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

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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.

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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

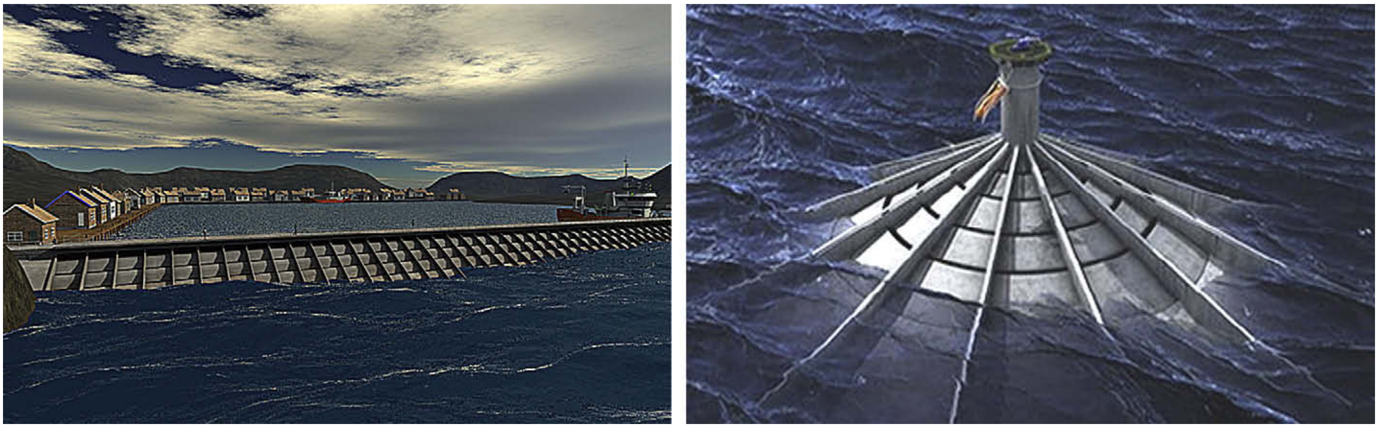

Fig. 2. Two applications of the SSG wave energy converter: on breakwaters (left) and offshore (right).

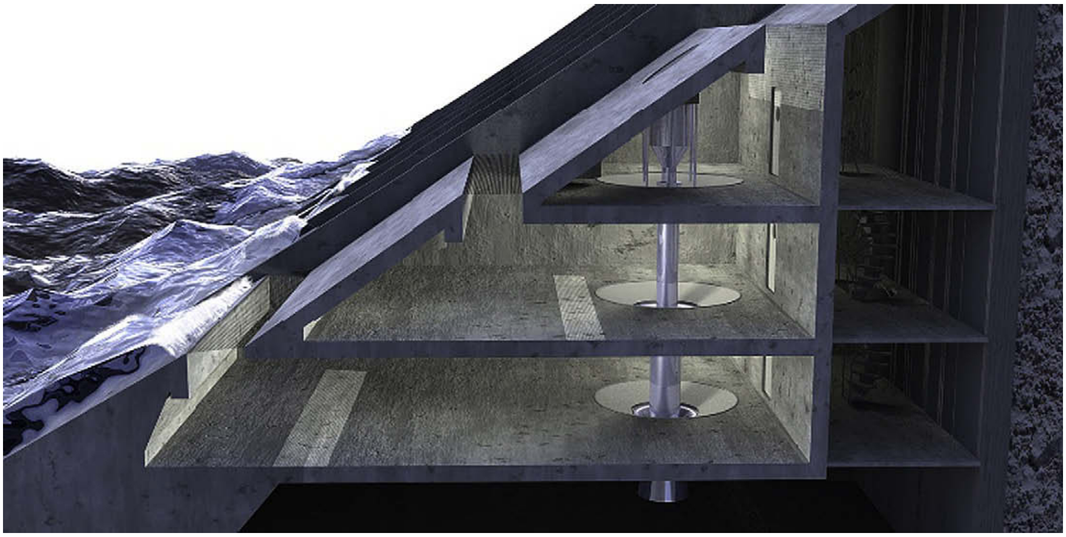

Fig. 3. Lateral section of a three-levels SSG device with Multi-stage Turbine (MST).

contributes to increase the run-up by offering a convenient slope to the incoming waves. The dimensions of the gaps between one reservoir and the above are controlled by the orthogonal distance between the reservoir and the fronts.

As mentioned, the dimensions of the reservoirs are affected by the strategy of the turbines: waves have a stochastic variation in height and period and it is impossible to predict how much water the next wave will bring, thus the dimensions of the reservoirs must be defined together with the operating strategy for the turbines. Using a multi level reservoirs results in a higher overall efficiency compared to single reservoir structure [1,2] and despite the similarity of the SSG structure to a breakwater caisson, the available formulas in literature to predict the overtopping in coastal protection projects are not sufficient in this case as they don't contain any information about the vertical distribution of it. Nevertheless this information is necessary with respect of the matter of maximizing the amount of stored potential energy at different heights: this is done through optimization of the crest levels $R_{c,n}$ (Fig. 5). Equation (1) describes the distribution of the overtopping rate with respect to the vertical distance [3,4]:

$$Q\prime = \frac{\mathrm{d}q/\mathrm{d}z}{\sqrt{gH_s}} = Ae^{B(z/H_s)+C(R_{c,1}/H_s)} \quad (1)$$

where Q' is the dimensionless derivate of the overtopping rate (q) with respect to the vertical distance z, $R_{c,1}$ is the crest freeboard of the lowest reservoir and H_s is the significant wave height. The coefficients A, B and C are empirical and need to be fitted with experimental data measured on a scale model of the SSG.

When a wave has just filled a reservoir, the turbine operates at a maximum head and power. It would then be ideal to stop the turbine when the reservoir is just empty enough for the next wave to fill it back to the brim without spillage. If increasing the installed turbine capacity or the storage volumes of the reservoirs has beneficial effects on the overall efficiency of the device, the cost may limit the enterprise. This is exactly the case when increasing the length of the structure ($L_{1,2,3,}$ in Fig. 5) and consequently the storage volume available per meter of crest; (increasing the width is considered as building a multi-module device, thus not affecting the overall efficiency). For a bigger storage volume the gradient of the water level in the reservoir is lower and the spillage losses are reduced, but the price of the construction is higher. In the other hands, when increasing the turbine capacity the consumption of energy utilized by the start/stop cycles of the turbines increases too, with a negative impact on the relative efficiency gain. The optimum turbine operating strategy minimizes the sum of head and spillage losses and finds a balance among all the above mentioned aspects. This can be done only by modelling the behavior of the whole system in the time domain. The SSG2 Power Simulation [5] is a program that has been realized in order to investigate the optimal geometry and the turbine strategy for the SSG wave energy converter. The power simulation program models the time distribution of the wave overtopping using a random process and the formulation for the overtopping flow rate of Equation (1). Every wave period is divided into a number of time steps for which Q (overtopping inflow), Q_{spill} (spilling discharge if above reservoir overflows), H_T (turbine head), Q_T

Fig. 4. Three-levels Multi-stage Turbine.

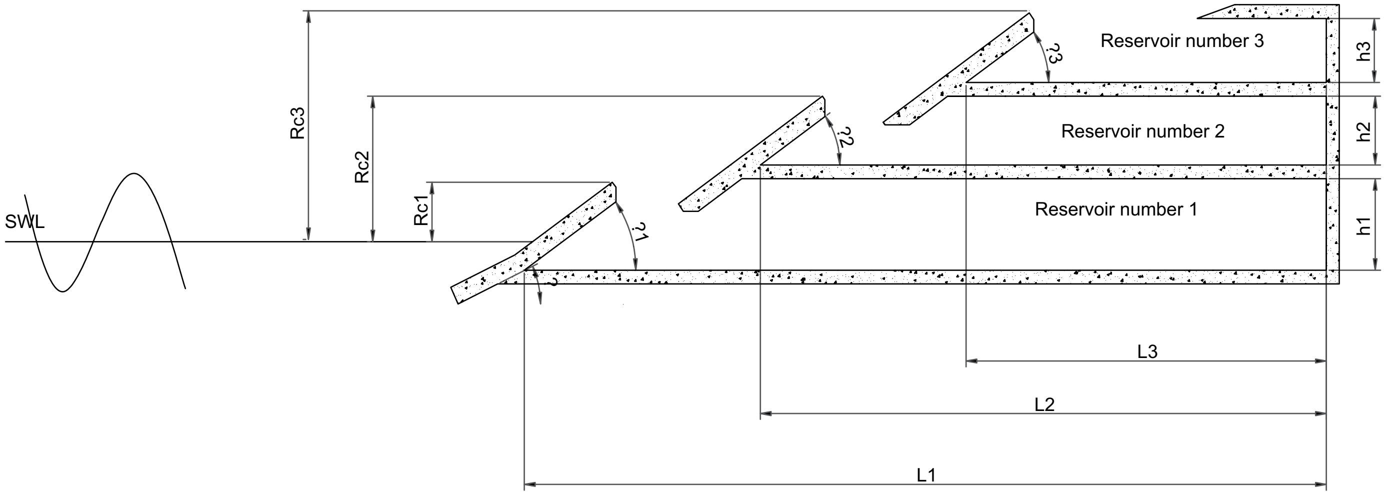

Fig. 5. Definition sketch of the SSG.

(turbine discharge), l_{res} (change of reservoir level) and P_{el} (generator output) are calculated. The used algorithm takes into account the spilling of the water from an above reservoir to a lower when the first is full and the head losses. In order to full fill its purpose, the program can elaborate various parameters that can be altered like geometry, sea state, turbine configuration (relationship between head, flow and efficiency) and turbine strategy (set points for switching turbines on and off). The power simulation program, supported by physical model tests, allows to predict the efficiency of the SSG in any wave situation and to estimate the annual power production.

4. Efficiency

Ideally, the power stored in the reservoirs (P_{res}) is the power related to the potential energy in the incoming waves (P_{wave}); in reality this storage incurs a limitation due to the dimensions of the structure and to the strategy of the turbines. For example, the power in the overtopping (P_{crest}) depends directly on the crest height, while the power in the reservoirs depends on their water level. In the same way, the power at the turbine (P_{tur}) is partially lost due to the hydraulic quality of the design and due to start-up and shutdown losses and so for the power at the generator (P_{gen}).

In Table 1, values for the partial efficiencies are presented; it has been estimated that overall efficiencies in the range of 10–26% can be obtained for different wave conditions.

Table 1
Relative efficiencies of the different energy conversion steps for the SSG device.

Formula	Definition	Efficiency %
$\eta_{crest} = \frac{P_{crest}}{P_{wave}}$	Hydraulic efficiency	30–40
$\eta_{res} = \frac{P_{res}}{P_{crest}}$	Reservoir efficiency	35–80
$\eta_{tur} = \frac{P_{tur}}{P_{res}}$	Turbines efficiency	80–90
$\eta_{net} = \frac{P_{gen}}{P_{tur}}$	Generator efficiency	95–97
$\eta_{tot} = \frac{P_{output}}{P_{wave}}$	Overall efficiency	10–26

5. Pilot project

The location for the pilot plant is the West part of the island of Kvitsøy in the Bokna fjord in Norway (Fig. 6). Kvitsøy municipality has 520 inhabitants and is one of 10,000 islands in Europe where wave energy can quickly be developed into a cost-effective energy production alternative to existing diesel generators. Preliminary estimates by WAVEenergy AS for first commercial shoreline SSG is that a full-scale plant of 500 m length will be able to produce 10–20 GWh/year for a price of electricity around 0.12 EUR/kWh. Even though indicative, such a price shows that the device will be cost effective and already competitive with the prices resulting from generating electricity on islands by means of diesel generators.

The SSG pilot project will be realized as a robust concrete structure built on the rocky shoreline and it is designed for a life

Fig. 6. The island of Kvitsøy, selected location for the SSG pilot plant.

Table 2
Summary of wave conditions at Kvitsøy location, with direction and probability of occurrence

T_p [s]	6.1	7.9	9.3	10.6	11.7	12.7	13.7
H_s [m] NW-315	1.2	1.7	2.2	2.6	3.2	4.4	6
Direction [deg.]	315	313	310	308	305	303	300
Prob. [%]	9.90	8.70	5.40	2.70	1.10	0.50	0.20
H_s [m] W-270	1.3	2.3	3.4	4.6	5.9	7.4	8.9
Direction [deg.]	270	273	275	278	280	283	285
Prob. [%]	4.80	4.20	2.60	1.30	0.60	0.20	0.10
H_s [m] SW-255	0.8	1.7	2.9	4.1	5.3	6.5	7.7
Direction [deg.]	225	230	235	240	245	250	255
Prob. [%]	7.50	6.50	4.00	2.00	0.90	0.40	0.10
H_s [m] S-180	0.6	1	1.2	3.2	4.2	5.5	7.1
Direction [deg.]	225	228	230	233	235	238	240
Prob. [%]	8.10	7.10	4.40	2.20	0.90	0.40	0.10

time of 25 years. The layout chosen consists of three reservoirs placed on the top of each others: total dimensions of the structure are approximately 17 m (length L_1) × 10 m (width) × 6 m (height). The crest levels ($R_{c1,2,3}$) are at 1.5 m, 3 m and 5 m and the inclination of the front plates resulted to be optimum at 35°. The structure is built in one piece and transported to the location via sea and installed on the foundation ensured by a number of tie beam anchors. The SSG pilot WEC will be connected to the grid for electricity production and the structure will be equipped with measuring devices in order to:

- monitor the efficiency and collect data;
- supervise the behaviours of the structure and for security reasons;
- validate model tests results.

The pilot project has been partially funded by the EU within the 6FW in 2004 with the objective of demonstrating at full scale the operation of a 150 kW module of the SSG wave energy converter, including turbine, generator, control system. Specific objectives of the 6th framework WAVESSG project are

- to design a full-scale technical prototype of the innovative MST turbine;
- to manufacture, test and install a full-scale technical prototype of the innovative MST turbine technology on the SSG;
- to design a full-scale 150 kW generator and control system;
- to measure the performance of the device including the structure in a period of up to six months for reliability and life time assessment;
- to manufacture, test and install a full-scale generator and control system equipped for grid connection;
- to obtain an hydraulic efficiency of at least 39% for the shoreline application;
- to obtain a wave to wire efficiency of more than 25% during the test period;
- to obtain a 96% availability of plant (with regard to operational hours);
- to obtain a 85% availability of production (with regard to wave climate).

The pilot project is meant to obtain reliability of the technology and contribute positively to wave energy; at the same time secondary issues like investigation of scale effects on pressures and overtopping flows will benefit of the high level of instrumentation of the SSG module. Field data within the pilot project will allow the correlation between real sea measurements, numerical model and tank testing.

The study of the wave climate at the selected location could benefit from three different offshore wave data sets: measurements at Utsira during the period 1961–1990 and from a buoy explicitly installed *m* offshore the selected location during the period 4/11/2004–11/3/2005 100; hindcast data from DNMI (Norwegian Meteorological Institute) during the period 1955–2005. The bathymetry of the area includes 100 m water depth on West direction, a plateau in front of the structure extending for 300 m at an average of 30 m depth and a steep slope leading to shore (≈ 35°). Such a bathymetry will allow higher waves to overtop the structure as waves of less then 15 m are not expected to break on the plateau. Transformation of waves from offshore to shore has been done by using the computer model MildSim developed at Aalborg University (AAU) [6,7]; the results are plotted in Table 2. For the device, West orientation was chosen being the best for capturing wave power. The near shore overall average power is estimated to be

Fig. 7. Physical setup of 3D laboratory tests on wave loadings. On the right the model in scale 1:60 equipped with pressure transducers.

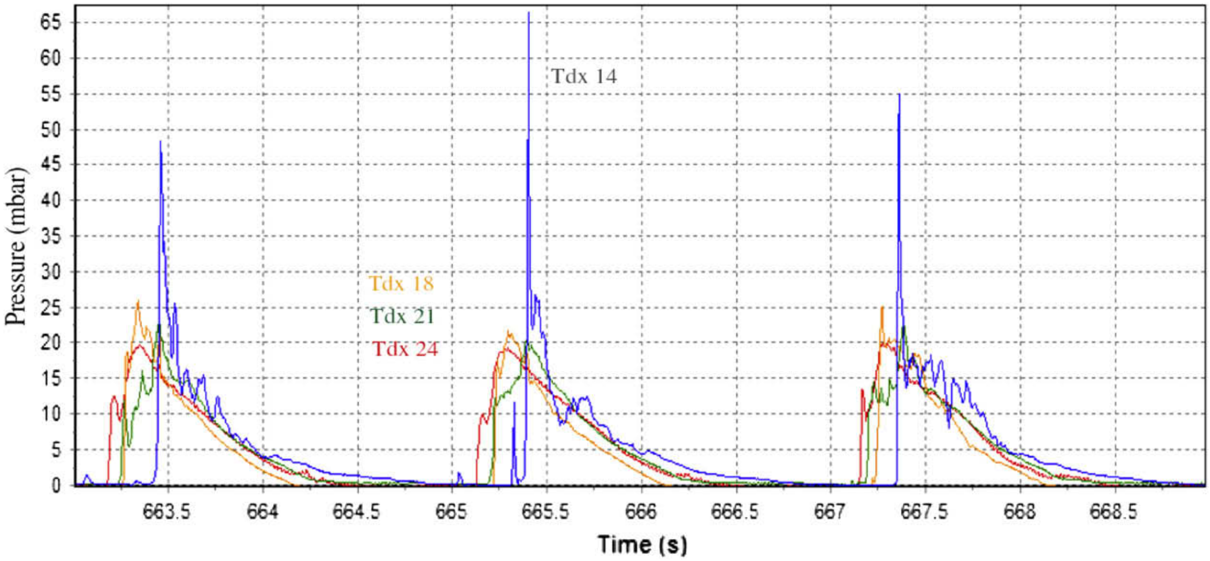

Fig. 8. Comparison of the pressures in the 3 front slopes (similar signals) and on the vertical real wall in the upper reservoir (peaked signal).

19.6 kW/m, (when neglecting wave conditions with H_S less then 1 m and more than 8 m, with a probability of occurrence, respectively, of 12.9% and 0.1%).

6. Wave loading

As mentioned during the description of the SSG concept, despite of the similarities of the structure to a breakwater caisson, the large differences existing prevented the utilization of literature formulas for design purpose without further investigations. This has been the case with overtopping and also with wave loadings. Thus, extensive 3D model tests on pressures under extreme conditions have been necessary in order to work out the design values for the construction of the structure. For those tests, the scanned bathymetry in the immediate proximity of the pilot plant was scaled down to model and used as the basis of the 3D laboratory tests (Fig. 7). SSG model in scale 1:60 to prototype, equipped with 14 pressure cells to measure 25 positions on the structure was tested under 32 different wave conditions, including waves of 100 years return period. In Fig. 8 difference between the pressures on the 3 front slops and on the rear vertical wall in the upper reservoir that was in the first design version of the SSG is presented: on this wall impact pressures under extreme waves (very peaked, short duration) of up to 580 kN/m^2 scaled to prototype were registered [8]. In order to avoid such loading on the structure vertical walls parallel to the attack wave crest will be avoided within the final design. In Fig. 9 a pressure history plot of 9 s for the three front plates is presented: the generated wave pressures do not vary substantially from one plate to the other, thus a quasi-static loading time history is recognizable. The order of magnitude of extreme peak pressure on front plates was up to 250 kN/m^2 scaled to prototype. Tests show an underestimation using prediction formula between 20 and 50% [9].

The results of these tests have also been used during the procedure to ensure the device as first full-scale wave energy converter.

7. Energy capture

The hydraulic efficiency has been defined as the ratio between the power in the overtopping water (Eq. (2)) and the potential power in incoming waves (Eq. (3)):

$$P_{\text{crest}} = \sum_{j=1}^{3} q_{\text{ov},j} R_{C,j} \rho g \tag{2}$$

$$P_{\text{wave}} = \frac{\rho g^2}{64\pi} H_S^2 T_E \tag{3}$$

where q_{ov} is the total overtopping in the single reservoirs and $T_E = m_{-1}/m_0$ is the energy period, where m_n is the n-th moment of the wave spectrum defined as

$$m_n = \int_0^\infty f^n S(f) df \tag{4}$$

Preliminary 2D tests with regular waves have been done in order to investigate a number of geometrical layouts and calculate a preliminary value of the stored potential energy in the reservoirs. A number of parameters influencing the capture of the overtopping water has been considered, those are the angle of inclination of the front plates, the horizontal distance between the front plates, the length of the frontal apron and the crest free boards $R_{c,n}$. During this phase measurements of overtopping flow rates for the individual reservoirs and incoming waves allowed the further calculation of the energy in the overtopping water and the hydraulic efficiency of the SSG pilot. At a second stage, 2D tests with irregular waves have been carried out in order to maximize the power capture of the SSG pilot and to estimate the efficiency of the device. This let to the present geometry of the wave energy converter that will be built in the island of Kvitsøy, Norway.

From the 2D physical tests on SSG model the hydraulic efficiency resulted to be 46%. This preliminary result was expected to change to a value of 40% for a 3D structure and to a value of around 30% in real operating conditions (effect of directionality and spreading of waves). This was verified by 3D laboratory tests where the effect of spreading and directionality was investigated separately and the effect of the combination of both was deduced [10]. In Fig. 10 on the left the 3D tests results are plotted against the efficiency with spreading divided the efficiency without spreading. The results are plotted for four typical wave conditions for West direction (frontal wave attack) at the selected pilot location for 2.3 m $\le H_S \le$ 5.9 m (Table 2). It is obvious that directionality is the primary responsible for decreasing the hydraulic efficiency of the SSG pilot module due to its low width-to-depth

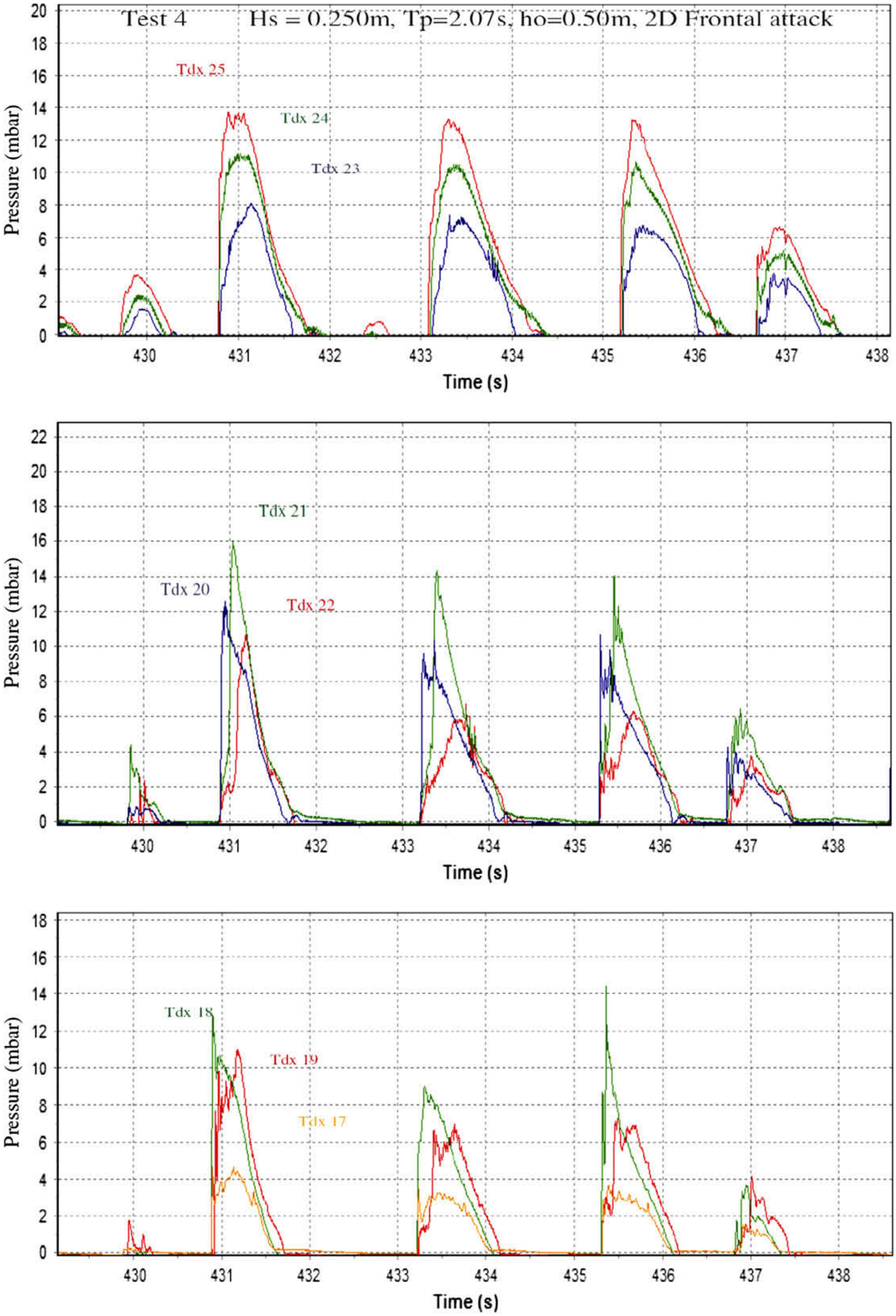

Fig. 9. Nine seconds history plot of the pressure in the 3 front plates (lower, middle and higher), each of them with signals from the pressure transducers.

ratio. In fact for side attack of waves, the side walls represent an obstacle to the storage of water. This "side effect" is not expected to be so dominant once that more that one module will be displaced one at the side of the other in a breakwater configuration.

8. Power takeoff

For the pilot plant of the SSG at island of Kvitsøy, 4 Kaplan turbines of identical size (0.6 m runner diameter) will be used: two in the lower reservoir and one in each of the middle and upper

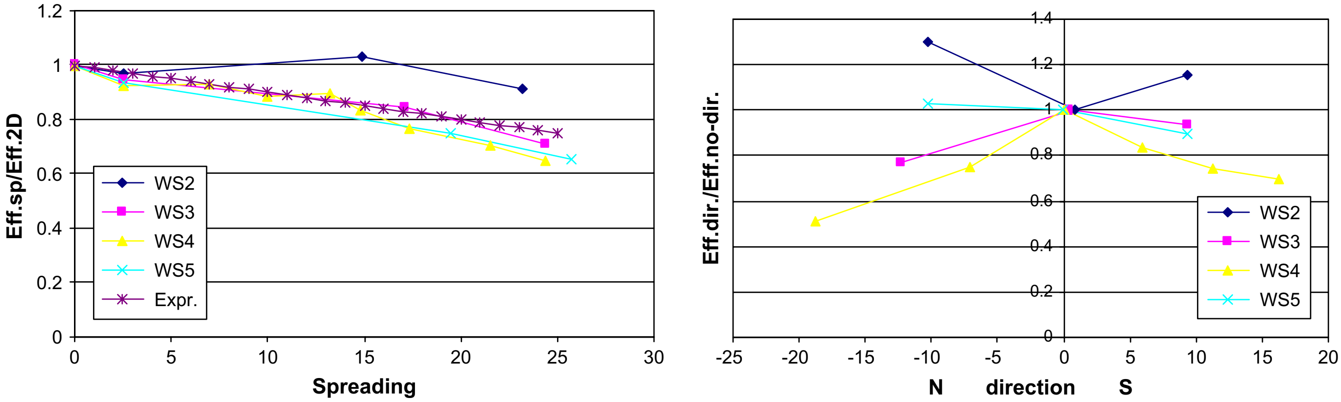

Fig. 10. Effect of wave spreading (left) and directionality (right) on the hydraulic efficiency of the SSG for different wave conditions (WS2,3,4,6 indicates increasing values of H_S).

reservoirs [11] (Fig. 11). The turbines will be manufactured using corrosion resistant steel. Due to economical considerations, the size of the reservoirs in the SSG pilot will be of the same order of magnitude as the overtopping resulting from a single big wave and this means that the turbines have a high frequency of start/stop cycles, approximately every 2 min. The cylinder gate has been chosen as mechanism to regulate the flow to the turbine; it consists of a cylinder directly combined to the turbine that when lifted allows the radial water flow to it. The cylinder gate seals by metal-to-metal contact to the outer turbine ring, closing by its own weight and offering a good reliability and transient time. The generators will be allocated at a higher level in order to avoid the risk of floods. They are driven by a tooth belt step-up drive which allows them to be matched with the optimal turbine speed. For the power levels of the pilot plant (15–100 kW), standard generators will be used.

9. Data acquisition and control system

The real time control of the pilot plant is one issue for the data acquisition and control system. This will mainly consist of generator control and emergency handling. Moreover, principal objective of the data acquisition and control system is to monitor the efficiency of the conversion of wave power into electrical power, thus the efficiency of the device, stage by stage. The structure will be monitored with pressure transducers for water levels measurements inside the reservoirs and run-up measurements on the slopes; these will record at 5 Hz in normal conditions. In storm and pre-storm conditions instruments on the front slopes will start acquiring at 20 Hz to investigate the occurrence of impact forces; this will be done by mean of a trigger criteria related to waves overcoming maximum heights. Moreover, significant wave heights, peak periods and energy periods will be processed by the whole spectrum of waves that will also be recorded in front of the SSG location. In Table 3 the measuring equipment for monitoring the hydraulic performance of the SSG in the island of Kvitsøy is presented. Moreover, the generator will be instrumented and the power production from the turbine measured directly on the generator. The data time series for each signal channel will be stored and elaborated in order to calculate statistical values. Once the pilot project will be built, it will be possible to carry out an

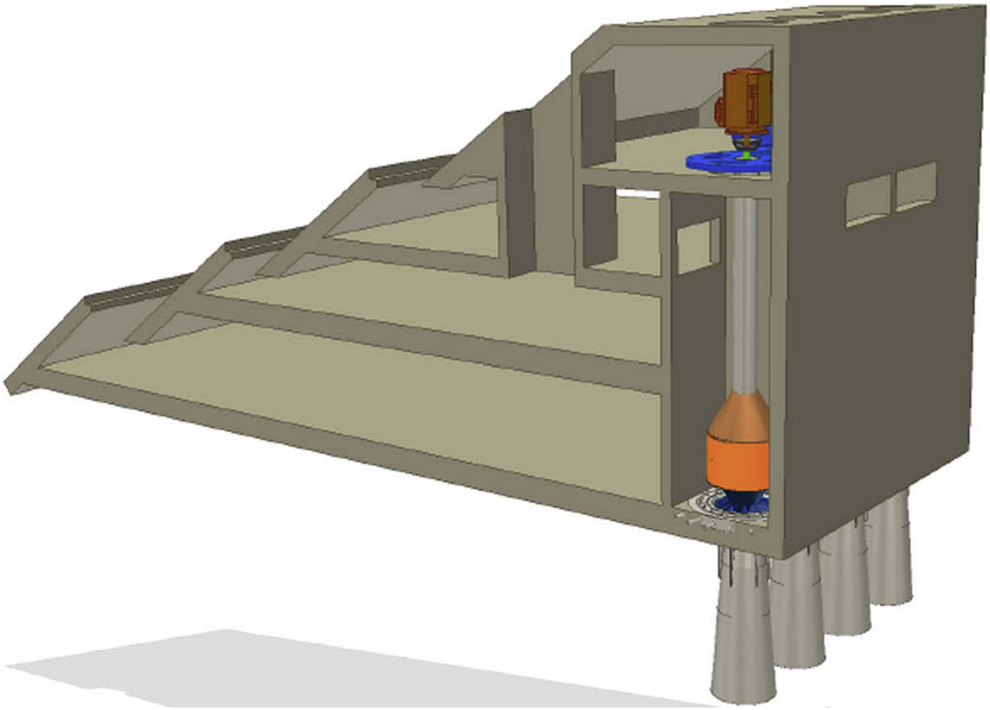

Fig. 11. The SSG pilot with 4 Kaplan turbines with cylinder gates, dry room for generators and outlets for the air trapped in the reservoirs.

Table 3
Instruments for monitoring the hydraulic behavior of the SSG pilot.

Sensor	Position	Sample freq.	Output	Range limits
Press. transducer	Lower reservoir, front position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Lower reservoir, middle position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Lower reservoir, rear position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle reservoir, front position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle reservoir, middle position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle reservoir, rear position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper reservoir, front position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper reservoir, front position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper reservoir, front position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Lower ramp, upper position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Lower ramp, middle position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Lower ramp, lower position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle ramp, upper position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle ramp, middle position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Middle ramp, lower position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper ramp, upper position	5 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper ramp, middle position	5–20 Hz	4–20 mA	0–100 mH_2O
Press. transducer	Upper ramp, lower position	5–20 Hz	4–20 mA	0–100 mH_2O
Press. transducer	In tail water	5–20 Hz	4–20 mA	0–100 mH_2O
Wave-rider buoy	100 m in front of the structure	2 Hz		

Table 4
Power matrix for the SSG pilot in the island of Kvitsøy, in a 19 kW/m wave climate.

H_s [m]	T_p [s]						
	5	6.1	7.9	9.3	10.6	11.7	12.7
0.5	0	0	0	0	0	0	0
1	3	3	3	3	3	3	3
1.7	21	21	21	20	20	20	20
2.4	67	65	62	60	59	57	56
3.6	144	140	134	130	127	124	122
4.7	154	152	150	148	146	144	143
5.9	155	154	152	151	149	148	147

important work regarding scale effects on pressures and overtopping by comparing the measurements at the pilot location to laboratory results.

10. Power production

The power matrix on Table 4 gives the power (kW) in different sea states for a structure with the characteristics of the pilot project. It should be noticed that while the main diagonal of the matrix corresponds to results from physical tests, the others are esteems obtained with the SSG2 simulation program. The formulas of the above-said program do not express a dependence of the power output on the period. This is because the period has not relevant influence on the average power output in long term. Moreover, the sides of the power matrix are very low probabilities combinations of significant wave heights and peak periods that induce breaking. By combining the power matrix with the probability of occurrence of the events, we obtain an expected annual production of approximately 320 MWh/y.

11. Conclusions

A new wave energy converter for electricity production based on overtopping principle has been tested and is now ready to be installed in the island of Kvitsøy, Norway. The device will be fully instrumented and will give real time data about energy production, wave loading and performance. Moreover the pilot project will contribute to the verification of results obtain in physical model tests and identification of scale effects.

The extensive preliminary studies led to the optimization of the design and even if some compromises have been done in order to realize the first full-scale wave energy converter (Kaplan turbines, low width-to-depth ratio…) their influence on the power production has been estimated. The pilot project will have

- three reservoirs one on the top of the other;
- an installed capacity of 163 kW;
- 4 hydro-turbines turbines;
- an annual production of 320 MWh/y.

Other devices are in the final stage of their R&D phase approaching the real sea testing with prospects for successful implementation. Nevertheless, extensive R&D work is continuously required, at both fundamental and application level, in order to improve steadily the performance of wave power conversion technologies and to establish their competitiveness in the global energy market.

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