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Developing the Irish Wave Energy Resource Atlas 2005

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1. Introduction

This 30 min. presentation, derived from the production of the above atlas for Sustainable Energy Ireland and the Irish Marine Institute, details an initial comparison made between several years of hourly wave forecasts derived from Wave Model (WAM) over a grid of points surrounding the Irish coast with corresponding records from a number of buoys installed by the Marine Institute in collaboration with the UK and Irish meteorological services in recent years. Data was available for 145 buoy months and approximately 51 million individual forecast and recorded values of wave height and period were utilised.

This presentation will show how the information derived can be used to estimate the available **theoretical**, **technical**, **practicable** and **accessible** wave power and energy resources (including seasonality) and also the performance of different types and configuration of wave power converter.

- **Fig. 1**

Comparison was made between hourly predictions of Hs and Tz derived using the internationally developed wave model (WAM) employed by the Danish Meteorological Institute, updated every six hours from satellite and meteorological observations, and buoy data derived from five buoys installed around the coast by the Irish Marine Institute in collaboration with Met. Eireann and UK Met. Office. Wave Records from the Kinsale Gas platform were also included. The WAM data were supplied for a grid of 724 ponts at 0.25^o spacing as shown on Fig. 1 which also shows the buoy locations. In order to establish a coastal boundary for the grid a series of 124 points were selected at the 20m depth contour along the coast at 0.125^o grid spacing as shown by the square points on fig. 1.

- **Fig. 2, 3**

The hydrodynamic power flux per metre of wave front is calculated from the formula $0.55\ TzHs^2$ as kW/m. Fig. 2 shows a correlation for the month of January 2004 at a grid point adjacent to Buoy M1. The WAM predictions were adjusted inversely with distance from the respective buoys so as to minimise their differences from the observed values at the buoys. The effect of this can be seen on Figure 3 where the power flux is plotted using the buoy (M1) values (blue), WAM (red) predictions and corrected values (green) which usually lie between the former values.

- **Figs. 4, 5 6**

  Figures 4, 5show the correlation archieved over the year 2004 between the measured values of Hz, Tz and the values predicted by WAM. These are then used to plot Fig. 6 showing correlation of the resultant power flux values for 2004 at a point adjacent to buoy M1 using WAM and the buoy M1 itself.

  It can be seen that most of the scatter occurs in the measurement of Tz where the buoy records round off to the nearest second. Similar plots were made for all the buoys and the WAM results were locally adjusted slightly to being them into convergence with the buoy results.

- **Fig. 7**

  Figure 7 shows the sequence of headings under which all renewable resources are examined, wave energy being no exception. The **theoretical** resource is the unhindered resource as it is believed to occur in nature and is estimated from observations and measurements made over the relevant area,in this case the seas surrounding Ireland. The **technical** resource is the next stage and this is estimated by applying start-of-the-art conversion systems to the theoretical resource. From this stage onward the power and energy levels can be quoted in electrical terms. It will be appreciated that the value of the national technical resource is a function of the efficiency of whatever conversion system is utilised. The better the system, the better the resource. Different conversion systems will have different operating limitations e.g. depth of water, distance off shore etc. so when these limitations are applied to the technical resource it is reduced to become the **practicable** resource. Finally a further deduction is made to account for all legislative restrictions that may be applicable in relation to rights of others, environmental and navigation protection, fisheries etc. This then gives the **accessible** resource. The succeeding figures follow this sequence in both power and energy terms.

- **Figs. 8, 9**

  Fig. 8 shows the distribution of **theoretical** mean annual wave power flux measured in kW of hydrodynamic power per metre of wave front and calculated from the formula (0.55 H_s^2Tz) as noted earlier. It can be seen that based on the data available this varies from 10kW/m near the coast to 80kW/m about 150km north west of Mayo. It falls off rapidly east of Malin Head and Fastnet Rock. Mayo appears to have a strong shielding effect on waters off Donegal. Fig. 9 shows the data used in Fig. 8 represented in energy terms by summing the hourly power flux values to give mean annual theoretical energy contours in MWh/m.

- **Figs. 10, 11, 12, 13**

  Figures 10, 11, 12, 13 present the seasonal theoretical power flux levels for Spring, Summer, Autumn and Winter respectively. It is clear that average conditions in Spring and Autumn are relatively similar, they are quiet in Summer and much more robust in Winter, reaching almost twice the annual average values.

- **Figs. 14, 15, 16, 17**

  Figures 14, 15, 16, 17 show the respective seasonal theoretical energy levels for the four seasons where again the relatively strong Winter performance in terms of theoretical energy availability is highlighted. This matches the annual electricity demand pattern.

- **Fig. 18**

  Estimation of the technical resource requires the selection of a particular converter type and the introduction of its power or scatter table (Fig. 18) relating to electrical power output to the Hs and Tz values of the waves experienced by the converter at sea. When this atlas was in preparation the converter at the most advanced stage of development was the 750kW Pelamis P1 designed by Ocean Power Delivery in Scotland and it was used as the reference converter. Since then the Pelamis PIB has been developed and is currently being installed in Portugal. The power table of a wave power converter is analogous to the power curve of a wind turbine but is a three dimensional surface like the hill diagram of a water turbine. The Pelamis PIB is used as reference turbine in this presentation.

- **Figs. 19, 20**

  Figs. 19, 20 show contours of mean annual **technical** power and energy resource in electrical terms for a notional cordon of Pelamis converters spaced 350m apart but staggered in a three deep formation broadly parallel with the coast. These contours are created by the interaction of the converter power table with the hourly Hs, Tz values and identify the “hot” regions for such converters off the coast. Fig. 19 shows that a mean annual technical power resource level of 2MWe/km is reached within about 30km of the Mayo and Kerry coasts. This power level would deliver about 18GWhe/km of electrical energy annually as shown by Fig. 20.

- **Figs. 21, 22**

  The **practicable** resource is derived by deleting all areas with depth less than 50m and areas outside 100km from the 12 nautical mile line on the basis that, respectively, the Pelamis is designed to operate in greater depths and that a.c. electrical transmission would be commercially non viable at such distances. The mean annual practicable power and energy contours as shown on Figs. 21, 22 are otherwise similar to the technical resource diagrams of Figs. 19, 20.

- **Figs. 23, 24**

  Figs. 23, 24 show the mean annual **accessible** power and energy resource contours with identification of under sea cables, pipelines, marine separation zones, military danger areas, notional navigation corridors to key ports, fishing grounds in respect of which some reduction in available cordon length would have to be recognised. As most offshore wind farms are sited in shallow water they are not identified.

- **Fig. 25**

  If the actual lengths of the respective available contours of Figs. 20, 22, 24 are measured and the mean annual energy crossing each contour is calculated the results can be summarised on Fig. 25 showing the gradual reduction in the energy resource through the technical, practicable and accessible stages for the Pelamis PIB. (The theoretical resource is so huge that it would not fit on the diagram at the linear scales used).

  The Wave Dragon is a projected 7MW converter which has not yet been tested at full scale but when a similar exercise is carried out using its power table the technical, practicable, and accessible energy yields shown on Fig. 25 are obtained. (It should be noted that with a machine spacing of 500m Wave Dragon is projected to have 14MW installed per km of contour while Pelamis PIB has 5.7MW. Further as each converter creates its own contours these are not identical between machines. In the final analysis cost per kWh delivered will be a deciding factor).

- **Fig. 26**

  Fig. 26 shows the theoretical wave power resource with the access limiting factors superimposed and divided into blocks that allow sections of the electrical network in coastal areas to be shown.

- **Figs. 27, 28**

  Figs. 27 and 28 show the full size Pelamis PIB and a 1 : 4.5 scale model of Wavedragon that has been undergoing sea trials in Denmark.

Conclusions

- The approach taken in developing the atlas is believed to represent a useful tool in quantifying the nature and value of the Irish wave energy resource.
- The original version of Irish Wave Atlas 2005 can be accessed on the Sustainable Energy Ireland website. That production used data for the original Pelamis which has now been superseded. In particular machine spacing has been increased from 140m to 350m and the converter geometry and performance has changed. Thus the technical, practicable and accessible resource contours given in this paper should be used in preference to those given in the Atlas.
- The costs quoted in the atlas are also being updated as a result of new information which has been received from converter developers.
- The theoretical resource remains unchanged although it is inevitable that as further data becomes available for analysis there will be changes here too.

Definitions

Hs : Significant Wave Height, originally being mean height of highest 1/3 of waves now computed as $4\sqrt{Mo}$ where Mo is variance of sea surface elevation about its mean value.

Tz : Zero Crossing Wave Period: The average of a series of time intervals between two successive crossings of mean sea elevation in an upward direction by waves in a given time record.

WAM: Wave Model, an internationally developed wave forecasting model used by various meteorological services to project wave conditions from meteorological measurements and parameters updated from satellite measurements.

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