The development of wave power

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The first newsletter focused on wave power concepts and stage of development. This newsletter continues with the larger picture i.e. wave power potential, national programs, support systems, environmental issues and consent processes. It also includes some impressions from the 2010 International Conference on Ocean Energy, the largest conference within the field. Finally the recent news that ABB has made a welcome entrance into wave power is described in the last part.

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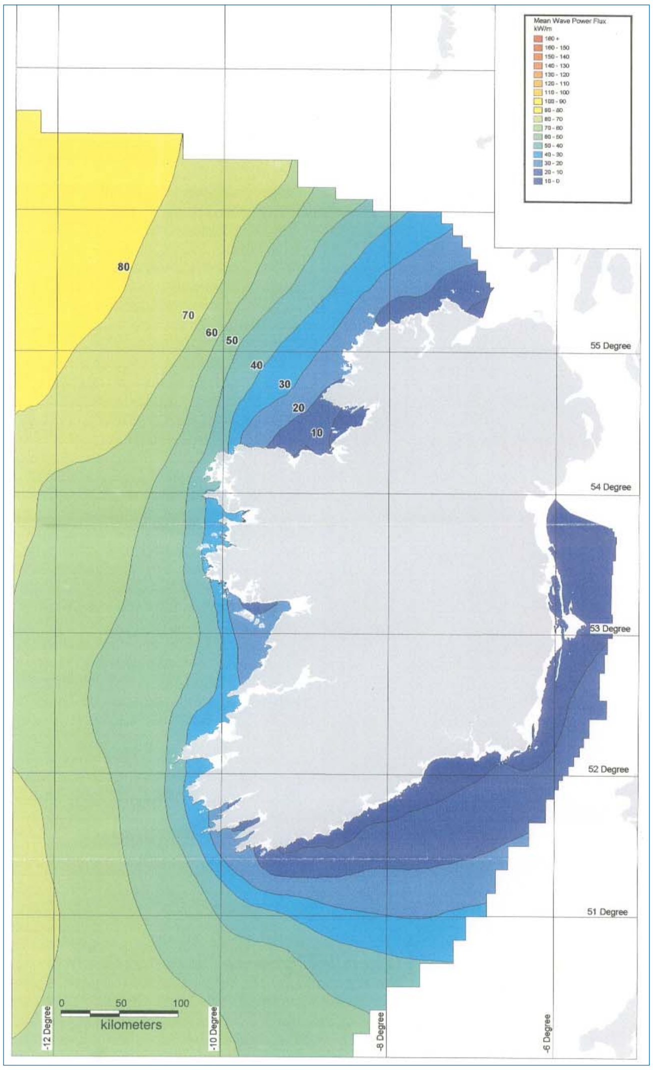
WAVE RESOURCES AND WAVE POWER POTENTIAL

Wave resources and wave power potential are generally rather poorly investigated in all countries. This is due both to the inherent complexity to compute them as well as the ambiguity of the results.

GENERAL

There is no absolute level of wave resources as they vary with time and distances from shore. Waves are primarily created in the open ocean and travel with small energy loss until nearing the shore when energy is lost through friction against the sea floor and breaking. Thus the incoming hydrodynamic power flux can be expressed as contour lines starting off shore with gradually lower levels when nearing the shore. This can be seen in the figure below from the Irish Wave Energy Atlas (Marine Institute/SEI 2005). Typically the Theoretical Resource refers to the power flux crossing a line sufficiently offshore to be unaffected by the bottom.



The power flux or wave climate is usually expressed as the annual mean power per m wave front and is a function of significant wave height and wave period. If for example a contour line of constant power flux is followed the Theoretical Resource will be the length of contour line times the power flux and annual hours. Alternatives may be e.g. following a depth contour line or a line of constant distance from the shore. However it has to be kept in mind that every reference line will give a different Theoretical Resource.

The Wave Power Potential is then how much of the Theoretical Resource that can be extracted from a technical point of view including wave power plant characteristics, various restrictions e.g. natural protection areas and shipping lanes and physical restraints e.g. maximum water depths or distance from shore.

NATIONAL WAVE RESOURCES AND WAVE POWER POTENTIAL

Looking at the Nordic countries and British Isles the level of knowledge around wave resources and wave power potential varies considerably.

The most ambitious attempt to determine the wave resource and wave power potential has been made in Ireland (SEI/ Marine Institute 2005). The theoretical wave resource offshore was estimated to approximately 500 TWh along the 70 kW/h contour line. The wave power potential has then been estimated by deploying a hypothetical double line of Pelamis wave converters resulting in a wave power potential of 28 TWh. After reduction for protected areas etc the net potential was found to be 21 TWh. Here some comments can be made; firstly the power curve used was for the now defunct P1 version of the Pelamis and a better performance should be expected for a new and optimised version and secondly that there is no reason that it should be just two lines of wave energy converters if the wave resource after passing through them is high enough.

In Norway an inventory of marine energy resources (Enova 2007) determined the offshore wave resource to be about 600 TWh. A rough estimate of the wave power potential has also been made in the report. It assumes that the same percentage of the wave power resource as the Norwegian hydro power resource is possible the develop, i.e. 25 %, and that the wave power conversion efficiency is between 10 and 25 % thus arriving at a wave power potential of 12-30 TWh.

No recent estimates have been made in the UK; a twenty-year old study (ETSU 1992) gives an offshore wave power resource of 6-700 TWh for the UK. A UK wave power potential of 50 TWh is quoted in a number of official publications including e.g. the 2010 Marine Action plan, although details on how this figure is derived are unknown.

The Danish wave resources are found on the west coast of Jutland and estimated to be 30 TWh offshore (Energistyrelsen 2005). The maximum offshore power flux is around 15-20 kW/m and a wave power potential of 5 TWh is given as "feasible".

There has not been done any study of the Swedish wave energy resource. However, the best conditions in Sweden are found on the West Coast north of Gothenburg where the offshore power flux is around 5 kW/m. Multiplying this with 150 km stretch between Gothenburg and the Norwegian border gives then an theoretical resource of 6 TWh. There is also a wave resource in the Baltic Sea but with lower power fluxes. A study (Henfridsson et. al. 2007) has estimated the total Baltic Sea resource to 56 TWh of which some would be included in a Swedish wave energy resource. However, the methodology used in this study differs from the others studies and results are not comparable. There has been no attempt to attempt to determine a Swedish wave energy potential.

References:

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NATIONAL PROGRAMS

SWEDEN

Sweden does have not have any national wave power program or targets for wave power. Wave power projects can apply for funding in competition with other renewable projects, the Skr 143 Million funding for the "Sotenäs wave power project" is e.g. from a fund for large demonstration projects for renewable energy. The Swedish Energy Agency supports wave power research at Uppsala University and the associated research facility for wave power at Lysekil.

(Note: The latter was erroneously described as a test site for Seabased in the previous Newsletter)

NORWAY

The Norwegian situation is similar to the Swedish with no national program or targets for wave power. Some funding is available from the Norwegian Research Council and Enova (new/small scale technology demonstration projects). Ocean Energy R&D is mainly carried out at NTNU in Trondheim.

DENMARK

Denmark had a wave energy program 1997-2002 where DKr 40 Million was allocated towards development of concepts in a three- staged process. Some 40 ideas were initially screened of which 15 proceeded to tank tests and one (Wave Dragon) to pilot test in the open sea.

There is a Danish wave energy R&D strategy (Energistyrelsen, 2005) that acknowledges the potential contribution of wave power to the Danish electricity supply and gives recommendations on how R&D for wave power should proceed. However, it does not suggest that any funds or other targeted support measures should be allocated to wave power, instead leaving it to the market to carry the development further.

Out of the approximately DKr 80-100 million annually available for energy R&D it is estimated that about 5 % goes to wave energy. There is one major collaborative R&D project, "Structural design of wave energy devices" started in 2010 and involving a number of Danish and international partners. The project is led by Aalborg University with a budget of Dkr 20 Million from the Danish Agency for Science, Technology and Innovation and will run for five years.

UK/SCOTLAND

Public funding and other support for marine energy in the UK exceed by certainty the rest of world put together although no aggregate figure can be found. The heading marine power includes tidal power as well as wave power with funding split about 50/50 currently. The Scottish government is self-governing in matters relating to e.g. renewable energy. Much of the marine energy resources are in Scotland, which in combination with employment issues, has led to some special Scottish initiatives regarding marine energy over and beyond the rest of the UK.

The UK has the best ocean energy resources in Europe while at the same time a huge demand for new renewable energy to fulfil its EU commitments. In the 2009 UK Renewable Energy Strategy £60 Million was allocated to the ocean energy sector for immediate use; see below. There is no firm target for marine energy but a figure of 1000-2000 MW deployed 2020 has been indicated.

There is a multitude of funding agencies and programs in the UK so only the major initiatives are described here.

- Three test facilities; NAREC (bench and tank testing), EMEC at the Orkney Islands (near shore testing of single wave and tidal devices) and the Wave Hub outside Cornwall (offshore for wave power arrays) has in total received ~£50-60 Million (of which £30 Million from the 2009 funds).
- Marine renewable proving fund (MRPF). £22 million (from 2009 funds) in capital grants for prototype testing allocated to 6 projects (2 wave and 4 tidal).
- Marine renewable deployment fund (MRDF). A 2005 fund of £42 Million so far unused but extended to 2014. The fund is to provide a combination of capital grants and feed-in tariffs. (Note: The combination of prerequisites to apply and support levels has made this fund unattractive and unless terms are changed likely to remain unused).

The Scottish government has with its Wates and Waters funds contributed another £20 Million towards prototype deployment. In addition the Scottish Government has announced the most spectacular support the Saltire Price (see side bar).

IRELAND

In the 2007 White Paper, "Delivering a sustainable energy future for Ireland", the Irish Government states that it intends to make Ireland a world leader for research, development and deployment of Ocean Energy technologies. Furthermore it sets the ambition to have 500 MW installed capacity by 2020.

The actual strategy had already been set out in the National Strategy for Ocean Energy (SEI/Marine institute, 2006) where development was set out in four stages:

- Phase 1 (2005-2007) Offshore test facility for ¼ scale prototypes, enhanced research capability and funding.
- Phase 2 (2008-2010) Support for pre-commercial single devices, development of a grid-connected offshore test site.
- Phase 3 (2011-2015) Pre-commercial small array testing and evaluation.
- Phase 4 (2016-) Strategies for commercial deployment of wave power technologies

Phase 1 was fulfilled with e.g. the Galway Bay test facility. For the 2008-2010 period the government allocated €27 Million and created a supervising authority, the Ocean Energy Development Unit (OEDU). The funds primarily allocated to support of device developers, development of the offshore test facility and enhancement at the primary R&D facility, Hydraulics and Maritime Research Centre, Cork.

At a glance the time schedule needs to be revised as test site (AMETS) is still at a planning stage and no pre-commercial devices have been deployed or even are planned.

THE SALTIRE PRICE

The Saltire price is a competition open for wave and tidal projects. The winner is the project that generates most electricity during a rolling two-year period starting the latest 2015. The winner will get £10 Million but must generate more the lower qualifying limit of 100 GWh.

(Comment: It would need a 20 MW array to accomplish this and it is unlikely that such a project will commence within this time frame. An educated guess is that the date will be adjusted.)

TARIFFS FOR WAVE POWER

As a new technology wave power will be dependent on subsidies until the industry has reached a competitive level. At the earliest stage there will be a need for upfront capital through primarily capital grants to decrease risk. However, the most important support when moving from the earliest prototypes is feed-in tariffs or similar. The table below shows what electricity generated by wave power plants would receive today in the Nordic countries and the British Isles (shown in € for comparison).

The remuneration in Nordic countries is essentially without any reference to wave power (there is a mention in the Danish tariff system but the level shows that it is a token gesture).

Country	Electricity price	Comments
UK	≥15 €cent/kWh	2 ROC's* + whole sale price (~6€cent/kWh)
Scotland	≥28 €cent/kWh	5 ROC's* + whole sale price (~6€cent/kWh)
Ireland	22 €cent/kWh	Feed-in tariff
Norway	5 €cent/kWh	Whole sale price
Sweden	8,5 €cent/kWh	Whole sale price + green certificate (~3,5 €cent/kWh)
Denmark	8 €cent/kWh	Feed-in tariff

*Renewable obligation certificate, floor price approximately 4,5 €/kWh although currently higher due to a deficit of certificates (2010 ~7 €cent/kWh)

The Scottish Government has used their prerogative to self determine renewable energy support. The level is based on the expected cost of wave power today and will be reviewed at certain intervals. However, existing plants will keep the level at their introduction, so called grandfathering. (Note: Tidal power receives 3 ROC's)

The UK support level is appreciated to be too low but is expected, at least initially, to need capital support as well.

WAVE ENERGY AND ENVIRONMENTAL CONSENT PROCESSES

Establishment of wave energy farms require consent from the authorities. Time consuming, unclear and complex consent processes could become a considerable barrier for a new industry as wave energy. There are examples of early consent processes requiring more than 25 permits and contacts with ten public departments. Introduction of "one-stop-shop" consenting processes, where all parts of the application, EIA and consent process can be handled through one authority is one strategy to avoid or at least reduce the complexity and waste of time and resources.

"ONE STOP SHOP" CONSENTING PRINCIPLES IN DIFFERENT COUNTRIES

Denmark has implemented the one-stop-shop principle in their regulatory framework for EIA and consent for offshore wind and ocean energy, which has resulted in a simplified system with lower degree of uncertainty. In Sweden, the regional Environmental Courts acts as the "one stop shop", giving consent for applications to construct and operate wave farms and other industrial activities that may affect the environment.

In Ireland, consenting of construction and operation of a wave energy farm is still spread among at least five different authorities. It is currently the developer's responsibility to seek opinion and consent from all of these authorities. However, introduction of a one-stop shop system is planned as one of the main tasks of the Ocean Energy Development Unit. Scotland started working with a one stop shop approach in April 2009 with the newly formed authority Marine Scotland, which has been given responsibility to coordinate consents for wave, tidal and offshore wind energy applications. In Scotland, a Strategic Environmental Assessment (SEA) has been performed to identify suitable areas and support the development of marine renewable energy. The Marine Institute in Ireland is also currently performing a SEA type study concerning marine renewable energy.

The differences in consent processes between different countries probably have historical background. In Ireland there have up to now only been minor industrial offshore activities in need of consents and therefore coordination between authorities has not been needed. The massive plans in Scotland for development of offshore wind, wave and tidal farms have shown the need for a more coordinated consent process between authorities. In Sweden the development of hydropower in the last century has been a template for the current procedure of environmental consent processes and in Denmark, the large wind energy establishment has driven the development.

DIFFERENT FOCUS IN BASELINE STUDIES

It is not only the consent processes that differ between countries. The focus of the consent and the requirements of baseline studies for the EIA process and monitoring program also differ. In Sweden, only one wave energy farm has been consented so far. The main topic of discussion in the Swedish consent process, both in stakeholder consultations and in the court judgement was the effects on the fishing industry, especially concerning the catch loss of Norwegian lobster in the closed off wave energy farm area. The baseline studies and investigations for the consented Swedish energy farm did not include any offshore surveys or investigations of birds, marine mammals or fish. When studying ongoing consent process in Scotland and Ireland, it is striking that the baseline study requirements are extensive, and primarily focusing on marine mammals and birds.

ENVIRONMENTAL EFFECTS FROM WAVE ENERGY

In the light of climate change and increasing energy demand the focus of renewable energy production is considerable. Among the renewable energy sources ocean wave energy is gaining increased attention. This is because ocean waves present a new renewable energy source of high energy density where only minor environmental effects are expected. Both positive and negative environmental effects are possible. At present there are no large-scale commercial wave energy parks and only a few full-scale tests and demonstration projects to draw experience from. The knowledge on environmental impacts from wave energy establishments is therefore very limited, and to a large extent built on speculations on probable effects or on assumptions that the impacts may be similar to the impact of other industrial offshore activities.

WHAT IS THE PROBABLE ENVIRONMENTAL IMPACT?

Wave power installations have potential to affect both the physical, biological and human environment. Effects on coastal processes, marine mammals, seabirds, fishery and shipping and navigation have been highlighted. Coastal processes may be affected because of changes in wave and current regimes due to presence and operation of wave power device. For marine mammals there is a risk for entanglement, entrapment and collision from presence and operation of wave energy converters, mooring lines and maintenance vessels. Fishery could be negatively affected because wave farm areas become restricted areas for fishing. The negative effects from wave energy on the environment are expected to be dependent of the geographical size of the wave farms.

Some of the potential environmental effects should be unique for wave energy installations and some are expected to resemble effects from other industrial offshore activities such as wind farms and sub sea transmission links. A specific negative effect of wave energy farms during construction, operation and decommission is generation of underwater noise that may disturb marine organisms. Electro Magnetic Fields (EMF) generated by sub sea cables is not an environmental risk that is unique for wave energy farms. Effects of construction work of wave energy devices and transmission cables on marine organisms are activities that also are not unique for wave power installations. Environmental effects of EMF from sub sea cables for wave energy farms and construction work for wave energy devices and sub sea cables should be similar as for wind farms and sub sea transmission links.

There are also possible positive environmental effects of wave power. Wave energy farms may function as artificial reefs (AR) or Marine Protected Areas (MPA), which should enhance local abundance of fish and invertebrates. It is also possible that surface-oriented wave energy devices (i.e. buoys, supporting structures) may function as Fish Aggregation Devices (FAD) for pelagic fish.

HOW TO GET KNOWLEDGE?

The potential impact of wave energy is in many cases generic e.g. studies carried out in one site may be used to judge impact on the marine environment in other sites. A cost-effective strategy to increase knowledge about environmental effects from wave power is collaboration in Joint Industry Monitoring Programmes (JIMP). Another opportunity is compilation of knowledge about environmental effects on marine organisms from other industrial offshore projects such as offshore wind, oil and gas and sub sea cables where some of the environmental impact is expected to resemble the possible impact from wave energy installations.

STANDARDISATION IN WAVE ENERGY

BACKGROUND

The wave energy sector initially emerged mainly from two sides – academia and technology inventors. Both these sectors have highly qualified people with a lot of skill. Generally, however, neither academia nor inventors have a solid industry background with a wide competence in quality assurance, production management, design, manufacturing, assembly, procurement, health and safety, environmental consenting etc. Standards could be used to minimise the risks and failures within the wave energy sector and to reach commercial wave energy farms faster.

WHY NEW STANDARDS?

So, why are new standards needed? Why cannot the marine energy sector use standards from the oil and gas sector and the already existing energy sector, e.g. wind? Well, partly it can. Standards from other sectors should be used when applicable, but there are a number of reasons to why they are not always applicable. The offshore oil and gas industry and the shipping industry are not producing electricity, which means that the standards in these sectors lack the aspects of electricity production. Energy sector standards on the other hand often lack the aspect of offshore demands. The marine energy sector develops new unproven technology, for which there are no standards developed.

Offshore wind turbines high up in the sky are subjected to different kinds of loads and requirements than wave energy devices situated under water or on the water surface where the loads from the water are very strong, and salt, marine growth and possibly ice present a challenge.

MARINE ENERGY STANDARDS UNDER DEVELOPMENT

There are currently no international standards for how design, manufacturing, performance measurement, environmental monitoring etc within the field of marine energy should be performed with high quality. To change that, the International Electrotechnical Committee (IEC), a global organisation that prepares and publishes international standards for all electrical, electronic and related technologies, started a standardisation committee for marine energy, a few years ago. The aim of this technical committee is to develop standards for the benefit of the marine energy industry.

The standards produced by the IEC technical committee for marine energy will address:

- System definitions
- Performance measurement of wave, tidal and water current energy con verters
- Resource assessment requirements, design and survivability
- Safety requirements
- Power quality
- Manufacturing and factory testing
- Evaluation and mitigation of environ mental impacts

ICOE IN BILBAO

There are two leading biannual conferences within the wave and tidal sector, the European and Tidal Conference (EWTEC) and the International Conference on Ocean Energy (ICOE). ICOE has an industrial focus and is held in even years. The 2010 conference was held in Bilbao, Spain and attracted more than 600 attendees.

GENERAL REFLECTIONS

Overall the feeling is that ocean energy is gaining momentum, although at the moment somewhat more for tidal power than wave power.

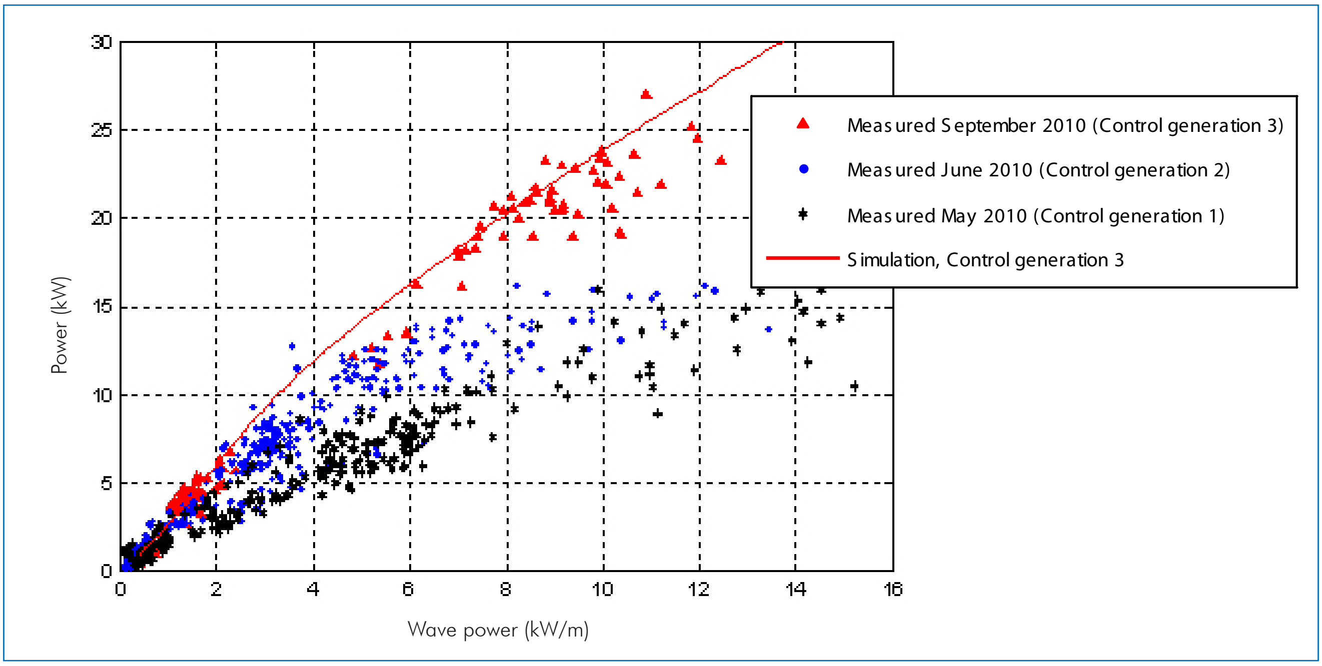
There was surprisingly few news from wave power developers. The most interesting presentation and only real news were from the Danish developer Wave Star A/S (see separate text). The challenges of a wave power project were illustrated by the Mutriuku project. The project involves the incorporation of OWC-type wave energy converters in a new breakwater where both bureaucratic and physical storms have created problems for the project. A whole session was dedicated to national test sites where the major news is that the Wave-Hub (see separate text) in the UK is now ready for operation while planning for the Bimep (Spain), SeaRev (France) and Amets (Ireland) is going ahead. All of these sites will be able to grid connect multiple wave power plants up to an aggregate 10-20 MW. Regarding national programs a Spanish €30 million R&D program, OceanLider, was announced, while on the other side of the Atlantic a first U.S. funding program is being put together aimed at the whole development chain from ideas to prototypes.

WAVE STAR

Wave Star A/S has been developing their point absorber concept for some ten years following the route of tank tests and 1:10 scale sea trial. Since September 2009 Wave Star have been testing a section of their full-scale device outside Hanstholm at the Danish West Coast. At the ICOE conference results were presented, which are among the first results for a full-scale wave energy converter to be made public.

The Roshage test unit consists of a section from a future full-scale 1 MW unit, with two 5 m diameter floats whereas the full-scale unit will have twenty. The test unit is located in 6 m water depth and can be reached from land by pier. It has been in operation since September 2009, is grid connected and can be operated remotely. Rated power is 110 kW, i.e. 55 kW per float. The power take off is hydraulic with pistons connected to the floats and the resulting pressurized oil run through hydraulic engines with attached generators.

The Roshage test unit and close up of floats



10-min average values of absorbed energy in the hydraulic cylinder of one float (Source: Wave Star A/S)

In the diagram results of absorbed wave power as function of incident wave power is shown. The absorbed power is shown as hydraulic power in the cylinder, i.e. generated electric power will be lower as losses in the hydraulic and electric system is added. The results are especially interesting as they clearly shows the importance of advanced control strategies where absorbed energy has been doubled without any change in physical equipment. Somewhat simplified the difference in control strategy is the timing and amount of force ("braking") put on the float.

WAVE HUB

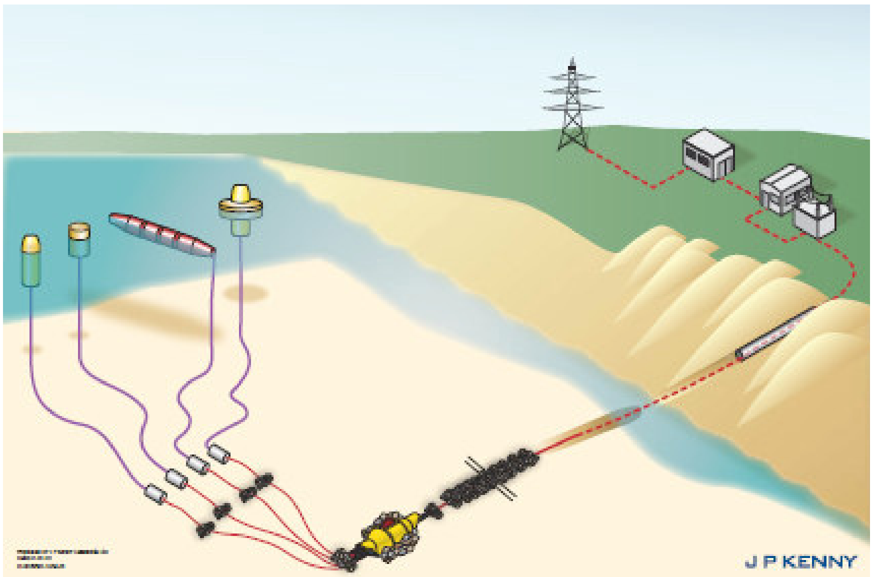
The £42 million Wave Hub test facility is the to date most ambitious investment in wave power infrastructure. Wave Hub encompasses a 4x2 km area of the coast of Cornwall in the South West corner of Great Britain. The site is the first true off-shore site for wave power located some 16 km from the shore at a water depth of around 50 m.

The facilities include grid connection for four developer berths where arrays up to 4 MW can be installed. The layout can be seen in the picture.

Each developer will have access to a cable tail on sea floor that runs to the hub (the yellow vessel in the picture). The hub (se picture) is a sub sea junction box on the sea floor connecting to the cables going to the onshore substation. By using a sub sea junction box the number of cables to shore and associated costs can be lowered. In theory it would be sufficient with one cable but at an early stage it was decided to operate the site at 11 kV, which necessitated two cables to allow 16 MW to be connected. However with a view towards the future the system is dimensioned for 33 kV and can at this rating accommodate up to 50 MW. Part of the cable route is over extremely rugged and rocky bottom, which have necessitated rock mattressing and partly explains the high cost of the project.

The hub is entirely passive and essentially contains two busbars. Ideally it would have included e.g. circuit breakers but it has been chosen to avoid active equipment, as any malfunction would necessitate retrieval of the hub to surface a complicated and presumably expensive operation.

Forts...



Layout of the Wave Hub (Source: JP Kenny)

Overall the Wave Hub gives wave energy developers an opportunity to test multiple devices at a true offshore location with grid connection. The site is operated by the South West Regional Development Agency (SWRDA) and has been financed by the UK government and regional development fund from EU. The site is currently in the closing stages of construction.

The hub during construction (Source: JP Kenny)

ABB INVESTS IN WAVE POWER

Recently it was announced that ABB will invest £8 Million (~SEK 100 Million) in the Scottish wave power developer Aquamarine Ltd through its venture capital arm, ABB technology ventures. rated power of 2,4 MW. Installation is planned for the summer 2011.

The significance of ABB's investment is substantial as this is the second time

Aquamarines Oyster 2 wave energy converter (source: Aquamarine)

Aquamarine ltd develops a wave power concept called Oyster consisting of bottom mounted hinged flaps. The action of the flaps pumps pressurized seawater to an onshore turbine. The first Oyster prototype has been tested outside the Orkneys for about one year. It will now be followed by the Oyster 2 that will consist of three larges flaps and associated onshore facilities with a total a large engineering corporation (the first was Voith Hydro) engages in wave power. Although it is not clearly stated how much ABB will be involved beyond the purely financial contribution it would be surprising if not ABB's capabilities in e.g. electrical engineer and control systems will be utilised in the further development of the Oyster.

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