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WORLDS LARGEST WAVE ENERGY PROJECT 2007 IN WALES

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0. Abstract

This paper introduces world largest wave energy project being developed in Wales and based on one of the leading wave energy technologies. The background for the development of wave energy, the total resource ands its distribution around the world is described. In contrast to wind energy turbines a large number of fundamentally different technologies are utilised to harvest wave energy. The Wave Dragon belongs to the wave overtopping class of converters and the paper describes the fundamentals and the technical solutions used in this wave energy converter. An offshore floating WEC like the Wave Dragon has to be scaled in accordance with the wave climate at the deployment site, which makes the Welch demonstrator device the worlds largest WEC so far with a total width of 300 meters. The project budget, the construction methods and the deployment site are also given.

1. Introduction

Wave Dragon, a leading developer in Wave Energy technology, is proposing the world's largest wave energy converter at a location off the Pembrokeshire Coast in Wales, UK.
The 7MW device will be located 4-5 miles off Milford Haven and tested for 3-5 years only, to gain operational experience and knowledge on the energy transfer efficiencies.
Commissioned in 2007, the project will even in this early demonstration phase produce enough clean, green electricity each year to meet the annual demand of between 2,500 and 3,000 homes. This clean generation will offset the release of about 1,000 tonnes of carbon dioxide (the main greenhouse gas contributing to global warming and climate change) every year. It is planned that this demonstrator devise shall form the first of 11 devices in a 77MW farm further off the Welsh coast.

The demonstration project is being supported by the Welsh Assembly Government under the Objective 1 initiative and the Welsh Development Agency (WDA) has been supporting the efforts of the project over the last few years. The Welsh Demonstrator project will also host an EC research and development project funded under the EC Framework 6 programme.

Further Wave Dragon Wales Ltd is backed by KP Renewables Plc who is providing the required match funding to deliver the project.

2. Background

The need for the development of renewable energy generation, including offshore wave energy, arises from the requirement to strengthen the security of supply, reduce emissions of greenhouse and acid rain gases, and to move towards a more sustainable future. As an example the UK Government has a target of generating 10% of UK electricity demand from renewable sources by 2010. This target has recently been extended by the Government to 15% by 2015 with an aspiration of 20% by 2020.

Wave energy is a means of generating electricity that does not produce emissions of greenhouse or acid rain gases, does not produce toxic waste products, and is not dependent on finite reserves of fossil fuels. It is inherently sustainable, and this is explicitly recognised in the Government's approach to the deployment of the technology.

The exploitation of wave power is seen as a complementary technology to the more mature technologies such as wind power. The waters off Wales offer great potential for wave technology, and an opportunity exists for a well-sited demonstration project to provide impetus to this nascent form of generation.

The global wave power potential is of the same order of magnitude as world electrical energy consumption. The best wave climates are found between 30-60 degrees latitude with annual average power levels between 20 -75 kW/m – orders of magnitude more powerful than solar and wind. For more that 100 years mankind has tried to capture and utilise this abundant energy, but until recently wave powered navigation buoys was the only practical result. In the last years a wide variety of promising wave energy converter concepts have however been developed and a handful of these have been or are now being tested.

Developers of wave energy converters face a series of major challenges. First of all they have to develop machinery that can operate and survive in this very rough environment. Secondly one has to optimise operation and maintenance systems to make wave power plants a viable solution. Wave energy converters have to compete with other renewable energy technologies, and it has now become obvious, that wave power can be much cheaper than for instance photovoltaic power. There are good reasons to believe, that wave power in a few years will be a serious competitor to offshore wind power.

The Wave Dragon is an offshore wave energy converter of the overtopping type. The development work is to a large extent built on the concept: use proven technologies when going offshore. The plant consists of two wave reflectors focusing the incoming waves towards a ramp, a reservoir for collecting the overtopping water and a number of hydro turbines for converting the pressure head into power. Wave Dragon is by far the largest known wave energy converter known today. Each unit will have a rated power of 4-11 MW or more depending on how energetic the wave climate is at the deployment site. The utilization of the overtopping principle as opposed to power absorption via moving bodies means that the efficiency grows with the size of the converter. This means that only practical matters set limits for the size of this WEC. In addition to this Wave Dragon due to its large size can act as a floating foundation for MW wind turbines, thus adding a very significant contribution to annual power production at a marginal cost. This boost in profitability makes Wave Dragon an economical profitable investment with the prices for renewable electricity today in for example the UK.

3. Abundant wave energy resources available

Wave energy ready for exploitation represents one of the largest renewable sources in the world, and is located near some of the world's major energy consumption centres.

Total resource

An estimate of the total wave energy resources that is available to be utilised in a short term perspective varies depending on how far offshore it will be technical feasible to deploy devices. As a conservative example IEA has estimated the potential world-wide wave energy contribution to the production of electricity to be between 10 and 50% of the world's yearly electricity demand of 15,000 TWh dependent of the obtained converter efficiency.

In the table below another estimate is related to other renewable resources and as it is shown ocean energy (of which wave energy is the major part) outnumber major renewable sources like biomass, wind and hydro.

Table 1: Technical Potential of Renewable Energy (ExaJoules)

	Biomass	**Hydro**	**Solar**	**Wind**	**Geothermal**	**Ocean**	**Total**
World	283	50	1,570	580	1,401	730	4,614
Current use	50	10	0.2	0.2	2	0	62.4
Total primary energy supply							420

Source: Federal Ministry for Economic Cooperation and Development and Ministry for the Environment, Nature Conservation and Nuclear Safety: Conference Issue Paper, Renewables 2004 – International Conference for Renewables Energies, Bonn 2004, p.27.

A study by the Department of Trade and Industry (DTI) and The Carbon Trust in UK (Renewables Innovation Review, 2004) is stating some 200,000 MW installed wave and tidal energy power by 2050 which with a load factor of 0.35 is resulting in a power production of 600 TWh/y. Independent of the different estimates the potential for a pollution free energy generation is enormous.

Distribution around the world

Wave Energy is not distributed evenly around the world. It is concentrated in northern and southern part of the globe. It is particularly interesting to note that the most wave energetic places are centred around some of the most energy consuming countries in northern Europe and northern US. Significant resources are found off UK, Ireland, North West US and Australia.

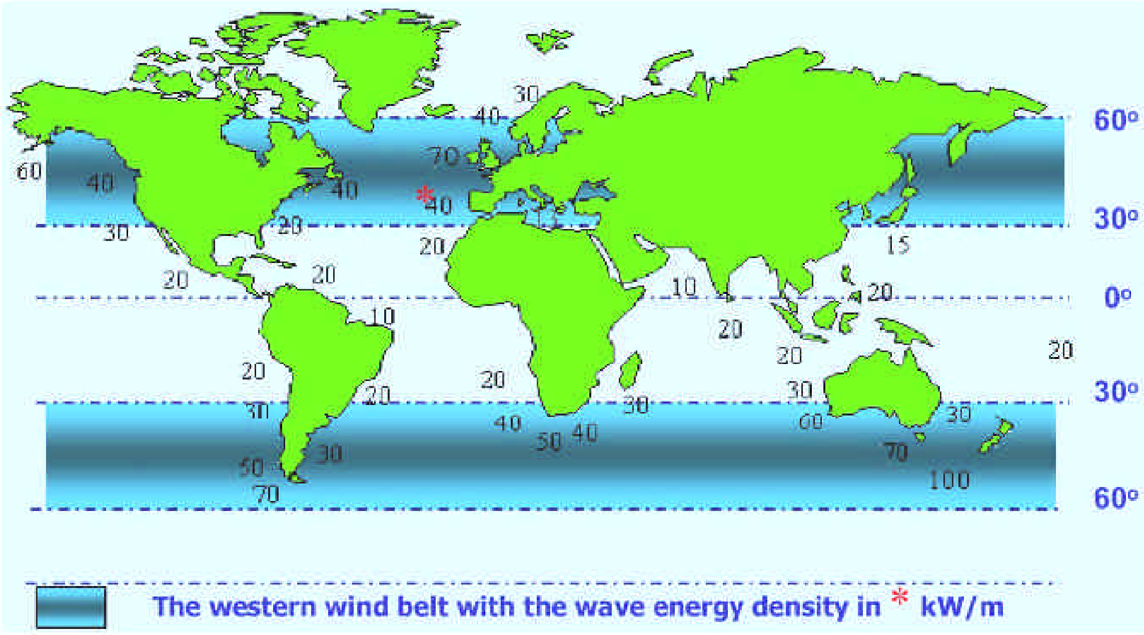

Figure 1: World distribution of average wave energy, European Thematic Network on Wave Energy, 2002.

4. Wave Dragon

Wave Dragon has been developed at an ever increasing speed during the last nine years. As part of the development activities towards a full size production plant in 2006 a grid connected prototype of the WD is presently being tested in a Danish fjord (a scale 1:4.5 of a North Sea production plant).

WD consists of three main elements:

- Two patented wave reflectors focusing the waves towards the ramp, linked to the main structure. The wave reflectors have the verified effect of increasing the significant wave height substantially and thereby increasing energy capture by 70 % in typical wave conditions.
- The main structure consisting of a patented doubly curved ramp and a water storage reservoir.
- A set of low head propeller turbines for converting the hydraulic head in the reservoir into electricity.

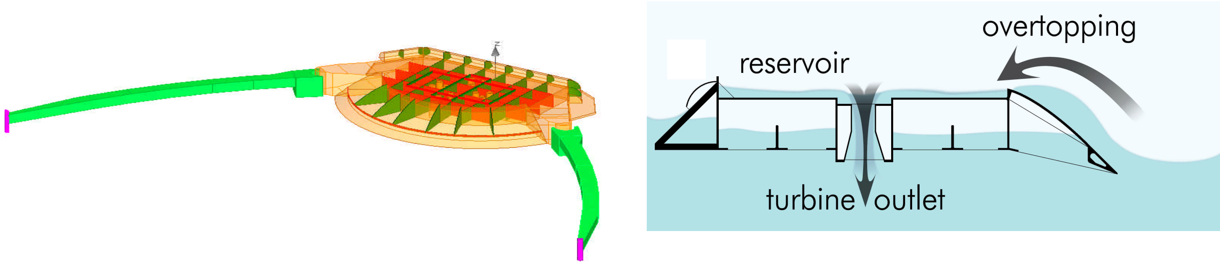

Figure 2: Left: Main components of the Wave Dragon. Right: The basic principle of the Wave Dragon, 1) waves overtopping a ramp, 2) water stored in a reservoir above sea level and 3) water discharged through hydro turbines. Wave Dragon floats on open air-chambers used to adjust floating level.

Figure 3: Wave Dragon prototype. Approaching waves are concentrated by the reflector towards the ramp.

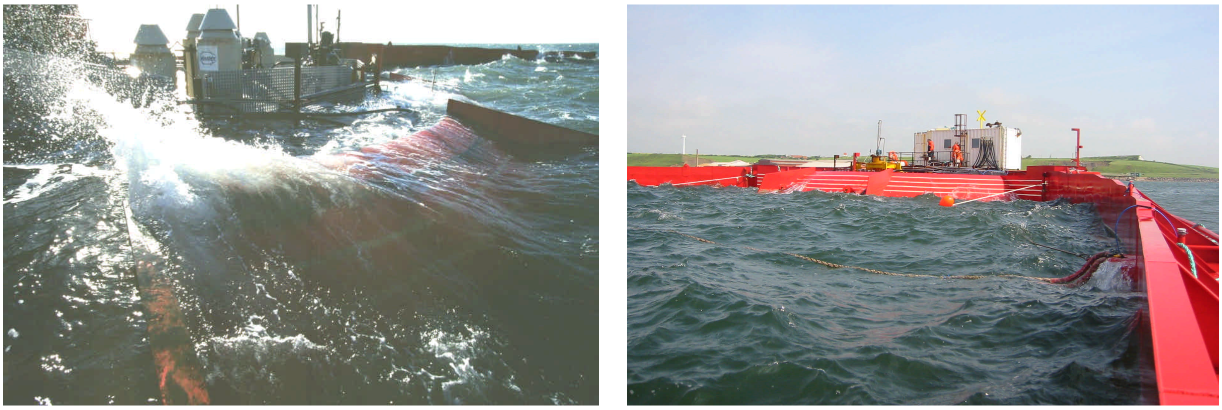

Figure 4: Wave Dragon in good waves (left) and in smaller waves (right).

Compared to other WEC types the Wave Dragon is quite unique as it uses the energy in the water directly via water turbines, i.e. a one-step conversion system, which yields a very simple construction and has only one kind of moving parts: the turbines.

But yet Wave Dragon represents a very complex design, where intensive efforts by universities and industry have been spent on designing, modelling and testing in order to:

- Optimise overtopping.
- Refine hydraulic response: anti-pitching and anti-rolling, buoyancy etc.
- Reduce (the effect of) forces on wave reflectors, mooring system etc.
- Develop efficient turbines for extremely low and varying head.
- Develop a turbine strategy to optimise power production.
- Reduce construction, maintenance and running costs.

All of this has been done with one goal: to produce as much electricity as possible at the lowest possible costs - and in an environmental friendly and reliable way.

The power take off system

Once the overtopping water has reached the reservoir, the potential energy is harvested by the installed low-head turbines. Early in the project it was concluded that the turbines had to be as simple and rugged as possible, with an absolute minimum of moving parts. Thus, a design with both fixed guide vanes and fixed runner blades has been chosen. The result has been a low head turbine specially developed by the Wave Dragon Team and tested at the Technical University of Munich.

The hydraulic efficiency of the turbine is between 92 % ±0.5% in the relevant head and flow ranges. The operating conditions of the turbines on the Wave Dragon differ strongly from those in a normal river hydro power station:

- Firstly, the turbines have to operate at very low head values ranging from 0.4 m to 4.0 m, which is not only on the lower limit of existing hydro power experience, but also an extremely wide variation.
- Secondly, due to the stochastic distribution of the wave overtopping and the limited storage capacity, the turbines have to be regulated from zero to full load very frequently.
- Lastly, they have to operate in a very hostile environment, with only a minimum of maintenance being possible on an unmanned offshore platform.

Efficient operation over the wide discharge range is ensured by using 16 relatively small turbines that can be switched on and off individually rather than a few large turbines. In order to grant a high efficiency throughout the wide head range, the turbines are operated at variable speed, using inverter-controlled and directly coupled synchronous permanent magnet generators. In order to keep the generator dimensions and cost low, the turbine design aimed at achieving a high specific speed; trying to attain a high unit discharge at the same time, which makes for a compact turbine.

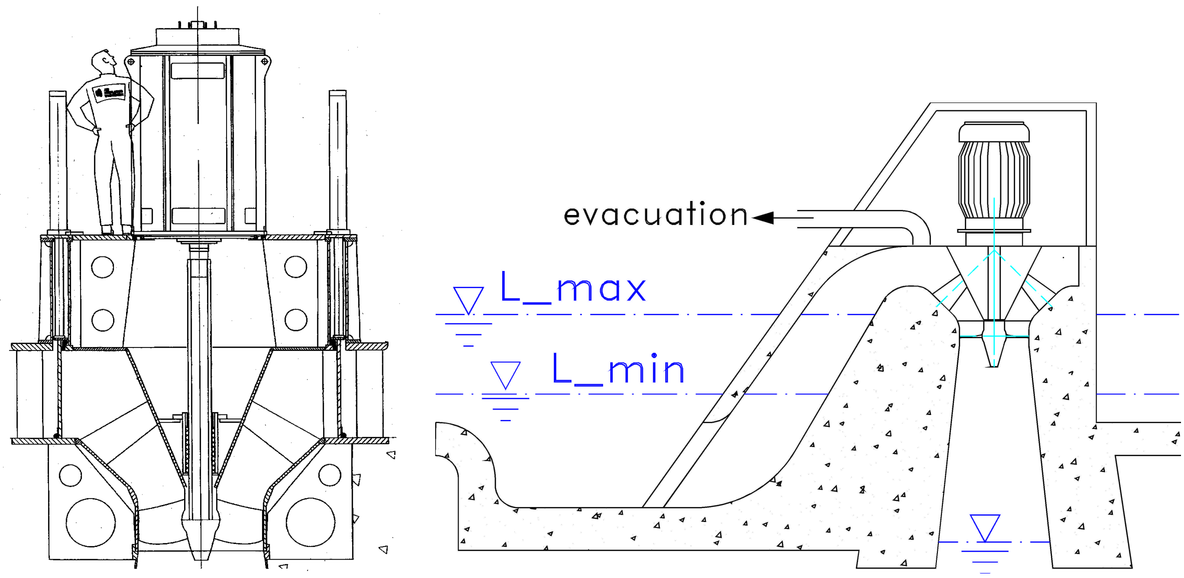

Figure 5: Left: A full scale WD cylinder gate turbine. Right: The principle of the siphon type WD turbine.

A comprehensive software package has been devised, enabling the overtopping of the individual waves and the operation of the turbines to be simulated. With the aid of this simulation software, optimum turbine operating strategies have been conceived. It has been found that for maximum energy production the turbines need to be switched on and off very frequently. In order to make this viable, two alternative solutions have been devised: A hydraulically operated cylinder gate upstream of the guide vanes and a siphon intake. Both designs have been considered worth pursuing and are at the present time being tested on the small scale prototype.

Figure 6: The six axial propeller turbines being assembled at Kössler GmbH (left) and one of the turbines being installed on the prototype in open sea

The control system

The Wave Dragon is equipped with a SCADA system allowing remote control and standard power plant operation

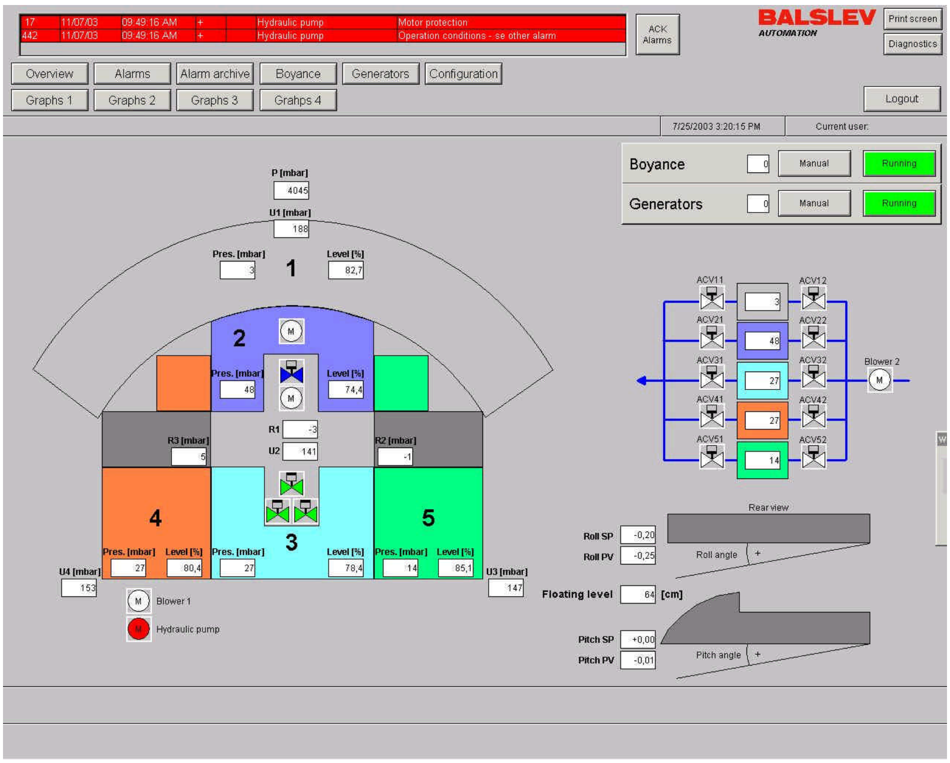

Figure 7: The main SCADA screen

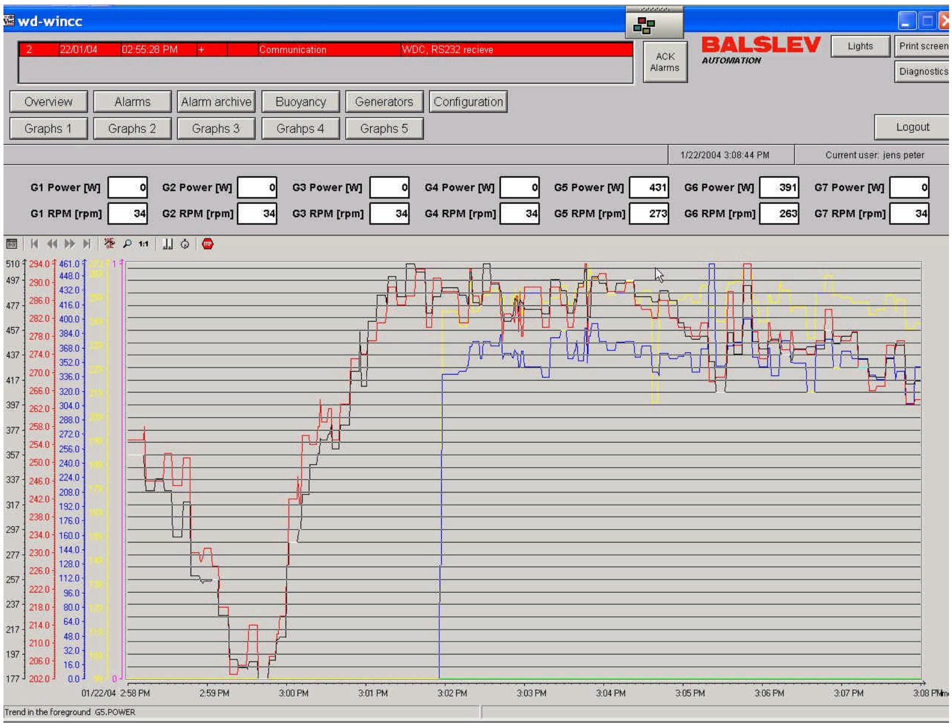

Figure 8: This SCADA screen dump illustrates rpm and power during start up of two turbines.

5. The Welsh Demonstrator project

Wave Dragon is a large floating barge structure. The main structural parts will be constructed in reinforced concrete plus additional structural steel elements. The total design weight of the Welsh demonstrator device is 33,000 metric tonnes. The overall geometrical layout of the device will be identical with the tested prototype.

On the device are mounted 18 low-head hydro turbines to drain the reservoir, each with a directly coupled 400kW permanent magnet synchronous generator. The operative range for the turbine and generators are between 0 and 290 rpm. Additional electrical systems, step-up transformers and service systems are placed in closed compartments.

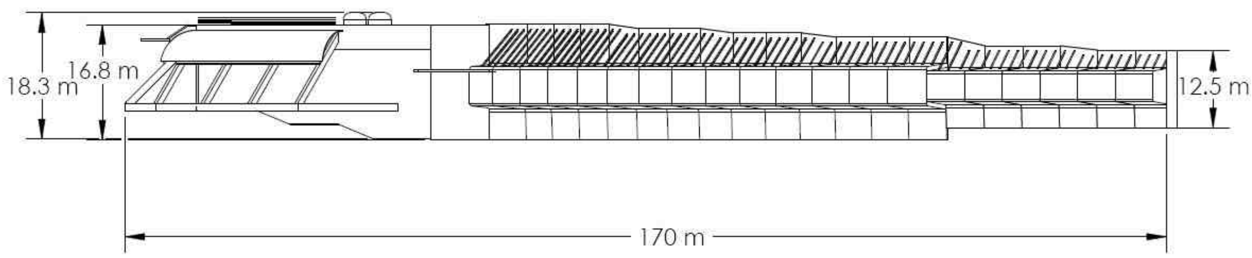

Figure 9 : Side View of the Wave Dragon Device.

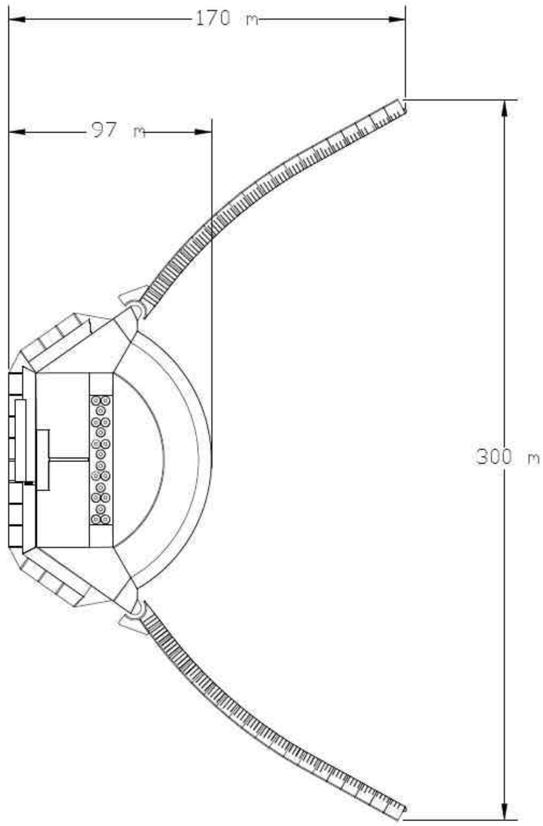

Figure 10: Top View of the Wave Dragon Device.

The preliminary demonstrator device dimensions are:

Distance between tips of arms	300m
Arm length	145m
Length (tip of arm to rear of central housing)	170m
Maximum height above sea level	6 – 3m
Draught	11-14m

Project budget

Financing early stage developments of renewable energy projects are difficult when it comes to unproven technologies as wave energy. To realise this project support has been given from the Welsh Development Agency for 3 years. Wales has a commitment to renewable energy and a strong wish to build up experience and industry in renewable energy. A £5 million (€7.4 million) grant has been awarded by the Welsh Assembly Government as an Objective One project. The project is also supported by the EC 6th Framework programme.

The Welsh Demonstrator device will initially be deployed in a wave climate much lower that it's rated power and size justifies, being able to test it properly. But the demonstrator project has been linked to a further development of a total 77MW wave energy farm in the Celtic Sea following the successful demonstrator testing. As significant cost saving exists when a series of re-inforced concrete structures and hundreds of turbines are to be constructed it has been possible to put together a fully commercial project. The overall total project investment for this 77MW project is approximately £1,740 per installed kW.

The Wave Dragon company has also been awarded a €2.4 million grant from the European Commission for research related to the Welsh Demonstrator project.

Construction

The Wave Dragon unit will be constructed at a port, close to the deployment site preferably Pembroke Dock.

The method for construction of the 33,000 tonnes heavy device will depend on the negotiation with contractors and the equipment available for the period of construction. The manufacturing of the reinforced concrete structure is straight forward using standard methods from the civil engineering field.

Three principal different methods exist:

- Using a floating barge of steel moored along the quay site in the harbour. The barge will be progressively submerged during construction until the Wave Dragon is able to float itself. The barge will then be moved and the structure towed to a quay for finishing work.

- Using existing building sites, onshore manufacturing different components and finally bringing the components to the quay site where they are connected using pre-stress technique known from bridge and tunnel building.
- Building the whole unit on a slip way and bringing the device in water the very same way as used in shipbuilding. This method cannot be used in the Pembroke / Milford Haven area as no slipway of a sufficient size exists. A Port Talbot slipway could possibly be used.

After having the device free floating it will be fitted with remaining installations like turbines and generators whilst still along the quay site.

Mooring

For a large floating structure like the Wave Dragon, which does not have to be kept stationary within 10's of meters, a slack catenary mooring solution is considered the only feasible option because of its ability to absorb large peak loads. This gives a high degree of safety against failure of the chains. Catenary moorings of large floating objects are a long established technically robust solution. They have been used for a variety of requirements, mooring of large ships, floating dockyards and large buoys to name a few.

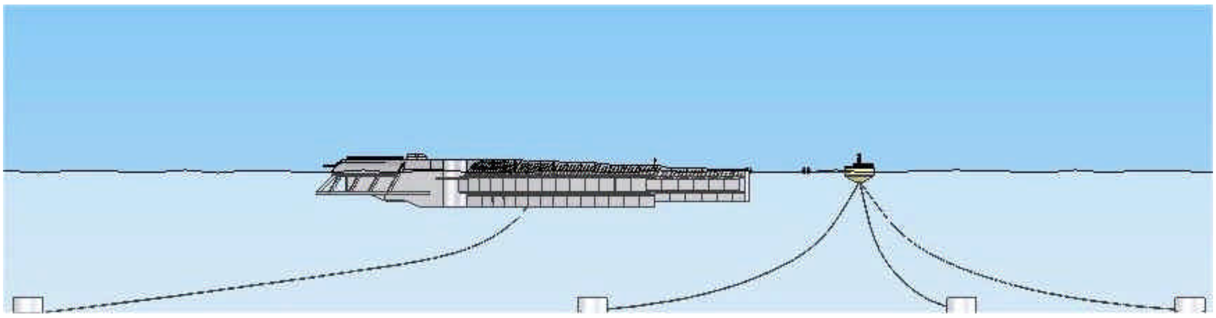

Figure 11: This figure shows the mooring system envisaged to be used on the demonstrator unit. Front mooring will be a CALM buoy system and a back mooring system will restrain the device to a +- 60 degree rotation around the front mooring. Concrete buckets filled with rocks will be used as gravity anchors.

Design and construction of large offshore foundations, sub sea installations and handling of heavy components and equipment is similarly a well established discipline within the offshore wind, oil and gas industries. Though the Wave Dragon wave energy converter in itself presents a new technology, the mooring and foundation of the Wave Dragon will be based on proven experience.

Wave statistics have been assessed based on a wave data for a number of years and compared to a global wave model. Finite Element Model data files for the Wave Dragon have been implemented for structural calculations of the Wave Dragon.
The configuration of a catenary mooring system can vary from a single leg mooring line to a multi-line mooring spread. The catenary mooring system consists of three main components:

a) Choice of mooring spread
b) Design of foundation structure for anchoring of mooring chains
c) The mooring chains

The geophysical survey of the sea bed at the deployment site showed that most of the area is solid rock save a number of locations with 1 to 2 m gravel. Based on these data we expect to use a mooring spread with 6 anchors in front of Wave Dragon and one restraining back anchor. Anchors will be gravity based anchors filled with natural material.

A mooring buoy will be introduced to further increase flexibility in the mooring system. This buoy will also harbour measurement equipment for wind and waves used in the Wave Dragon control and optimisation system.

Location

The demonstrator device will be located 2 - 3 miles off the South West Wales coast, off St Ann's Head, north and west of Milford Haven, and covers an area of approximately 0.25 km^2
The demonstration site has been selected in order to be:

- Exposed to the predominant wind/wave direction
- Relatively close to land, for economic and operational purposes
- Close to a major port, Milford Haven
- Away from commercial shipping interests
- Outside military firing ranges
- Close to potential grid connection locations (Dale, Marloes)

Due to these practical reasons, the demonstration site is located within the Pembrokeshire Marine SAC (Special Area of Conservation), and a full Environmental Impact Assessment is being conducted. The area marked with the black square on the map, Figure 12, shows the area being investigated and not the area occupied by a Wave Dragon device.
In addition, one export cable is required in order to transmit the generated electricity to shore.

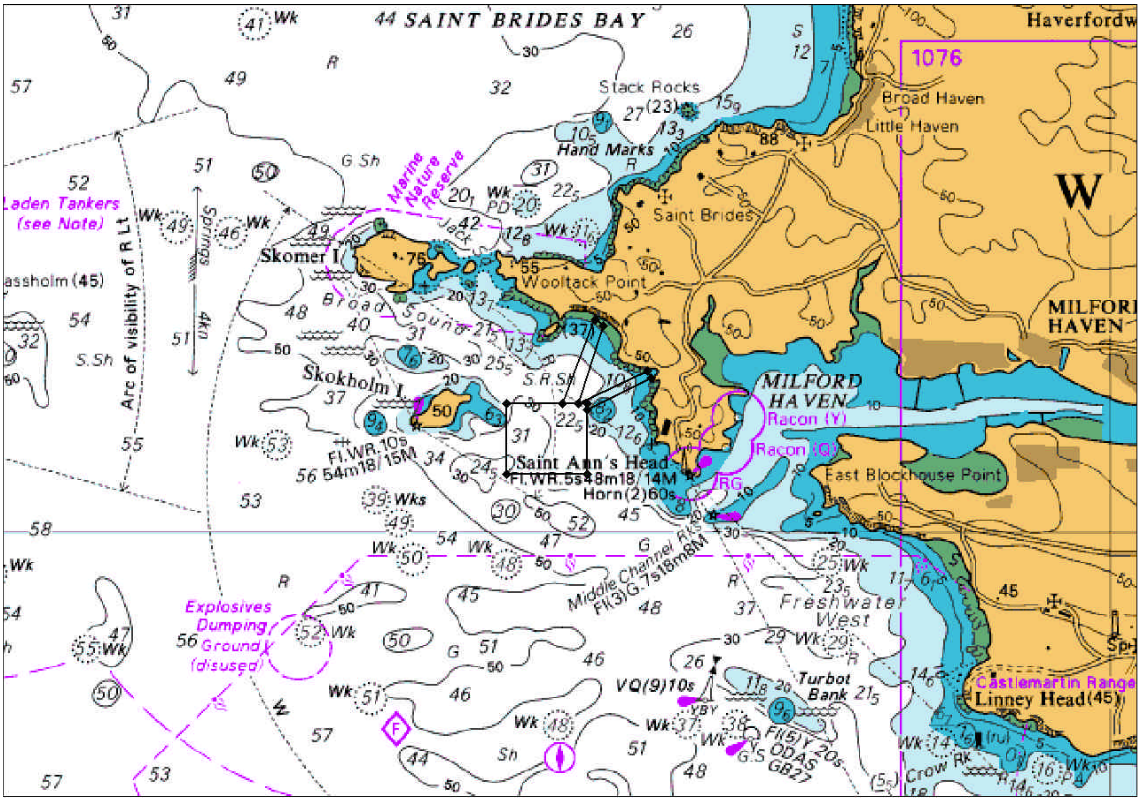

Figure 12: Map of South West part of Wales with indication of the area being investigated. At time of writing this article the most likely area of location will be in the upper North East of the indicated area.

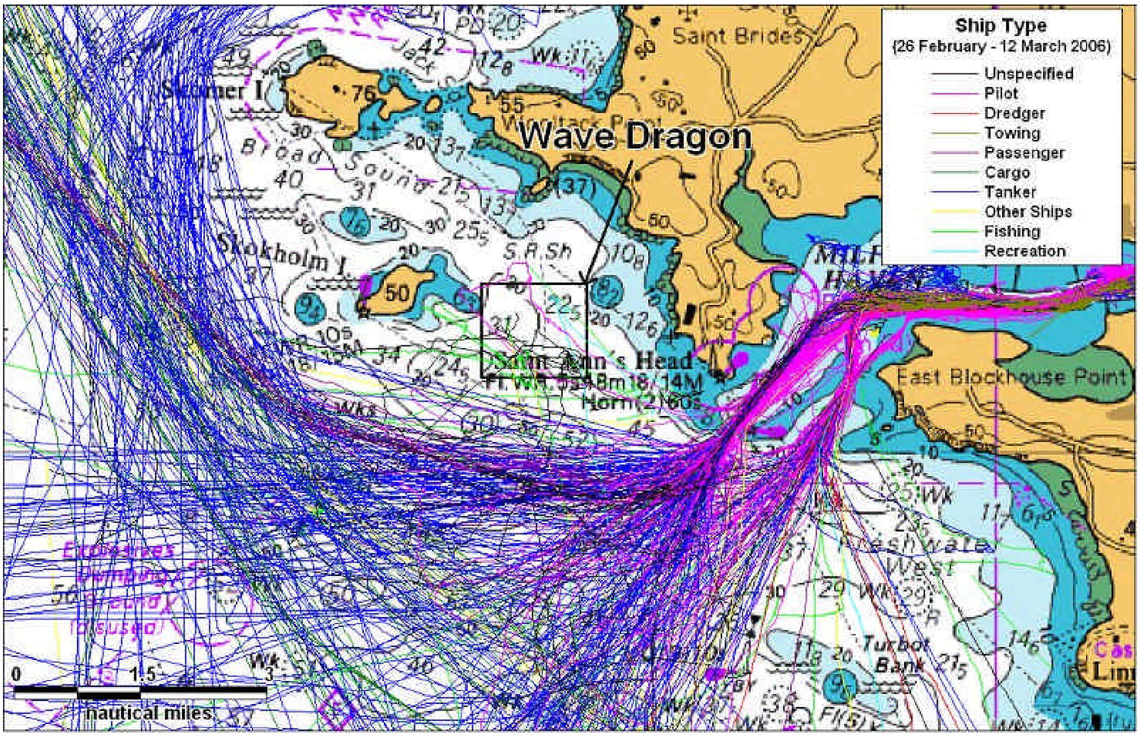

Figure 13: This map show the result from two weeks observation of traffic around the deployment site. There is heavy traffic in the area, especially from liquid natural gas tankers, but all traffic is well away from the deployment site.

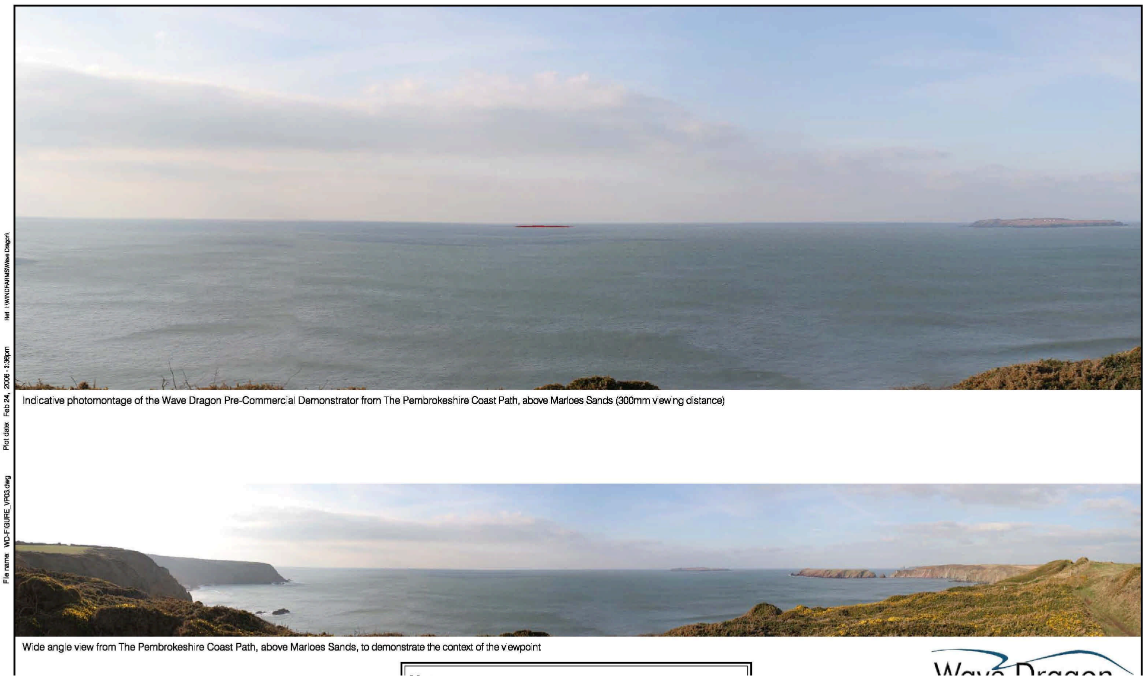

Figure 14: These photomontages illustrates how visible the Wave Dragon will bee seen from shore. The entire coastline in South West Wales is a National Park. The lower picture illustrate how little can be seen and the upper picture how it can be seen using a 300 mm zoom lens.

Conclusions

A prototype in of the Wave Dragon has, as part of the preparations towards the full size multi MW Welsh production plant, been undergoing real sea testing in Nissum Bredning, Denmark. The testing has verified the data earlier achieved from the laboratory tests. Furthermore, invaluable experience has been obtained in most operational aspects, such as regulation strategies for crest freeboard and turbines, remote control of operation and testing, etc. The testing of the Wave Dragon prototype has proven its seaworthiness, floating stability and power production potential.

Planning for deployment of the 7 MW demonstration power plant in Wales is now well underway and furthermore a second generation WD with secondary hydraulic power take off systems is ongoing at the prototype.

The profitability of the Wave Dragon technology will - as outlined above - improve due to continuous technological development of the WD technology; and WD will in the longer perspective be scaled the up for even more energetic wave climates. Due to the fact that the WD platform is very stable even in storm waves, it is also not unlikely that MW wind turbines will be installed on WD platforms when the two renewable offshore technologies have matured.

Further information can be found at:

www.wavedragon..co.uk , www.wavedragon.net and www.civil.auc.dk/~i5jpk/wd/wdnb.htm.

REFERENCES

Erik Friis-Madsen et al. 2000. 'Publishable Final Report – Low Pressure Hydro Turbines and Control Equipment for Wave Energy Converters (Wave Dragon)', Contract JOR3-CT98-7027, EMU, Denmark.

Hald, T. and Frigaard, P.: Forces and Overtopping on 2. generation WD for Nissum Bredning. Phase 3 project, Danish Energy Agency. Project No. ENS-51191/00-0067. Hydraulics & Coastal Engineering Laboratory, Aalborg University, Denmark, 2001.

European Thematic Network on Wave Energy (2002): Wave energy Utilization in Europe,Current Status and Perspective, EU, www.wave-energy.net

Soerensen, H.C., et al (2003): *Development of Wave Dragon from scale 1:50 to prototype*, Proceedings from the 5th European Wave Energy Conference, Cork, Ireland 2003.

Knapp, W., Holmen, E. et. al. (2003): *Turbine development for the Wave Dragon wave energy converter*, Paper presented at the Hydro 2003 conference in Croatia, November 2003.

EPRI (2004): *Offshore Wave Power Feasibility Demonstration Project*, Palo Alto, CA, USA, www.epri.com

Kofoed J.P., Frigaard P., Friis-Madsen E. and Sørensen H.C. *"Prototype testing of the wave energy converter wave dragon"* Renewable Energy 31, 2006.

Kofoed, J. P. and Frigaard, P. 2004. *Hydraulic Response of the Wave Energy Converter Wave Dragon in Nissum Bredning*. Hydraulics and Coastal Engineering No. 11, Dep. of Civil Eng., Aalborg University, Denmark.

Christensen, L., Friis-Madsen, E. and Kofoed, J. P. 2005. *The wave energy challenge. The Wave Dragon Case.* PowerGen 2005 Europe Conference, Milan, Italy.

Tedd, J. et al. 2005. *Design and testing for novel joint for wave reflectors*, 6th EWTEC. UK.

Kramer, M., Frigaard, P. 2005. *Reflectors to Focus Wave Energy*, 6th EWTEC, UK.
Frigaard P. and Kofoed J.P. *Power production experience from Wave Dragon prototype testing in Nissum Bredning: 2003 to 2005"* Aalborg University, 2005.