air-flow inside the pneumatic chamber of an OWC-WEC.

The Development of a Turbo-Generation System for Application in OWC Breakwaters

T.V. Heath
Wavegen, UK

Abstract
A breakwater is currently under construction in the town of Mutriku in the Basque country of northern Spain. Following a contract award for the Nereidas project under the EU Framework 6 programme an OWC system using Wells Turbine - Induction generator power take off units will be incorporated into the breakwater scheme. The plant, with a nominal 300kW rating, is scheduled for commissioning in the spring of 2009. The paper describes the development of the turbogeneration system through:

- Characterisation of the collector in tank model tests.
- Specification of the turbine in terms of operational envelope and damping.
- Mechanical arrangement of turbine and generator.
- Test programme on LIMPET
- Environmental considerations.
- Control equipment and architecture.

Advances in Oscillating Water Column Air Turbine Development

W.K. Tease, J. Lees and A. Hall

Wavegen, UK

Abstract

This paper describes the methods developed by Wavegen during the design and development phase of its air turbine suitable for installation into active renewable energy breakwater schemes. The main areas of focus are related to design optimisation, product standardisation and refining manufacture methods to enable development of a commercial product. Different types of parametric frequency and time domain based models were developed to predict the systems': (i) Power performance. (ii) Structural component performance. (iii)Acoustic performance. Numerical routines and semi empirical relationships were used to generate the characteristic curves for the power take off system. Site generated experimental data was used for validation purposes. Due to the bespoke nature of the systems involved Finite Element Analysis (FEA) was used to stress critical components. This information was fed into fatigue analysis routines for component life estimation. These methods enabled the maximisation of turbine performance, minimisation of construction costs, while ensuring the acoustic signature of the device adhered to international standards under the particular project design constraints imposed. The final product is safe to operate, reliable and easily maintained.

Numerical Analysis of a Variable Pitch Reversible Flow Air Turbine for Oscillating Water Column Wave Energy Systems

P. Cooper and A. Gareev

University of Wollongong, Australia

Abstract

This paper presents the results of a fundamental numerical analysis of the performance of a reversible axial flow air turbine designed to service Oscillating Water Column (OWC) ocean wave energy systems. A new approach to the analysis of such devices is presented wherein an actuator disc/blade-element analysis is formulated purely in terms of non-dimensional variables (ie flow factor, blade lift/drag data, angle of attack, etc) rather than the usual mixture of non-dimensional and dimensional input parameters. The non-dimensional pressure drop, torque, input and efficiency coefficients were then determined using the numerical model for a variable-pitch Denniss-Auld turbine developed by Energetech Australia. Numerical results are presented for simulations using the lift and drag characteristics of both an isolated aerofoil and a cascade of blades. Agreement between numerical and laboratory-scale experimental data was found to be reasonably good, although the quantitative predictions of efficiency were significantly higher than in practice. The implications for optimal design of such air turbines are also discussed.

Dynamic System Modeling of an Oscillating Water Column Wave Power Plant based on Characteristic Curves obtained by Computational Fluid Dynamics to enhance Engineered Reliability

R.G.H. Arlitt[1], K. Tease[2], R. Starzmann[1] and J. Lees[2]

[1]Voith Siemens Hydro Power Generation, Germany, [2]Wavegen, UK

Abstract

In the development process of a new technology it is of highest importance to obtain a firm grip on the underlying physics. Furthermore it is not sufficient to investigate into separate physical domains. The opposite, a multiphysics integrated model of the wave energy converter, builds the necessary fundament for a successful technology. It will be described how the collaborative development of computational fluid dynamics, structural mechanics analysis and dynamic system modeling is conducted and how these interact. A short introduction into the Oscillating Water Column technology (OWC) technology using a Wells turbine will be given, followed by an overview of R&D activities in the simulation and modeling of the OWC plant with Wells Turbine. Results from CFD calculations performed on the Wells turbine, structural mechanics and a description of the time domain dynamic system model development will be attached with an emphasis on the interfaces in between the single physical domains. The importance and the impacts on design to increase performance, safety, reliability and decrease cost complete this contribution.

Session 12

Tidal Energy Device Modelling 1

Room 3, Wednesday, 12th September, 14:00-15:40

Chair: Andrew Grant, University of Strathclyde, UK
Co-Chair: Luke Myers, University of Southampton, UK

Modelling of free surface proximity and wave induced velocities around a horizontal axis tidal stream turbine

J. Whelan[1], M. Thomson[2], J. M. R. Graham[1] and J. Peiró[1]
[1]Imperial College London, UK, [2]Garrad Hassan Ltd, UK

Abstract
The aim of this work is to model the flow field around a horizontal axis tidal stream turbine to include the effects of both free surface proximity and wave induced velocities. Theoretical results are presented for the case of a linear array of tidal stream turbines that account for the proximity of the free surface and the seabed. The theory is then developed further to account for wave induced velocities and the resultant unsteady loading on a turbine. The theoretical results are compared to open channel flow experimental results. The flow field has been first experimentally simulated using various resistance discs. These results will be complemented by more detailed measurements using a model turbine. A combination of oscillatory flow and current is used to simulate the effects of wave and current motion on the turbine. The work on free surface proximity culminates in a blockage correction for free surface flows. The extension of this theory for inclusion of wave induced velocities provides a characterisation of the unsteady loading on the turbine due to the wave motion. Incorporation of the corrections for free surface proximity into a blade element code is discussed.

Towards realistic marine flow conditions for tidal stream turbines

I. Masters[1], J.A.C. Orme[2] and J. Chapman[1]
[1]Swansea University, UK, [2]Swansea Turbines Ltd, UK

Abstract
The marine environment offers many challenges for accurate performance modelling. Capturing the spatial and temporal variation in the marine flow is vital for the prediction of both performance and loading on tidal stream turbines. Conventional blade element and momentum theory (BEMT) assumes a uniform flow velocity normal to the horizontal axis rotor. Alterations have been made to allow for non-uniform, three-dimensional flows. This work involved a system to map the rotor blades in a three dimensional global space and resolve flows into blade relative, local vectors. This also allows for yawing, teeter and rotation of the blade system. An open source code has been employed to model the velocities and accelerations of water due to waves. The BEMT analysis is modified to use this varying velocity regime to calculate rotor performance. However, the acceleration of the fluid is also taken into account in a post-processing routine. Tidal flow has been modelled as a power law boundary layer. This gives a variation in flow velocity with water depth. The flow velocities of wave action and tide are combined to give a flow velocity field, which may be used in BEMT. The implementation of these approaches is shown and the results discussed.

Numerical and Experimental Investigation of a Ducted Vertical Axis Tidal Current Turbine

V.R. Klaptocz, G.W. Rawlings, Y. Nabavi, M. Alidadi, Y. Li and S.M. Calisal
University of British Columbia, Canada

Abstract

A three blade, fixed pitch, vertical axis tidal current turbine was designed, instrumented and tested in the BC research towing tank. Prior to the testing, a specialized auxiliary carriage was designed for testing of ocean energy devices. Additional instrumentation was acquired to allow for improved data acquisition capacity and a wider range of testing capabilities. Experimental results were obtained for an un-ducted as well as a ducted turbine with Venturi type ducting. In both cases, the turbine torque was measured as a function of phase angle for several fixed blade angles of attack. The drag forces, angular position and rpm were also recorded for each test case. In addition, pressures along the duct were measured for a select number of cases. Due to the highly transient as well as turbulent nature of the flow, significant effort was spent on ensuring the quality of data through careful instrument calibration and multiple repeatability tests. These efforts resulted in data repeatability within 1%. The experimental results are used for validation and calibration of two numerical models: a 2D RANS model and a 3D Free Vortex model. Both models show good agreement with experimental results. The advantages and limitations of the numerical approaches are discussed in the paper.

Tidal current turbine fatigue loading sensitivity to waves and turbulence – a parametric study

G.N.McCann
Garrad Hassan Ltd, UK

Abstract

A parametric study of the sensitivity of fatigue loading experienced by a tidal current turbine to the environment in which it operates is reported. The design tool GH Tidal Bladed is used to model a generic 2MW turbine operating in a range of flow turbulence and sea-state environments representative of the turbine's lifetime. Time histories of the salient load component 'blade root out-of-plane bending moment' are rainflow cycle counted to provide lifetime damage equivalent loads as functions of both mean flow turbulence and significant wave height. Fatigue load criticality is then assessed by comparing the resulting fatigue damage margins with the ultimate yield stress resulting from the 50-year extreme wave event. Although in this particular study it is found that the selected extreme load case drives the blade root design, fatigue stress margins are observed to fall as low as +8% under certain environmental conditions, suggesting that fatigue loading is still an important consideration in the overall design process - particularly for those projects where the severity of site conditions may exceed those considered in this study. Generally, strong correlations are observed between turbine fatigue loading and levels of both turbulence and sea-state severity. This indicates the necessity of a detailed description of environmental conditions at a potential tidal turbine site, coupled with sophisticated, validated models of the complex interaction of this environment with the turbine's operational behaviour, if more optimised, cost-effective design solutions are to be achieved in the future.

An innovative modelling approach to optimize the design configurations of marine (river) cross-flow current energy converters' farm

T. Maitre[1], S. Antheaume[2], C. Buvat[2], C. Corre[1] and J.L. Achard[3]
[1]Institut National Polytechnique de Grenoble, France, [2]Electricité de France, France, [3]Laboratoire des Ecoulements Géophysiques et Industriels, CNRS, France.

Abstract

In 2001, the Geophysical and Industrial Fluid Flows laboratory (LEGI-France) launched the HARVEST research program (Hydroliennes à Axe de Rotation Vertical Stabilisé) to better understand and develop a suitable technology for hydroelectric marine or river power farms using Cross Flow Current Energy Converters (CFCEC) piled up in towers. The LEGI researches deal with the hydrodynamic part of these systems, with the support of the R&D Division of the EDF Group; other laboratories of the Rhône-Alpes Region are in charge of the respective mechanical (3S-INPG and LDMS-INSA) and electrical aspects (LEG-INPG). A hydroelectric HARVEST farm consists of a cluster of barges, each barge gathering several towers. The present study concerns the spatial optimization of towers, at the scale of the barge and of the farm. The optimization is done using an innovative numerical method that couples a macroscopic model of the tower with RANS calculation of the flow field. For the barge, it is shown that the decrease of the gap between aligned towers increases their efficiency. For the farm, aligned and staggered rows are considered. Results show that staggered rows are more interesting only if a sufficient spacing is used between barges in rows.

Session 13

Wave Energy New Concepts

Room 1, Wednesday, 12th September, 16:10-17:50

Chair: J. Michael R. Graham, Imperial College, London, UK
Co-Chair: Sergio Camporeale, Politecnico di Bari, Italy

Hydrodynamic Optimization of a Wave Energy Converter Using a Heave Motion Buoy

Marco Alves[1], Huw Traylor[1] and António Sarmento[2]
[1]IT Power Limited, UK, [2]Instituto Superior Técnico, Portugal

Abstract

This paper reports a numerical study to optimize the buoy of a wave energy converter which uses the heave motion to absorb wave energy. To proceed to the buoy evaluation the equation of motion in the frequency domain is expressed as a function of the complex amplitude of the displacement, which can be determined from the amplitude of the excitation force and the hydrodynamic coefficients of added mass and damping. From the stroke and the *PTO* characterisation the mean power absorption by the device is computed as well as the capture width. In the study it was assumed a *PTO* connected to the ground which can be described through two terms: one is proportional to the stroke and the other proportional to the velocity. If the stroke is lower than a prescribed maximum, the (optimal) mechanical spring and damping coefficients are computed from maximum power absorption. If larger, the mechanical spring and damping coefficients are set to limit the stroke to the prescribed maximum value. The methodology developed to optimize the buoy consists in the definition of a cylinder with the adequate length to tune the resonance at the desired frequency. Then, the specified cylinder is transformed into two buoy components, keeping the same hydrostatic coefficient as the original cylinder. The upper component (the "surface buoy"), which crosses the free surface, may have a high hydrodynamic damping. Its volume, as low as possible, is set up according to the stroke required. The other component (the "submerged mass") carries the remaining mass (cylinder mass minus the surface buoy mass) and is placed deeper in the water, at a depth dependent on its volume, to avoid the interference with the hydrodynamic damping of the surface buoy. A non-dimensional analysis has been performed allowing the establishment of relations between the maximum power increment (as the cylinder is progressively transformed into a more suitable shape) and the fraction of the cylinder volume reduction. It was also possible to relate the buoy centre of gravity with the absorbed power reduction if the submerged mass position is not deep enough to avoid any interference with the surface buoy.

Hydraulic characteristics of seawave slot-cone generator pilot plant at Kvitsøy (Norway)

L. Margheritini[1], D. Vicinanza[2] and J. P. Kofoed[1]
[1]Aalborg University, Denmark, [2]Seconda Universita degli Studi di Napoli, Italy

Abstract

This paper presents results on wave overtopping and loading on an innovative caisson breakwater for electricity production. The work reported here contributes to the European Union FP6 priority 6.1 (Sustainable Energy System). The design of the structure consists of three reservoirs one on the top of each other to optimize the storage of potential energy in the overtopping water. The wave loadings on the main structure can be estimated using experiences from breakwater design, but the differences between the structures is so large that more reliable knowledge is needed. Model tests were carried out to measure wave loadings and overtopping rates using realistic random 2D and 3D wave conditions; the model scale used was 1:60 of the SSG pilot at the selected location in the island of Kvitsoy, Norway. Pressure transducers were placed in order to achieve information on impact/pulsating loadings while in a second phase the model has been adapted and equipped with pumps to measure the overtopping flow rates in the single reservoirs. The results of the tests highlight differences between 2D and 3D conditions in terms of pressures and hydraulic efficiency.

CETO, a Carbon Free Wave Power Energy Provider of the Future

L.D Mann, A.R. Burns and M.E.Ottaviano
Seapower Pacific Pty Ltd, Australia

Abstract
The CETO project has been formulated from inception to compete with the lowest cost fossil fuel base load systems. CETO relies on energy capture from sustaining seas and swells to provide high capacity factor while also maintaining good reliability of the offshore plant. Wave motion generates pressurized seawater that is piped to shore where it can either be used to run turbines for electricity generation or the high pressure water stream may also be used in part to drive reverse osmosis desalination plant for the creation of potable water. The CETO methodology focuses on using proven low technology components in the critical offshore plant while also moving all of the electricity and water generation components onshore. This paper will outline the design that has been underpinned by computational fluid dynamical modeling using FLUENT® software and backed up with a comprehensive in-sea device testing program. CETO market development in Australia is proceeding with site identification and detailed discussions with major stakeholders. This is viewed as an important stepping stone to future market entry worldwide and a suitable proving ground for demonstrating workable financing arrangements for commercial-scale marine energy projects.

Non-linear methods for next wave estimation

A.A.E. Price and A.R. Wallace
University of Edinburgh, UK

Abstract
The prediction of near future wave excitation force is the fundamental problem associated with optimal control of a wave energy converter. This becomes clear when the latching technique is considered. In this case the central control problem is the choice of the moment at which to release the latched working surface, such that the resulting velocity is in phase with the wave exciting force. To calculate the ideal time to unlatch, the time until the next peak or trough in the excitation force is required. This paper describes the development of various techniques, including neural networks, for estimation of the time until the next peak in excitation force. Two sets of synthetic excitation time series were used: one that was close to sinusoidal, with little variation in period and height, and the other with a high variation in these parameters. Several neural networks were trained and the results compared to alternative methods. It was found that neural networks performed better than the alternative methods for the time series that contained more variation.

Session 14

Air Turbines 2

Room 2, Wednesday, 12th September, 16:10-17:50

Chair: Kim Nielsen, Ramboll, Denmark
Co-Chair: Ken Tease, Wavegen, UK

A New Test Facility for evaluating turbines for use in OWC power plants

S. J. Herring[1] and G. Laird[2]
[1]dstl Porton Down, UK, [2]Peter Brotherhood Ltd., UK

Abstract
The need was identified for a relatively large test facility which could be used to reduce the risk in OWC turbine development, by enabling the performance of turbines to be evaluated under more representative - but nevertheless controlled - conditions. The overall objective was to have a system which enabled the various trade-offs within the power extraction system, and perhaps most importantly the effect of irregular flow conditions on performance to be evaluated. This paper describes the design and development of such a facility and presents some results for a datum turbine design.

Experimental and numerical investigation on the performance of a Wells turbine prototype

M. Torresi, S. M. Camporeale and G. Pascazio
Politecnico di Bari, Italy

Abstract
This paper presents the results of the experimental and numerical investigation of a small prototype of a high solidity Wells turbine. The prototype, with blades of constant chord and NACA0015 profile, has been designed in order to be matched with the REWEC (Resonant Wave Energy Converter) breakwater located off the beach of Reggio Calabria. The aim of this work is to characterize the turbine performance and determine the causes of the main losses in order to improve the turbine design. In particular, the simulations have been devoted to evaluate the influence of the hub-nose geometry at the entrance and the tip gap on the turbine performance.

A small scale field experiment on a Wells turbine model

P. Filianoti[1] and S. M. Camporeale[2]
[1]University Mediterranean of Reggio Calabria, Italy, [2]Politecnico di Bari, Italy

Abstract
A small breakwater reproducing a 1:10 scale model of a ocean REWEC3 (Boccotti, [9]) has been realized off the beach of Reggio Calabria. This small scale model has the following sizes: 16.3m (length) x 4.5m (width) x 3.5m (height), and weights about 350tons. A previous experiment, in which the system has been tested without turbine, has been successfully carried out in 2005, showing that the energy absorption can reach up to 100% of the incident energy. This paper describes the experiment in which a small Wells turbine has been installed in the REWEC system aiming to measure the wave energy absorbed by the plant under these new conditions, the performance of the turbine under the action of a randomly varying flow and, finally, to compare the actual production of electric power with the estimates based on numerical simulations. To this purpose a high solidity monoplane unit of 31 cm of diameter without guide vanes, has been chosen. The preliminary results of the experiment, that is still under course when this communication is written, are provided in the work.

Viscous flow analysis in a radial impulse turbine for OWC wave energy systems

F. Castro[1], A. el Marjani[2], M. A. Rodriguez [1] and T. Parra[1]
[1]Universidad de Valladolid, Spain, [2]University of Mohammed V Agdal, Morocco

Abstract

The Oscillating Water Column system (OWC) is considered as interesting concept for ocean wave energy extraction. Several kinds of air turbines have been envisaged for pneumatic energy conversion to mechanical energy. The Wells turbine has been used widely in OWC plants. However an alternative self-rectifying turbine called Impulse turbine has gained more attention last years. In the present study, we are interested in the radial version of the Impulse turbine, which was initially proposed by McCormick. This numerical study is aimed to improve the understanding of the local flow behaviour inside a radial version of the Impulse turbine and the prediction of its performances. The research work has been carried out using FLUENT® code. Model validation has been conducted through a comparison with experimental results available in the literature. It is planed that this model will be exploited next in the design and the optimisation stages of a high performances radial Impulse turbine project for an OWC of 250 kW.

Session 15

Strategy and Economics

Room 3, Wednesday, 12th September, 16:10-17:50

Chair: Gouri Bhuyen, Powertech Labs Inc., Canada
Co-Chair: Alla Weinstein, Finavera Renewables Ocean Energy, UK

The Hawaii Wave Energy Opportunity

M.H. Kaya, M. Anderson and A.T. Gill
State of Hawaii Department of Business, Economic Development and Tourism, USA

Abstract

Surrounded by the Pacific Ocean and experiencing high electric utility rates, the State of Hawaii enjoys a wave energy resource averaging 10-15 kW/m at the 80 m depth contour. Hawaii's legislated renewable portfolio standard (RPS) mandates that 20% of the state's electricity be generated from renewable sources by 2020. Among the challenges to be overcome before wave energy can be a major contributor in Hawaii are the dearth of verifiable performance data from current wave technologies, a complex permitting regime, and competing uses for the state's near-shore waters. Governor Linda Lingle has directed state agencies to streamline the permitting process for renewable energy, specifically including wave power. To facilitate consideration of Hawaii as a location for wave energy projects, the State of Hawaii's Department of Business, Economic Development and Tourism (DBEDT) has published resource assessments, a summary of state permits applicable to ocean energy development, maps and supporting documents which are posted on the department's website. Two wave technologies have been demonstrated in Hawaiian waters and other companies are considering opportunities. Highly experienced naval design, engineering and shipyard companies supporting ocean energy development are established in Hawaii.

Internationalization within the ocean energy industry - a remedy for entrepreneurial challenges?

N. Løvdal[1], A. Sarmento[2,3] and F. Neumann[3]
[1]Norwegian University of Science and Technology, Norway, [2]Instituto Superior Técnico, Portugal, [3]Wave Energy Centre, Portugal

Abstract

On political level there are typically three objectives when supporting the development of wave or tidal energy; national value creation, security of power supply and decreased pollution and safety concerns. The typical main objective of new technology based firms in early phases is rapid development towards commercialization (and survival), and later on growth. This paper reveals some preliminary data from a world wide survey which shows that firms in the ocean energy industry intend to use foreign markets as a remedy to obtain their objectives. Further, we explain this tendency towards early internationalization by using entrepreneurship theories. Based on examples of public support systems in England and Portugal, we present potential opportunity and threats this early internationalization might lead to. Some implications and further research are given.

An assessment of growth scenarios and implications for ocean energy industries in Europe

W.M.J. Batten and A.S. Bahaj
University of Southampton, UK

Abstract

Ocean energy (wave and tidal stream) is anticipated to contribute an appreciable amount of sustainable electrical power over the next 20 years. An analysis of the anticipated growth in ocean energy industry in presented here. The work was based on assessment of published targets and growth scenarios for Europe. The assessment presented in the paper is compared with the current exponential growth in offshore wind. Consequently, the appropriateness of some of these targets are also assessed in the study. Based upon current estimated costs of electricity for tidal and wave energy and estimated learning rates, the future costs of energy can be predicted. Combining growth scenarios and electricity costs for ocean energy industries the implications of required investment and job creation has also been assessed and discussed. The investment costs were derived for different learning rates and show large sensitivity to future costs. An estimation of the socioeconomic effect of job creation has been determined using input-output tables, derived in partial from offshore wind. These results highlight strong growth possibilities for ocean energy.

Wave energy: going down the tube?

P.M.Connor
University of Exeter, UK

Abstract

While there have been numerous pilot projects with different wave energy devices, the commercial application of wave energy will see the technology installed in more diverse locations. Their deployment has the potential to conflict with other, perhaps already established, use of both the space in which wave energy devices are likely to be best situated and the surrounding areas which might also be impacted by wave energy exploitation. This paper details conflict that has already arisen with regard to the proposed deployment of a 20MW wave energy farm off the north coast of Cornwall, England.

Session 16

Wave Energy Converter Control

Room 1, Thursday, 13th September, 8:50-10:30

Chair: Gareth Thomas, University College Cork, Ireland
Co-Chair: Duarte Valério, Instituto Superior Técnico, Portugal

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Advanced Control Techniques for WEC Wave Dragon

J. Tedd[1], J.P. Kofoed[1], M. Jasinski[3], A. Morris[1], E. Friis-Madsen[2], R. Wisniewski[4] and J.D. Bendtsen[1]

[1]Aalborg University, Denmark, [2]WaveDragon ApS, Denmark, [3]Warsaw University of Technology, Poland

Abstract

This paper presents the ongoing work on control of the Wave Dragon wave energy converter. Research is being conducted in and between several centres across Europe. This is building upon the knowledge gained in the prototype project, and will enable much better performance of the future deployment of the full scale Wave Dragon.

Dynamics of a force-compensated two-body wave energy converter in heave with hydraulic power take-off subject to phase control

Jørgen Hals, Reza Taghipour and Torgeir Moan

Norwegian University of Science and Technology, Norway

Abstract

In this study we use a hybrid frequency-time domain model to study the dynamics of a two-body wave-energy converter with hydraulic power take-off subject to phase control. Both bodies - a buoy and a semi-submersible platform - are restricted to move in the heave mode only, and the power is extracted from their relative motion. The geometry of the buoy and the platform is chosen so as to obtain so-called force compensation, i.e. the vertical wave excitation forces on the two bodies are opposite and approximately equally large. The effect of force compensation is studied by varying the geometry of the platform in order to reveal its effect on the system dynamics and power absorption. Furthermore, one-body oscillation is compared to two-body oscillation for power absorption, and the effect of viscous damping of the platform motion is studied. Simulation results are given both for regular and irregular waves, and they show that the platform geometry and degree of force compensation strongly influences the performance of the system. It is further shown that flow losses in a hydraulic power take-off system can be substantial, and should thus be thoroughly assessed. Also, the large potential increase in power output using phase control is demonstrated.

Phase control through load control of oscillating-body wave energy converters with hydraulic PTO system

António F. de O. Falcão

Instituto Superior Técnico, Portugal

Abstract

Oscillating bodies constitute an important class of wave energy converters, especially for offshore deployment. Phase-control by latching has been proposed in the 1970s to enhance the wave energy absorption by oscillating bodies (especially the so-called point absorbers). Although this has been shown to be potentially capable of substantially increasing the amount of absorbed energy, the practical implementation in real irregular waves of optimum phase control has met with theoretical and practical difficulties that have not been satisfactorily overcome. The present paper addresses the case of oscillating-body converters equipped with a high-pressure-oil PTO that provides a natural way of achieving latching: the body remains stationary for as long as the hydrodynamic forces on its wetted surface are unable to overcome the resisting force (gas pressure difference times cross-sectional area of the ram) introduced by the hydraulic PTO system. A method of achieving sub-optimal phase-control is developed, based on the theoretical time-domain modelling of a single-degree of freedom oscillating body in regular and irregular waves, by adequately delaying the release of the body in order to approximately bring into phase the body velocity and the diffraction (or excitation) force on the body, and in this way get closer to the well-known optimal condition derived from frequency-domain analysis for an oscillating body in regular waves.

Control of the Archimedes Wave Swing using Neural Networks

Pedro Beirão[1], Mário J. G. C. Mendes[2], Duarte Valério[3] and José Sá da Costa[3]
[1]Instituto Superior de Engenharia de Coimbra, Portugal, [2]Instituto Superior de Engenharia de Lisboa, Portugal,
[3]Instituto Superior Técnico, Portugal

Abstract

This paper addresses the control of the Archimedes Wave Swing, a fully-submerged Wave Energy Converter (WEC), of which a prototype has already been built and tested. Simulation results are presented in which Internal Model Control (IMC) is used, both with linear models and with non-linear neural network (NN) models. To the best of our knowledge this is the first time NN-based control is being applied to design a controller for a WEC. NNs are a mathematical tool suitable to model the behaviour of dynamic systems, both linear and non-linear (as in our case). Significant absorbed wave energy increases were found, both using linear models and NNs. Results were better when IMC with NNs was employed (with a nearly sixfold increase against a fivefold increase), except for the May.September period, when IMC with linear models performs better.

A Frequency Converter Control Strategy for a MW Wave Energy Take-off System

Zhongfu Zhou[1], H. Ch. Sørensen[3], M. Jasinski[2], M. Malinowski[2], W. Knapp[4],
J. MacEnri[5], E. Friis-Madsen[3], L. Christiansen[3], I. Masters[1] and Petar Igic[1]
[1]University of Wales Swansea, UK, [2]Warsaw University of Technology, Poland, [3]Wave Dragon APS and LTD, Denmark, [4]Technische Universität München, Germany, [5]ESB International, Ireland

Abstract

A control scheme of the frequency power converter for a MW wave power station is described in this paper. The system configuration, generator, frequency converter and interface to the local grid are also discussed. The speed control method for maximum power tracking in a variable speed low-head hydroturbine by using IGBT AC/DC converter is described in details. The power supplied to the utility grid is controlled using PWM voltage source inverter by balancing the input-output power of the dc link. The effect of the torque fluctuation on the output power has been simulated.

Session 17

Wave Energy Resource 2

Room 2, Thursday, 13th September, 8:50-10:30

Chair: Peter Frigaard, Aalborg University, Denmark
Co-Chair: Francisco Taveira Pinto, Universidade do Porto, Portugal

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Integrating Offshore Wind and Wave Resource Assessment

M. T. Pontes[1], AM. Sempreviva[2], R. Barthelmie[3], G. Giebel[4], P. Costa[1] and A. Sood[5]
[1]INETI, Portugal, [2]Institute of Atmospheric Sciences and Climate, ISAC-CNR, Italy, [3]The University of Edinburgh, UK, [4]Risoe National Laboratory, Denmark, [5]Universities of Oldenburg and Hannover, Germany

Abstract
The aim of this paper is to review the sources of wind and wave information, the methodologies to assess offshore wind and wave energy resources, and the more relevant results at the European level as a first step to integration of the evaluation of both resources. In situ and remote sensed wind and wave data (using satellite based sensors) are done generally by distinct systems (except for SAR) but numerical atmospheric models and wind - wave models are closely related. Offshore wind resource studies using various types of data are reviewed especially in northern European seas and in the Mediterranean. The wave energy resource assessment at European and national levels is also reviewed and the various atlases are identified.

Wave energy resource in the North Sea

C. Beels[1], J.C.C. Henriques[2], J. De Rouck[1], M.T. Pontes[2], G. De Backer[1] and H. Verhaeghe[1]
[1]Ghent University, Belgium, [2]INETI, Portugal

Abstract
Due to the high potential of wave energy and the goal to raise the share of renewable energy supply in the EU up till 20 % in 2020, the development of wave energy is accelerated. Until now the wave energy resource was highlighted in regions with a high wave energy density. As Wave Energy Converters (WECs) still contend with problems such as structural strength and mooring in a severe and energetic wave climate, the prospects of wave power conversion in a less aggressive wave climate should be investigated. This paper describes the wave power resource in a rather sheltered area i.e., the North Sea. The available wave power is studied on 34 locations. Characteristic sea states are defined for the Belgian, Dutch, German, Danish, Norwegian and UK Continental Shelf. An inverse-ray refraction model, implemented at INETI (Instituto Nacional de Engenharia, Tecnologia e Inovação), is presented to calculate the resource on more convenient locations for wave energy conversion. The wave power potential in the North Sea is compared with the resource of the West European coast. Near shore (< 30 km off the coast) up to a maximum of approximately 11 kW/m is available in the North Sea.

Wave climate and energy off the Catalan coast

X. Gironella[1], A. Sanchez-Arcilla[1], D. Gonzalez-Marco[1], J. Gomez[1], R. Bolaños[1,2] and J. Sospedra[1]
[1]Universidade Politecnica de Cataluña, Spain, [2]Proudman Oceanographic Laboratory, Liverpool, UK

Abstract
This paper deals with the wave climate and energy at the NW Mediterranean and, more specifically, along the Catalan (NE Spanish coast) and Balearic Islands coast. The analysis is based on 6 years of wave records and simulations. The data come from buoys deployed along the Catalan coast and from the operational predictions obtained using the WAM code and the wind fields from the MASS model. The 6 years average error, in energy flux terms, and for the whole Catalan coast stretch is of the order of 0.5 kW/m. These errors, of order 10% of the available mean energy, allow concluding that the WAM simulated results are accurate enough in average terms for the energetic assessment here pursued.

Scalability of a Benign Wave Energy Test Site

S. Barrett, B. Holmes and A.W. Lewis
University College Cork, Ireland

Abstract

A benign quarter scale test site for floating wave energy devices has been provided off the west coast of Ireland in a semi-enclosed coastal bay, partially sheltered from the Atlantic by the Aran Islands. It is expected the provision of this site will encourage developers to progress to Phase 3 of the Ocean Energy: Development & Evaluation Protocol. The site characteristics have been determined from a hindcast model using the 3rd generation wave model SWAN for the year 2000, and a non-directional wave recording buoy in situ since the test site's inception in late 2005. Analysis of this data has shown that there are high occurrences of twin peak spectra, comprising a local fetch limited wind sea and a long period swell which approaches the site around the Aran Islands from offshore. The method that identifies and separates these multi-modal wave generation systems into their constituent processes will be presented in this paper. Through the application of this method the wind and swell sea components will be presented in various forms to engender a thorough knowledge of the conditions at the test site. Phase 3 of the Development Protocol bridges the end of laboratory model testing and the beginning of sea trials. As completion of the previous two phases is a prerequisite for the use of the test site, this paper explores several considerations that WEC developers will need to take into account. Phase 1 and 2 of the protocol will have involved controlled laboratory conditions, mostly being a combination of monochromatic trials with idealised irregular trials such as the standard representative formulae for JONSWAP or Pierson-Moskowitz spectra. As most floating wave energy converters have a narrow response bandwidth, a high occurrence of twin peaked spectra may not produce the expected power production from the device, especially if resonance falls within the valley between the wind and swell spectral components. What effect will a long period swell occurring at the test site have on the motions of the device, and particularly the power output? Finally, this paper will look at the scalability of the conditions at the benign test site and compare these to a fully exposed site off the west coast of Ireland which would be typical for full scale prototype deployment.

Session 18
Wave Energy Converter Hydrodynamic Modelling 3
Room 1, Thursday, 13th September, 11:00-12:40

Chair: Chiang C. Mei, Massachusetts Institute of Technology, USA
Co-Chair: Kai-Uwe Graw, Technische Universität Dresden, Germany

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Experimental validation of the performances of the SEAREV wave energy converter with real time latching control

M. Durand, A. Babarit, B. Pettinotti, O. Quillard, J.L. Toularastel and A.H. Clément
Ecole Centrale de Nantes, France

Abstract
In this paper, the two campaigns of experiments made on the SEAREV wave energy converter are presented. These campaigns happened in year 2006 in the "Ecole Centrale de Nantes" (ECN) wave tank. Purposes of these campaigns were to verify the numerical models and the efficiency of latching control applied to the SEAREV WEC. The system was tested both in regular waves and in random waves. Comparisons were made between the numerical models and the experiments. A good agreement is found while the wave remains small. When amplitude of the wave becomes larger, non linear effects such as slamming and parametric roll appears. These phenomena limit the motion of the buoy and consequently the energy absorption. It has been shown numerically in previous papers [4] that latching control is an efficient way of improving the global efficiency of the SEAREV. So, latching control was implemented in the model and was tested in the wave tank. In regular waves, we observed that the amplification of the energy production by the control can be up to 10 times the energy production without control. In random waves, we achieved an improvement of the energy production by 50 to 86 %.

Performance of a point absorber heaving with respect to a floating platform

G. De Backer, M. Vantorre, R. Banasiak, J. De Rouck, C. Beels and H. Verhaeghe
Ghent University, Belgium

Abstract
A linear frequency domain model has been developed to simulate the behaviour of a heaving point absorber, moving with respect to a floating reference. A linear external damping coefficient is applied to enable power absorption and a supplementary mass is introduced to allow for tuning the point absorber to the incoming wave conditions. Two motion restrictions are applied to the buoy. The first restriction decreases the occurrence probability of slamming; the second one limits the stroke of the relative motion between the buoy and the platform. The influence of the motion restrictions on power absorption is examined. Optimal values for the external damping and motion control parameters are determined under the given conditions. A sensitivity analysis on these values is conducted to know the effects of less optimal tuning and/or damping on power absorption. The forces associated with these parameters have to be realized by the power take-off and motion control system respectively. The sensitivity analysis allows for assessing the influence on the power extraction of restrictions applied on these forces.

The design of small seabed-mounted bottom-hinged wave energy converters

M. Folley, T.J.T. Whittaker and J. van´t Hoff
Queen`s University Belfast, UK

Abstract

A linearised frequency domain numerical model of small seabed-mounted bottom-hinged wave energy converters is developed that accounts for vortex shedding at body edges and decoupling at large angles of rotation. The numerical model is verified and calibrated using data from wave-tank experiments. It is found that in general the device capture factor increases with both the device width and wave frequency due to increasing wave force. The model also indicates that for typical flap dimensions and incident wave amplitudes the peak in capture factor at the body's natural pitching frequency is suppressed due to viscous losses and motion constraints. The effect of viscous losses and motion constraints are also responsible for limiting the increase in performance that is obtainable with phase control. Three cost functions, power per unit displaced volume, power per unit structural task and power per unit surge force are produced and applied to the results of a parametric analysis. Three distinct regions of the design space are identified; EB Frond and BioWave are found to sit in one region, WaveRoller in another region and Oyster in the final region. Characteristics are identified for each region and related to the distinct designs of the commercial systems identified.

WRASPA, Wave Interactions and Control in a new Pitching-Surge Point-Absorber Wave Energy Converter

Robert V. Chaplin and George A. Aggidis
Lancaster University, UK

Abstract

There is a worldwide opportunity for local and distributed clean renewable electrical power from Marine Energy. It has the potential to become competitive with other forms of energy and by 2020, 3% of the UK's energy could be derived from wave and tidal energy, providing up to 1/6 of the UK government's aspiration of 20% renewable energy by this time. The key to success in clean electrical power lies in a low lifetime-cost of power as delivered to the user. For wavepower this must start with a compact, powerful and reliable wave energy converter, or WEC. Pitching-surge point-absorber WECs have the potential to generate average annual powers of around 1.5MW in North Atlantic conditions from relatively small devices. The paper reports very early work on one such device – WRASPA (**W**ave-driven, **R**esonant, **A**rcuate action, **S**urging **P**oint-**A**bsorber) - in water depths greater than 20m including the effects of collector geometry on power output, based on both experimental and computational modelling. In particular, the progress towards an optimum collector geometry will be described. Engineering designs for devices based on these findings will be outlined.

Modelling of Multibody Marine Systems with Application to Wave-Energy Devices

Mícheál Ó'Cáthain[1], Bernt J. Leira[2] and John V. Ringwood[1]
[1]NUIM, Ireland, [2]NTNU, Norway

Abstract

Time-domain modelling of wave-energy devices is important. This is due to the need for information on the device's transient response characteristics; even when linear potential theory is assumed when modelling hydrodynamic loads, significant non-linearities may be present in the system due to the power-take off (PTO), mooring, and control subsystems. In this paper, an approach for modelling multibody marine systems is presented. The Newton-Euler equations with eliminated constraints (NE-EC) are utilised to capture the rigid body dynamics of the constrained multibody system. This results in the convenient integration of active loads (as opposed to interbody *constraint* forces) acting on the multibody system. In this paper, the active loads considered are: hydrodynamic, PTO, and mooring loads.

Session 19

Wave Energy Resource 3

Room 2, Thursday, 13th September, 11:00-12:40

Chair: Tony Lewis, University College Cork, Ireland
Co-Chair: César Vidal, Universidad de Cantabria, Spain

Specific Kinetic Wave Energy Definition

Raquel Silva and Francisco Taveira-Pinto
University of Porto, Portugal

Abstract

Ocean waves' energy represents a major renewable energy resource to which Portugal has a considerable potential, due to its favorable geographical location and its high energetic wave climate. A fundamental part of wave energy conversion is the design process of the energy transfer mechanism from the ocean surface gravity waves to the energy converter device. Existing devices usually work near the water surface where most of the wave energy is concentrated. This way, the knowledge of the vertical distribution of the wave kinetic energy may be of interest in this design process. A methodology has been developed to evaluate the wave kinetic energy distribution as a function of depth level from the velocity components, allowing detail achievement on the analysis of the wave action. This concept has already been applied and verified for regular waves, using laboratory measurements. The obtained results encouraged an extension to irregular wave fields, to which the traditional method used in the evaluation of the energy per unit wave length is not applicable. In this paper, numerically simulated specific kinetic energy profiles will be compared with values calculated from measured velocity components, giving special attention to depth levels higher than minimum water surface elevation.

Short TermWave Energy Variability off the West Coast of Ireland

G. Nolan[1], J.V. Ringwood[2] and B. Holmes[3]
[1]EirGrid Plc, Ireland, [2]National University of Ireland Maynooth, Ireland, [3]University College Cork, Ireland

Abstract

Within the context of wave energy conversion, this paper investigates the practice of using wave (frequency) spectra to characterise wind waves. In particular, this paper looks at the major shortfall of the wave spectrum - its lack of information provision on the temporal variability of the wave activity. Finally, the issue of different spectral shapes with the same seaway summary statistics (i.e. H_s, the significant wave height, and T_z, the mean zero crossing wave period) is investigated. Measured wave data recorded off the West Coast of Ireland provides the basis for this analysis, with the wavelet transform providing the primary analysis tool.

A methodology to evaluate wave energy resources in shallow waters

Paula Camus, César Vidal, Fernando J. Méndez, Antonio Espejo, Cristina Izaguirre,
Jose Manuel Gutiérrez, Antonio Cofiño, Daniel San-Martín and Raúl Medina
Universidad de Cantabria, Spain

Abstract

A global frame for the determination of shallow water wave energy resources is developed. The methodology steps are: a) calibration of a wave reanalysis data base; b) classification of the sea states by means of the Self-Organizing Maps technique to obtain the number of sea states representatives of the wave climate in deep waters; c) propagation of the selected sea states using any state-of the-art wave propagation model and propagation of the whole reanalysis data base using an interpolation scheme; d) application of different statistical models to define energy resources.

Providing Sea Surface Elevations for Marine Energy Converters using a Novel Optical Fibre Sensor: Progress in the Flume

Brian G. Sellar, Tom Bruce and Robin Wallace
University of Edinburgh, UK

Abstract

Marine energy converters will require the implementation of control strategies to achieve viability in some cases and maximise profitability in most. These control strategies may require distributed information on the wave field in which the device resides. A novel method of obtaining this data is investigated using a lattice of treated optical fibres constrained on a flexible substrate and fitted with floatation aids. By measuring the intensity of light lost at bends along its length the patented device, Shape TapeTM, can sense its position in three dimensions. Preliminary tests involving JONSWAP spectra, generated in a 20 metre long, 0.7 metre deep two-dimensional wave flume, show the flexible ribbon predicts Hm0 and Tm01 with errors less than 16% and 9% respectively when compared to wave gauge measurements. Repeatability tests using regular wavetrains provide standard deviations away from the results of wave gauges of 5% in wave height and 1% in wave period. Keywords: optical fibre sensor, sea surface elevation, wave

Generalisation of wave farm impact assessment on inshore wave climate

H.C.M. Smith[1], D.L. Millar[1] and D.E. Reeve[2]
[1]University of Exeter, UK, [2]University of Plymouth, UK

Abstract

The impact on the inshore wave climate in the lee of a proposed 3km wave farm off the North Cornwall coast in the southwest UK has previously been modelled. The study estimated that an average decrease of less than 1% of significant wave height and a maximum decrease of 3% would occur with a 90% energy transmitting wave farm. While these results might be barely detectable at the shoreline, the prospect of larger wave farms, or wave farms sited closer to the shoreline, raises the question of when inshore wave climates become significantly impacted. This paper summarises the results of a wave climate study that generalises the approach of the previous study, providing results applicable not just to one site, but to the wider field of wave farm development. The study comprises a much wider series of idealised SWAN model runs which aim to assess how the impact on inshore wave climates of a wave farm, considered in a simplified manner as a single object, is affected by four key variables: the length of the obstacle parallel to incoming wave crests, the distance of the obstacle from the shoreline, the percentage of wave energy transmitted through the obstacle, and the directional distribution of the local wave climate. The results show that there will always be a minimum percentage decrease in wave height in the lee of such an obstacle, even at substantial distances. This minimum varies with energy transmission and directional spread of the waves. The distance taken to reach this minimum is mainly dependent on the size of the obstacle. Although the modelling of an actual wave farm comprising arrays of devices would be more complex, the results allow a preliminary assessment of how far from the shoreline a wave farm should be sited to ensure wave height decreases are below a certain threshold.

Session 20

Tidal Energy Device Modelling 2

Room 3, Thursday, 13th September, 11:00-12:40

Chair: Cameron Johnstone, University of Strathclyde, UK
Co-Chair: Graeme McCann, Garrad Hassan Ltd, UK

Facilities for marine current energy converter characterization

G. Germain[1], A.S. Bahaj[2], C. Huxley-Reynard[3] and P. Roberts[4]
[1]IFREMER, France, [2]University of Southampton, UK, [3]Tidal Generation Limited, UK, [4]VerdErg Engineering Limited, UK

Abstract
The utilization of marine currents for power production offers a sustainable option to augment the traditional power technologies and enhance the expansion of renewables. The marine current resource is potentially large and could generate a significant part of the European Union's electricity requirements. Before the installation of marine prototypes, specific trials are necessary to evaluate the behaviour of each system and the ability to exploit tidal or marine currents. This paper presents experimental campaigns carried out on marine energy converter systems under METRI II program performed in the IFREMER free surface hydrodynamic water tunnel. Two of them concern horizontal axis marine current turbine systems: a "classical" pile-mounted turbine concept and a fully submerged machine in deep water. The third concept is an innovative marine current and wave energy system based on Venturi principle from a submerged pipe network. The results presented provide useful information for the hydrodynamic characterization of marine energy converter systems, their design and for the validation of numerical studies.

Close Coupled Tandem Oscillating Hydrofoil Tidal Stream Generator

M. Y. Paish[1], H. Traylor[2] and J. O'Nians[2]
[1]Pulse Generation Ltd, UK, [2]IT Power Ltd, UK

Abstract
This paper aims to explain how a pair of coupled oscillating hydrofoils can be used to exploit tidal flows cost effectively. This approach is compared with other promising approaches to tidal power extraction, as well as previous oscillating hydrofoil research. It outlines how oscillating foil systems can offer significant advantages over axial flow rotors if comparable power capture efficiencies can be achieved. It then explains how coupling a pair of foils can help achieve the required efficiency, and overcome other challenges which are inherent to oscillating systems. It briefly discusses the current project to build a gridconnected 100kW demonstrator system in The Humber, and outlines the plans for future development and commercial exploitation.

Aspects of mathematical modelling of a prototype scale vertical-axis turbine

Gareth I. Gretton and Tom Bruce
University of Edinburgh, UK

Abstract
Hydrofoil section data, comprising coefficients of lift and drag, are a key input into blade element momentum models of turbines. The aim of this paper is to investigate whether differences in this section data are to account for the predictions from blade element momentum models and Navier-Stokes solutions (using a computational fluid dynamics programme) disagreeing. To this end, a number of sources of hydrofoil section data were researched and compared. It was found that there were notable differences in the coefficients given by the data sets. Two of the data sets, namely the Sheldahl and Klimas data and results produced by the authors with Xfoil, were used as input into the blade element momentum model. When compared with the results from the CFD solution, there is disagreement between all of the results, although the results produced from the blade element momentum model with the Xfoil coefficient data are closer to the CFD results than those produced with the Sheldahl and Klimas data. This shows that whilst uncertainties in the section data may be partially responsible for the disagreement between the two models, other uncertainties must also be significant.

A direct drive generator for marine current energy conversion - first experimental results

K. Nilsson, M. Grabbe, K. Yuen and M. Leijon
Uppsala University, Sweden

Abstract

Marine currents can be an effective source for renewable electric energy conversion. In this paper a direct drive permanent magnet synchronous generator capable of being connected to a vertical axis turbine for marine current energy conversion is presented. This 5 kVA, 120 pole, 10 rpm prototype generator was initially designed for ocean current speeds of 1.5 m/s using a finite element based electrical machine design software. Unlike most conventional generators this machine has a cable wound stator. To evaluate the electrical and mechanical performance characteristics of this machine, laboratory experiments are being carried out using a speedcontrolled motor drive system and resistive three phase loads. First measurements of voltage and current show good agreement between the modelled and built generator.

Development of a Contra-Rotating Tidal Current Turbine and Analysis of Performance

J.A. Clarke, G.Connor, A.D. Grant, C.M. Johnstone and D. Mackenzie
University of Strathclyde, UK

Abstract

The Energy Systems Research Unit within the Department of Mechanical Engineering at the University of Strathclyde has developed a novel contra-rotating tidal turbine. A 0.82 m diameter scale model has been built and tested in the University's tow tank, the results of which were used to inform the design and construction of a larger 2.5 m diameter prototype device. This prototype device has undertaken initial sea trials and the results are encouraging. This paper reports the advantages of a contra-rotating marine turbine, the engineering design rationale, the testing programme undertaken in both the test tank and at sea, and how data from the test programme can be used to verify the design methodology. The paper concludes by reporting the progress being made towards the design and deployment of a grid-connected device.

Session 21
Wave Energy Converter Hydrodynamic Modelling 4
Room 1, Thursday, 13th September, 14:00-15:20

Chair: António Sarmento, Instituto Superior Técnico and Wave Energy Centre, Portugal
Co-Chair: David Pizer, Ocean Power Delivery Limited, UK

Representation of non-linear aero-thermodynamic effects during small scale physical modelling of OWC WECs

J. Weber
University College Cork, Ireland

Abstract
This paper recalls the combined hydrodynamic-aerodynamic scaling requirements for small scale physical model testing of OWCs due to air compressibility. General considerations and an analysis of test results indicate complications associated with the implementation of these requirements. Through numerical simulation in the frequency domain it is shown that the disregard of the requirements leads to considerable errors in the prediction of the prototype behaviour from scale model tests. This is dependent on the absolute size of the representative air chamber height at full scale. A perturbation expansion method is employed to quantify the non-linearities associated with the simultaneous changes of interior air pressure and air volume. These are shown to be of significance at full scale but not replicated during small scale physical model testing when the established scaling requirements are applied. An alternative method is proposed where the fixed additional volume is replaced by a significantly smaller variable additional volume at model scale. The variations of this air volume may be controlled passively or actively to substitute the required air compression and possibly other effects that influence the hydrodynamic-aerodynamic coupling in accordance with the full scale conditions.

The Effect of Wavelength on the Response of Floating Ocean Wave-Energy Conversion Devices

D.R.B. Kraemer
University of Wisconsin – Platteville, USA

Abstract
Resonance and frequency-domain effects are well documented for floating bodies such as barges and moored ships. If a body's waterplane dimensions are small in comparison to the wavelength, it can be treated as a point absorber, and its response can be found in terms of response amplitude operators (RAO's) which are functions of the wave frequency. However, for wave-energy devices and breakwaters, the waterplane dimensions of the body are often of the same order as the wavelength, so wavelength effects become important. Simple relationships between the wavelength and the response in different degrees of freedom would be very useful in the design of buoyant ocean wave-energy conversion devices. In the present study, a numerical integration scheme is used to solve an initial-value problem and simulate the motions of a rectangular prismatic floating body in regular waves. Wave forces are calculated numerically at each time step using results from a panel-based potential flow method. Response amplitudes in heave, pitch, and surge are plotted versus wave frequency (normalized by the barge undamped natural frequency in the appropriate degree of freedom) and simultaneously versus wavelength (normalized by the barge length). This amounts to an extension of the traditional two-dimensional RAO (response versus frequency) to a three-dimensional plot (response versus frequency and wavelength). The simulated data agree well with expectations, and they show that the wavelength-to-bodylength ratio is an important factor in the design of floating bodies, especially buoyant ocean wave-energy conversion devices.

Oscillating Water Column (OWC) wave power caisson breakwaters – the present status, the need for new developments, the problems

K.Thiruvenkatasamy and Michio Sato
Kagoshima University, Japan

Abstract

Oscillating Water Column (OWC) wave power device is one of the most pioneering devices in terms of hydrodynamic efficiency. An OWC with two parallel walls (called harbour walls) extracts more power for a wider frequency band width. Literature evidence shows that the MOWC in array are more efficient rather than an isolated device. The array acts as a perforated breakwater which absorbs wave energy. Besides absorbing energy, remaining waves get dissipation and reflection. The array protects the shore from beach erosion, sediment control due to rough sea waves. An experimental study using method of images shows that an array spacing of three times the OWC width extracts more power. The array is subjected to breaking, broken and non-breaking waves. The wave - structure interaction at the end of the array needs particular analysis. Since, at the end or corner point, the dynamic action of waves produces vortex shedding, turbulence, etc. Hence, the wave power absorption for the corner caisson will be different from that of the other caissons. This anomaly can be said as the end effect. The hydrodynamic stability of such corner device also needs to be studied. Over topping effect needs to be studied. The engineering design aspects of such an array need several parametrical investigations in addition to cost-benefit analysis. Several design aspects are to be explored, before venturing to commercial developments. This paper features on the present status, the need for new developments and the problems ahead for prototype development.

A modular graphical user interface for WAMIT

Grégory S. Payne
University of Edinburgh, UK

Abstract

The hydrodynamic numerical modelling package WAMIT is a widely used boundary element method code. It is mainly distributed in its PC executable version which does not include any graphical user interface. Instead, input settings are entered into the program by means of text files. Computation results are output in the same way. Preparation of the input files and post-processing of the outputs is often time consuming and repetitive. This paper presents a graphical user interface addressing this task. The interface, programmed in MatLab, is split into pre- and post-processing parts. Its key feature is its modular structure. The programme consists of numerous independent modules that carry out specific and self contained tasks. This makes it easy to customise the interface to suit new requirements.

Session 22

Future Guidelines

Room 2, Thursday, 13th September, 14:00-15:20

Chair: Mats Leijon, Uppsala University, Sweden
Co-Chair: Raymond Alcorn, University College Cork, Ireland

Wave Energy Development & Evaluation Protocol

B. Holmes[1], K. Nielsen[2] and S. Barrett[1]
[1]University CollegeCork, Ireland, [2]Ramboll, Denmark

Abstract

This paper describes a development and evaluation protocol that has been specifically adapted for the advancement of wave energy devices. The basis of the schedule is similar to that established by NASA and widely used by many engineering research establishments in other fields. It is geared towards the actual converter evolution and improvement rather than any of the equally important generic aspects of wave energy extraction, such as resource investigation, site surveys, electrical grid location, planning, permissions and licensing etc. These latter criteria are considerations that will be both country and national policy dependant and will become important following on from this development programme, when a device is ready for the economic demonstration stage (Phase 5). It also concentrates on physical modelling techniques rather than mathematical procedures. It is highly recommended, however, that theoretical or numerical methods are pursued in parallel with the empirical approach outline in the following. The paper is based on a full document that was produced for the Marine Institute of Ireland and can be found at www.marine.ie It has also been adopted by Sustainable Energy Ireland as a working report when evaluating developers device proposals and planning future wave energy research activities. However, it is extremely important to acknowledge that following the recommended programme is no guarantee to producing a successful WEC. Rather it offers an opportunity since not adopting such a scheme will undoubtedly ensure that an invention has limited potential to progress to an acceptable conclusion. The early phases of the schedule are very important for investigating the numerous optimisation options that most devices have, before the activities advance to the more difficult and expensive prototype phases. The illustrations used in this paper also represent the accompany presentation. This approach has been taken so both documents are supplied at the same time.

Small scale physical model tests of floating wave energy converters

J.-M. Forestier, B. Holmes, S. Barrett and A. W. Lewis
University College Cork, Ireland

Abstract

This article describes the specifics of WEC physical testing compared to offshore platform testing and exposes the reasons of performing initial tests at small scales. The first difference is in the mooring philosophy: In case of floating WECs, the mooring is to be designed to give the maximal freedom of motion to the devices, which is not the case for offshore platforms. The second difference is that WECs have larger and thus more nonlinear motions. These large amplitudes of motions imply the necessity of a rigorous representation of the rotation of the device. The third difference is the definite influence on the PTO on the WEC motions. The PTO has therefore to be physically modeled. WEC design is today not an established technique; the uncertain points still have to be assessed with a sufficient level of confidence. This implies their physical testing at the preliminary study stage at small scales and subsequently their physical testing at larger scales.

Wave energy and the Pacific Islands market

Barbara Vlaeminck
Societé de Recherche du Pacifique, New Caledonia

Abstract

Following two and a half years of activity in wave energy project development in the South Pacific region, and an investment of almost one million Euros, Société de Recherche du Pacifique (SRP), based in Nouméa (New Caledonia) has acquired considerable experience in carrying out feasibility studies for wave energy implementation in this area of the world. As it is the case for any new market, SRP has encountered a number of issues while completing island-based project feasibility studies in New Caledonia, Wallis and Vanuatu. Although the obstacles to wave energy implementation may vary according to the size and location of the wave farms to be implemented, they are omnipresent in small Pacific Islands. Given the availability of the resource in the region, the extremely high cost of energy (all islands mostly use diesel generation, which becomes expensive due to high transportation costs), and the difficulty to implement other alternative sources of energy (solar, wind) due to customary land ownership issues, Pacific Island Countries are likely to benefit significantly from wave energy generation and to become important consumers of wave energy. This presentation will relate to the Pacific Islands energy sector; through the experience of the feasibility study undertaken in New Caledonia it will present the positive aspects of waves energy in this area of the world, and also some criteria to be met by the Wave Energy Converters to better adapt to this market. The Funding of projects and customary aspects in this area of the world will also be looked at.

An investigation of the Knowledge Base of the UK Marine Renewable Sector

Henry F Jeffrey[1], Markus Mueller[1] and George Smith[2]
[1]University of Edinburgh, UK, [2]University of Exeter, UK

Abstract

This Supergen Marine study highlights the issues facing the UK marine renewables energy industry in conjunction with identifying, investigating and discussing the pertinent issues surrounding this fledgling sector. A review of technology forecasting methods has identified the “Delphi Interview Method” as providing a suitable mechanism to facilitate the investigation of a forward direction for the sector. The use of this method has provided a robust and auditable set of results from a series of 22 interviews with leading academics in the marine and renewable energy fields. The analysis of the results from the interviewees has facilitated the presentation of the qualitative interview results in quantitative terms, thereby allowing the identification of a unique set of technology trends. The outcomes of the investigation have in turn been fed into the population of the UK Energy Research Centre (UKERC) Marine Renewables Research Roadmap (where there has been close collaboration) in order to forecast an efficient and effective route forward for the sector. The results from the road-mapping work are discussed in the companion paper presented by Dr Markus Mueller: “UKERC Marine Renewable Energy Technology Roadmap”.