Renewable Energy 34 (2009) 1371–1380

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

# SSG wave energy converter: Design, reliability and hydraulic performance of an innovative overtopping device

L. Margheritini [a], D. Vicinanza [b,*], P. Frigaard [a]

[a] Department of Civil Engineering, Aalborg University. Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
[b] Department of Civil Engineering – CIRIAM, Seconda Università di Napoli. Via Roma 29, 81031 Aversa (Caserta), Italy

ARTICLE INFO

*Article history:*
Received 3 September 2007
Accepted 6 September 2008
Available online 1 November 2008

*Keywords:*
Wave energy converter
Overtopping
Caisson breakwater
3D model tests

ABSTRACT

The SSG (Sea Slot-cone Generator) is a wave energy converter of the overtopping type. The structure consists of a number of reservoirs one on the top of each other above the mean water level in which the water of incoming waves is stored temporary. In each reservoir, expressively designed low head hydro-turbines are converting the potential energy of the stored water into power. A key to success for the SSG will be the low cost of the structure and its robustness. The construction of the pilot plant is scheduled and this paper aims to describe the concept of the SSG wave energy converter and the studies behind the process that leads to its construction. The pilot plant is an on-shore full-scale module in 3 levels with an expected power production of 320 MWh/y in the North Sea. Location, wave climate and laboratory tests' results will be used here to describe the pilot plant and its characteristics.



## 1. Introduction

Together with the overall trend of all renewable energies, wave energy has enjoyed a fruitful decade. Improvement of technologies and space for new ideas, together with financial support, led the research to gamble on different concepts and develop a number of new devices. While innumerable projects went through an initial simple testing phase, only few of them reached the sea prototype testing and even fewer have been commercialized. After many failures, it is obvious that much has been wasted on designs which could never be economic and serviced economically, or on designs which are unsuitable to survive storms.

The SSG is a Wave Energy Converter (WEC) of the overtopping type: the overtopping water of incoming waves is stored in different basins depending on the wave height. Turbines play an important and delicate role on the power takeoff of the device. They must work with very low head values (water levels in the reservoirs) and wide variations in a marine aggressive environment. In the following paragraph, the concept of the innovative Multi-Stage Turbine (MST) will be presented as integrant part of the SSG concept. The Company WAVEenergy AS found in Stavanger Norway, is developing the device (patented in 2003) since 2004 when the pilot project has been partially funded by the European Commission FP6-2004-Energy (WAVESSG project) and it can now benefit of 2.7 M€, the majority of which are from private investors. Partners from different countries in Europe collaborate for the realisation of the pilot project. The installation of the structure is foreseen for summer 2008 in the island of Kvitsøy, Norway (Fig. 1).

The main strength of the device consists on robustness, low cost and the possibility of being incorporated in breakwaters (layout of different modules installed side by side) or other coastal structures allowing sharing of costs and improving their performance while reducing reflection due to efficient absorption of energy. Even though, an offshore solution of the concept could be investigated to reach more energetic sea climates (Fig. 2).

In the following paragraphs the SSG concept and its optimizations will be presented, together with the work for the realisation of the prototype. Particularly the main results from power simulations, 3D model tests on overtopping and wave loadings used for the final design of the pilot plant will be reported. Moreover, other issues regarding funds, location of the pilot installation and instrumentation will be also discussed.

## 2. Concept description

Being an overtopping wave energy converter means that the structure must be overtopped by incoming waves; during these events, indeed, the overtopping water is captured in different basins above the mean sea level. The energy extracted from a given volume of water in the reservoir is in direct proportion to its elevation above the mean sea level (turbine head). Different ventilation openings must be included in the design of the structure in order to prevent air pressure to obstruct the water storage.

* Corresponding author. Tel.: +39 081 5010245; fax: +39 081 5037370.
*E-mail addresses:* lm@civil.aau.dk (L. Margheritini), diegovic@unina.it (D. Vicinanza), i5pf@civil.aau.dk (P. Frigaard).

0960-1481/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2008.09.009

**Fig. 1.** The SSG pilot plant in the island of Kvitsøy, Norway.

In the SSG the water in the reservoirs on its way back to the sea falls through a turbine spinning it and generating electricity (Fig. 3). For energy conversion, the innovative concept of the Multi-Stage Turbine (MST) is under development at WAVEenergy AS and its design integrated in the structure consists of a number of turbines (depending on the number of reservoirs) staggered concentrically inside each other, driving a common generator through a common shaft (Fig. 4). Each of the runners is connected to one of the reservoirs by concentric ducts. By taking advantage of different heights of water head, the MST technology is willing to minimize the start/stop sequences and operate even if only one reservoir is supplying water, resulting in a higher degree of efficiency. Preliminary 3D computational fluid dynamic analysis of the guide vane and the runner made by the Norwegian University of Science and Technology (NTNU) shows an efficiency of 90% for the individual stages with a quite flat efficiency curve. Further investigations are needed to test the behavior of the turbine under simultaneous varying conditions and in general to optimize the concept before manufacturing a full-scale machine. For this reason, the first devices that will be realized may not utilize this technology, but a set of Kaplan turbines instead. In any case, the flow to the turbine is regulated by gates that are virtually the only moving parts of the structure; this is an important characteristic for any device working on marine environment where loads on extreme events can be 100 times bigger than in operating normal conditions.

## 3. Optimization of the device

The optimization of the device regards particularly the geometry and the turbine strategy. These two aspects are tidily bonded one to the other as it will be explained.

With regard for the length and the inclination of the front plates leading to the different reservoirs, these are designed with the following purposes:

- Optimize the energy captured (waves overtopping and run-up).
- Reduce loads during design conditions.

Not only the wave climate but also the bathymetry of a specific location plays an important role on the design of the frontal plates as well as of the frontal “apron” at the toe of the structure that

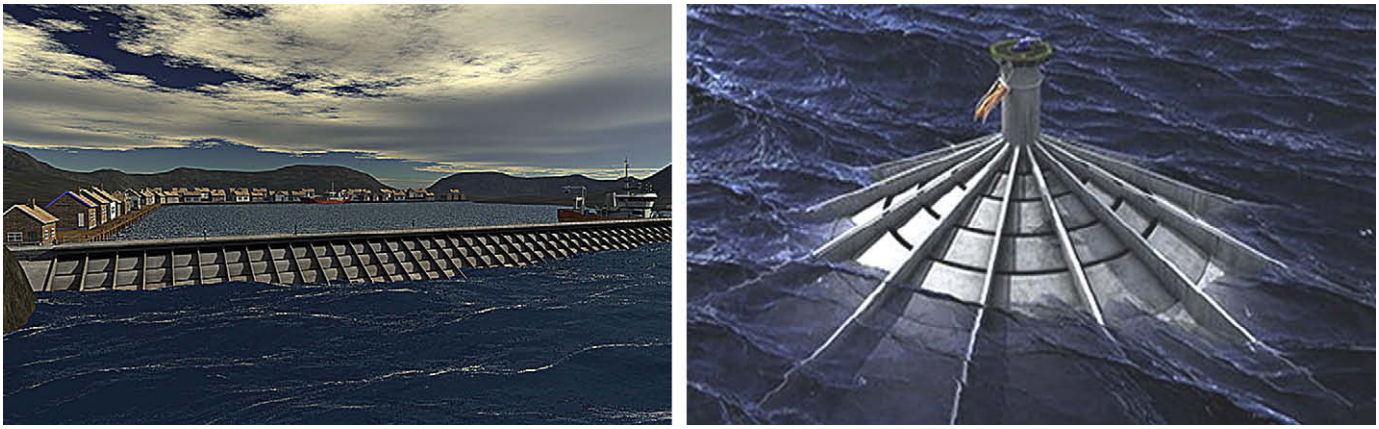

**Fig. 2.** Two applications of the SSG wave energy converter: on breakwaters (left) and offshore (right).