

Wave Energy Exploitation Project

LABBUOY: ECONOMICALLY EFFICIENT FLOATING DEVICE FOR WAVE POWER CONVERSION INTO ELECTRICITY

PHASE I: MATHEMATICAL AND PHYSICAL MODEL TESTING.

5th Framework Programme of the European Commission

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- National Technical University Athens, GR
- Athena SA, GR
- Rambøll, DK
- Queen's University Belfast, UK
- University College Cork, IE

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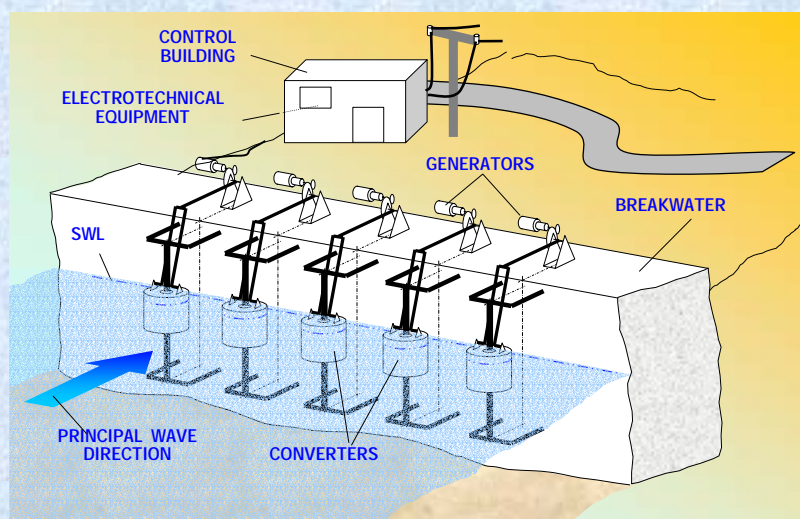
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Objectives

The present project concerns the mathematical and physical model testing of a novel wave power converter. The converter is of the floating type, the power transmission and conversion systems being mounted on solid fundament (breakwater or pier). This architecture yields increased power production due to wave reflection on the breakwater frontage, and high reliability and operational safety.



Schematic of a LabBuoy wave power plant

The central objectives of the project have been:

- development of reliable mathematical system models to be used for system design and loads prediction; the models are valid for various representative wave climates met along the European coast line;
- validation of the mathematical models and verification of the applicability of the technology by experiments in small scale in a wave tank;
- elaboration of sophisticated system configuration for maximum power absorption, production and reliability;
- assessment of feasibility, socio-economic and environmental impact of the technology for representative sea states in Europe.

Challenges & Approach

The project objectives have been attained through different research and validation tasks. Two approaches have been applied: mathematical modelling and physical model testing.

In the first approach development of electro-mechanical time-domain models are made for the prediction of the response of a row of five converters to known wave input. The main model features are: consideration of the hydrodynamic interactions between the converters and the adjacent breakwater; modeling of two different mechanical power transmission systems (chain and gear driven) and two different electrical power conversion systems (gear driven generators and direct driven alternators).

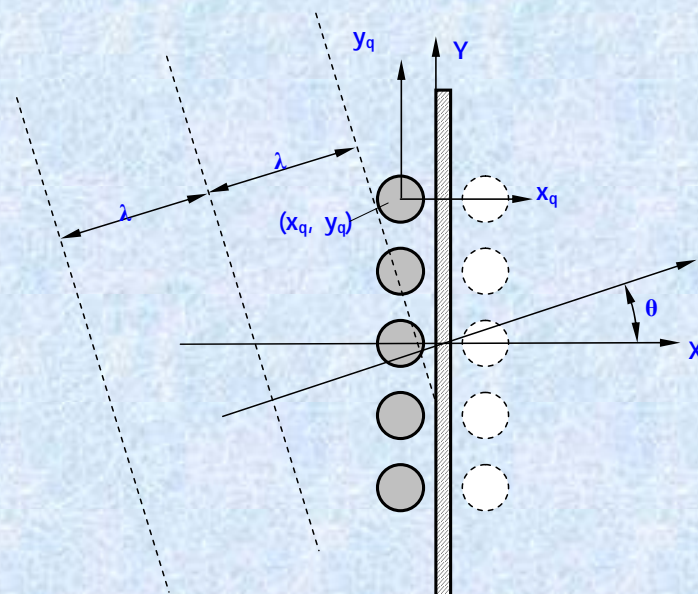
In the second approach a model of a row of five converters in appropriate scale (1:10 ... 1:15) was designed and constructed. The impact of the electrical machines attached to each converter was simulated by computer controlled electro-mechanical speed control devices. The experiments were performed under various wave conditions, simulating typical wave climates met along the coastline of Europe.

The experiments were supported by an interactive, internet-based laboratory "network", allowing remote experimental monitoring, and data transfer and partner communication.

Additional studies have been conducted dealing with investigation of the standards environment and certification regulations applying to the present technology, the prediction of the system performance at full-scale, the assessment of the environmental and socio-economical impact of the technology, and the estimation of its economical feasibility and market prospects.

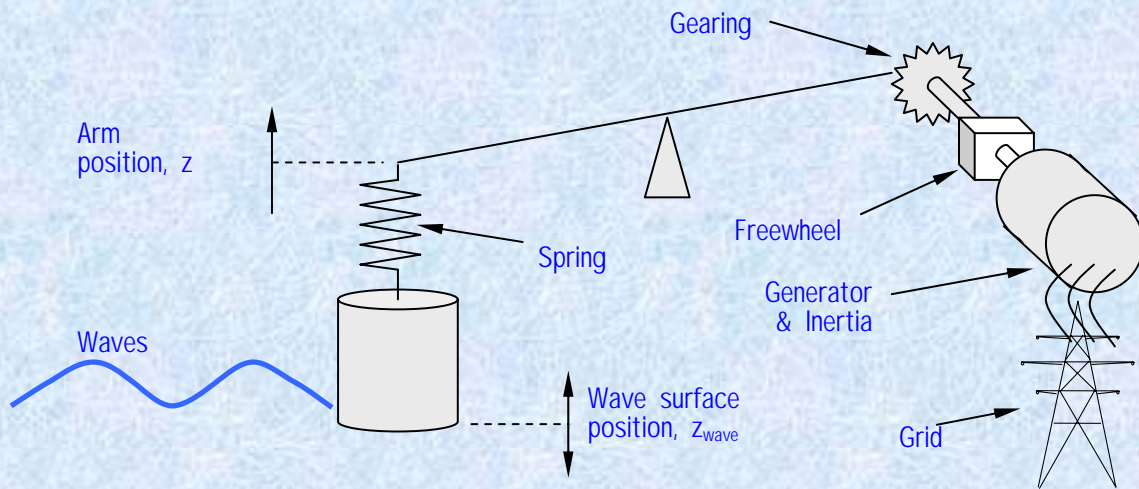
Numerical Simulations

The numerical simulation model of the device consists of two modules, a hydrodynamic-kinematical and an electrical module. The hydrodynamic-kinematical model describes the heave motion of each converter in the array. A non-linear system of coupled equations of the floaters' motions was established and solved both approximately in a linearized version, as well as and in its complete non-linear form using time-domain techniques. The hydrodynamic interactions between the converters themselves and the adjacent breakwater have been properly taken into account by solving the exact first-order hydrodynamic diffraction and radiation problems.



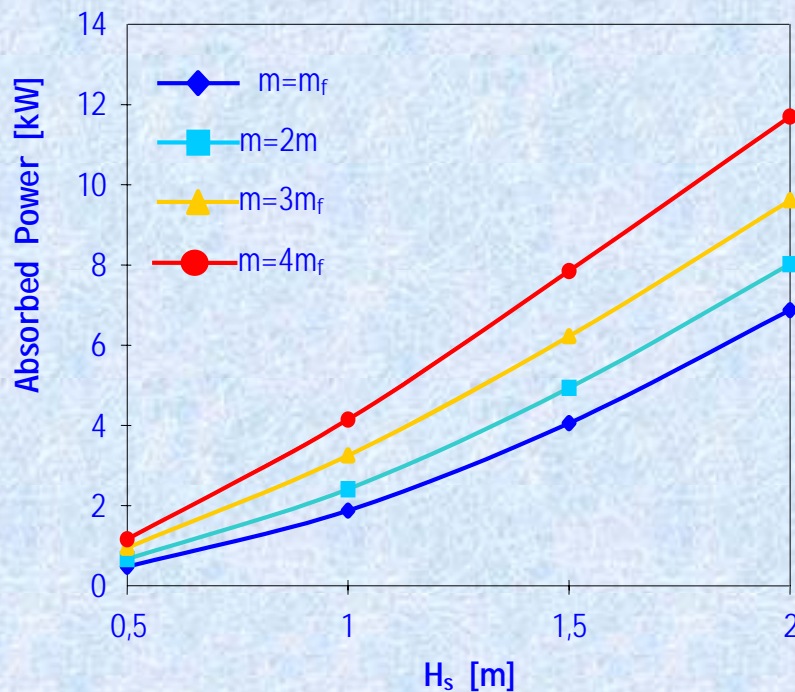
Plan view of the cylinder array in front of the breakwater (image cylinders denoted dashed simulate the breakwater effect)

The electrical machine model consists of a Simulink model of the beam arm, freewheel and electrical machine and a MatLab script file called by Simulink to solve the induction machine equations. A special experimental device was constructed and deployed in a narrow wave tank to test the functions of this model.



Arm Freewheel Machine Schematic

The numerical simulation results indicate a strong influence of the system inertia and of the power conversion damping on the converter performance. At appropriate adjustment of these properties to the local wave conditions, the system can be tuned to maximum power production.



*Influence of the buoy inertia on capture efficiency
 (diam.=1.5 m, draught = 1 m, $m_f = 1.8$ t)*

Experiments

A 1:15 scale model consisting of a row of 5 converters was manufactured and deployed in the wave tank of the National Technical University of Athens.



1:15 scale model of five converters in front of breakwater in the wide wave tank of NTUA

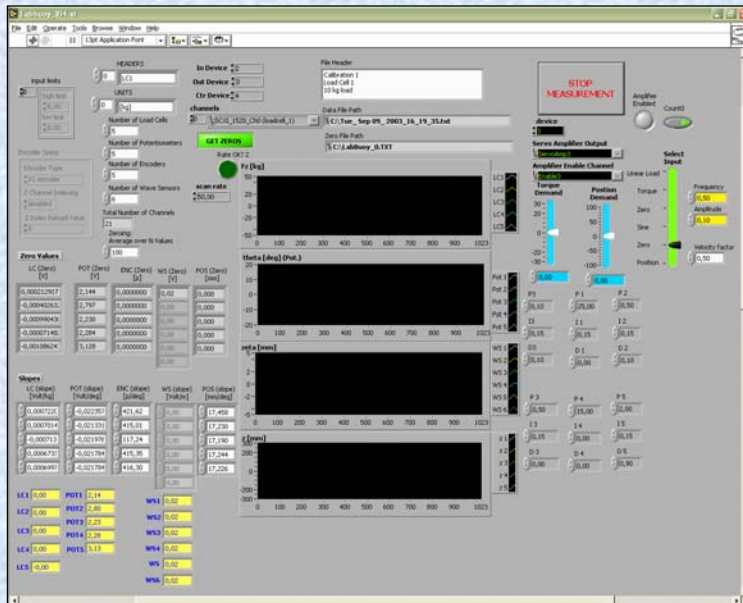
Each model converter is equipped with the following sensors:

- force sensor for the measurement of the vertical buoy force
- angular position sensor for the measurement of the instantaneous position of the model arm
- optical encoder for the measurement of the instantaneous rotational speed of the model arm

A DC-motor is attached to the rear end of the arm of each model providing a resistance torque to the arm motion via a toothed belt. Each motor is controlled by a controller with encoder feedback.

The data acquisition and data management system is capable of real-time measurements, being thus not affected by limitations regarding data transfer rate of the host PC.

DAQ system



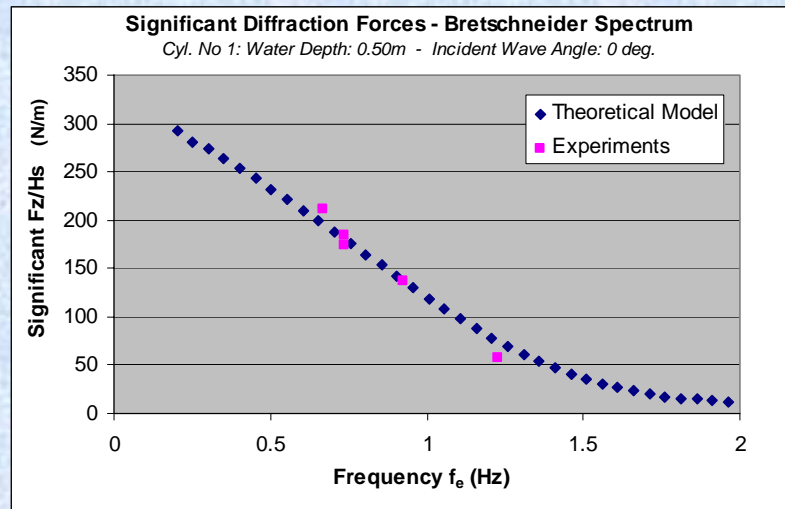
Several functions of the data acquisition and data management system are controlled by a graphical interface ("virtual instrument"-vi). The vi can be made available on the internet, allowing remote monitoring and operation to selected users.

DAQ and control vi

With the equipment described above a number of experiments have been conducted, in particular:

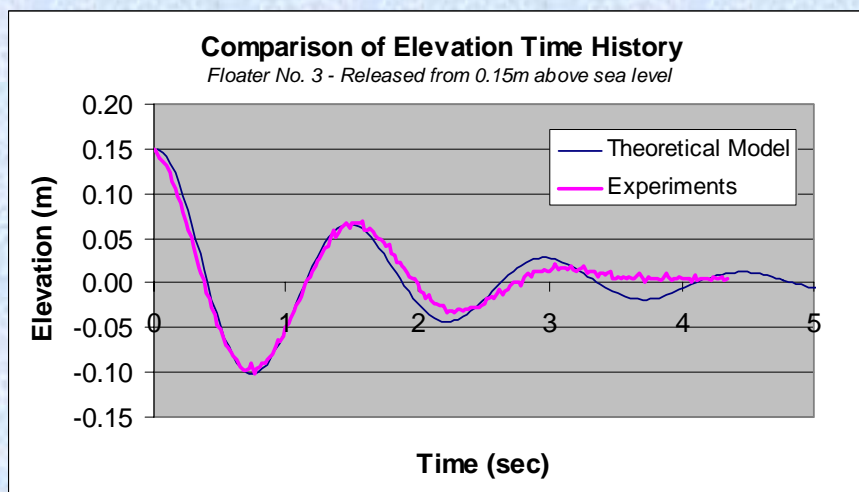
- Diffraction experiments with fixed buoys under various wave conditions of interest. This series of experiments includes measurements of the vertical forces acting on the buoys at regular waves of various heights H and periods T , as well as irregular waves of various significant wave heights H_s and energy periods T_e . The experiments were conducted at two different wave incident angles (0° and 30°).
- Free oscillation measurements. This series of experiments includes measurement of the buoy motion and forces during the free oscillation of the buoy after its release from a submerged position, and parallel measurements of the waves radiated by the buoys. This experimental series provides information about the system inertia and the radiation coefficients of the buoys.
- Forced oscillation measurements. In this experimental series the buoys are forced to harmonic oscillations about their state of equilibrium. The motion is driven by the DC-motors. The experimental series includes measurement of motion, forces and radiated waves at various oscillation frequencies and amplitudes.

The results show a very good agreement between numerical simulation and experiment, and confirm the capability of the numerical models to accurately predict the converter behavior, as well as its performance and power output under various wave conditions of interest.. Representative results of diffraction and free oscillation calculations are shown on the next page.



Diffraction forces: comparison between experiments and simulation

The following figure shows a comparison between the experiments and the theoretical results for a free oscillation test. Good agreement between them can be observed. The discrepancies towards the end of the motion may be influenced by the frictional non linear forces inherent to mechanical systems, which were unavoidably present during the experiments, and which were not possible to be included in the theoretical model, apart from an increase in the system damping value. The frequency content and shape of the decaying oscillations are sufficiently predicted by the theoretical model.



Free oscillation tests: comparison between experiments and simulation

Supporting Studies

The supporting studies provided important information concerning the perspectives of the large scale implementation of the technology in Europe and its expected socio-economic and environmental impacts. Some general conclusions are summarized below.

Economics and Market Prospects

Depending on the local wave power level, the generation costs of the device have been estimated to range on the average from ~7-9 c€/kWh. These costs are still higher than for conventional electricity, but considerably lower than for some other ocean energy technologies or "expensive" RES, and are expected to reduce with the refinement of the technology.



Considering an initially available coastline of ~180 km for the EU (incl. Iceland and Norway), the initial market is expected to amount to ~24,000 converters, with a total power output of up to ~2,50-3,0 GW and a total annual energy yield of up to ~11-14 TWh.

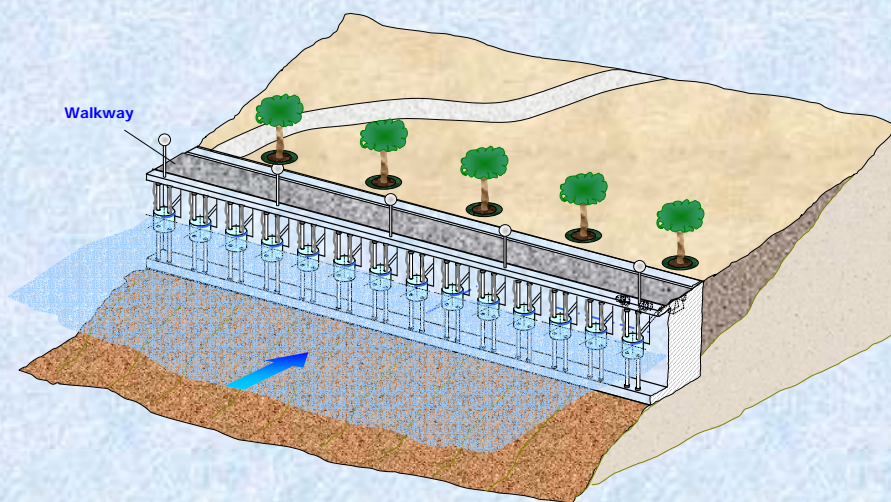
Potential European market; candidate areas (dotted lines) of device deployment in Europe

The manufacturing and deployment of the devices for the above market would require ~19,200 man-years of skilled technical personnel and ~700-1000 m-years of engineers.

Environmental Impact

The main environmental impacts of the technology have been identified to be: visual and acoustic impact, annoyance of fish and sea mammals, and shore alteration.

Visual and acoustic annoyance is expected to be lower than e.g. with wind turbines. Suitable landscaping around a "Labbuoy-breakwater" with appropriate acoustic insulation of the converters could minimize, even eliminate, visual and acoustic impacts.



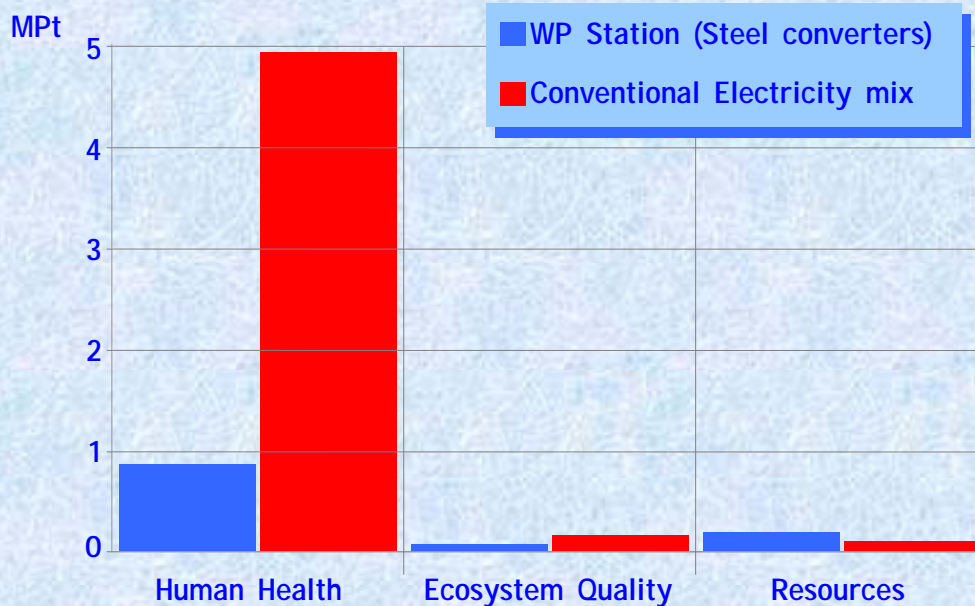
An optically acceptable LabBuoy-breakwater

The effects of wave power devices on fish or sea mammals are not known yet; these have to be studied thoroughly in future. Any results should be made available to the public. Even if the operation of a LabBuoy plant is found to induce fish ousting in the environment of the plant, which will cover a comparably rather small area, local authorities should be confronted with outranking benefits of the technology: pollution free generation, low life cycle impact and social benefits.

As coastlines experiencing intense wave conditions are in general subject to erosion, the effects from installation of a LabBuoy breakwater could be positive.

The deployment of LabBuoy plants in built-up industrial areas, e.g. harbours, is not expected to meet public objection.

Life Cycle Analysis has shown that, when compared to conventional electricity, the present technology reduces adverse impacts on areas of major environmental concern by up to 70%.



Environmental Impact of electricity produced by a Labbuoy-plant compared to conventional electricity