First Power Production figures from the Wave Star Roshage Wave Energy Converter

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Abstract

Wave Star A/S has produced and installed a test and demonstration Wave Energy Converter (WEC) by Roshage pier near Hanstholm at the west coast of Denmark. The test unit is a prototype/test section of a complete commercial WEC. Only a few days after the installation, which took place in September 2009, the first storm with wind speeds above 30 m/s passed. During the winter more storms have passed without any damage. After an initial period of finalizing the installation and testing, the WEC was launched for production in January 2010 and in May 2010 automatic unmanned operation was initiated. The first power production figures show that the power absorption is taking place in accordance with the expectations and targets. No unexpected performance has been noticed.

The Roshage WEC is an ideal test converter for the further development of the Wave Star concept, and several activities are planned in order to demonstrate the future potential. The converter can be accessed by foot on a 300 m long access bridge via the pier from the beach. More than 30 groups have already visited the converter.

Keywords: Wave power , Wave Star, wave energy converter

1. Introduction

The Wave Star Roshage test unit is the main result of several years of development. In 2004 a small 6 m long scale 1:40 converter with 40 floats was tested in an indoor wave basin at Aalborg University in Denmark. In 2006 a 30 m long scale 1:10 converter with 40 floats was installed in the sea at Nissum Bredning in Denmark. The converter has been in daily operation in Nissum Bredning since, and has been connected to the public grid. The WEC has been able to produce energy persistently during 4 years. During the test period the WEC has demonstrated high reliability and it has survived 15 storms. Only very limited maintenance has been necessary. [1-5]

Based on positive results from the small-scale experiments Wave Star produced and installed the large-scale test and demonstration WEC by Roshage pier at the western coast of Denmark, see Fig. 1. The WEC is a prototype/test section of a complete commercial 1000 kW WEC. The test section has 2 floats whereas the full commercial converter will have 20 floats. The test section was installed in September 2009 at a water depth of approximately 6 m.

The purposes of the test section are primarily to:

1. Test the structure and components
2. Prove the storm protection strategy
3. Verify the reliability and document the ability to be in daily operation 24/7/365
4. Confirm the calculated power-curves for harvested wave energy
5. Demonstrate and improve the efficiency of the power take off
6. Provide a test-platform for future new components

Furthermore, the WEC is used as a demonstration plant for politicians, journalists, investors and other stakeholders. The WEC can be accessed at any time and in any weather condition due to its place near the Roshage pier and a 300 meter long access platform.

2. Status of the Roshage unit

After an initial period of final installation and testing of components the WEC was launched for production in January 2010 and in May 2010 it was ready for automatic unmanned production. Only the jacking procedure, which is used to survive extreme storms are coming, is still remotely controlled. The status with respect to the purposes for the test section is described in Table 2. The Wave Star Roshage test unit is now supplying wave energy to the public grid.

Figure 1: Wave Star Roshage Wave Energy Converter. Top: Location of site (Google Earth).
Bottom left: Photo of installation by barge. Bottom center: Photo of storm protection. Bottom Right: Photo of normal operation.

Parameter	Commercial Wave Star C5-1000 kW	Roshage test unit
Number of floats	20	2
Float diameter	Ø5 m	Ø5 m
Maximum water depth (extreme)	20 m	8 m
Maximum wave height (operation)	6 m	6 m
Arm length	10 m	10 m
Main structure dimensions	70m x 17m x 6.5m (LxWxH)	32m x 17m x 6.5m
Length of legs	Site depended, ~ 15-25 m above MWL	~ 18 m above MWL
Operation height	5.5 m above MWL	5.5 m above MWL
Storm secure height	Site depended, ~ 6-15 m above MWL	~ 8 m above MWL
Weight	1600 Tons	1000 Tons
Materials	Main structure: Steel. Floats: Fibreglass	Main structure: Steel Floats: Fibreglass
Foundation	Four skirted spud cans, or two mono piles or gravity based foundations	Four gravity based founda-tions
Design service life	Minimum 20 years	Minimum 20 years
Maintenance interval	1 service period per year	1 service period per year
Nominal electrical power	1000 kW	110 kW

Table 1: Technical data for commercial Wave Star C5-converter and Roshage test unit. MWL is Mean Water Level.

Purpose	Status by June 2010
Test the structure and components	All structural, mechanical, electrical and hydraulic components in the WEC have proven 100% functionality
Prove the storm protection strategy	The WEC has by the storm protection strategy survived several storms with no damages and no service afterwards
Verify the reliability and document the ability to be in daily operation 24/7/365	The WEC is running in automatic unmanned operation and the control system automatically extracts the floats from the water lifting them to the upper latched position when needed. The jacking procedure to storm protection level is still operated manually. A longer period (of several months) with continuous operation without stops is still to be documented.
Confirm the calculated power-curves for harvested wave energy	Measurement points have verified the expected level of harvested power, although further development of the control system is expected to increase the level further. More details are given in Section 4.
Demonstrate the efficiency of the power take off	The first test results have shown challenges in ensuring a high efficiency of the complete power transmission to the electrical grid. A focus point for the future work is optimization and further efficiency improvements of the hydraulic and electrical systems.

Table 2: Status for the Roshage unit in June 2010.

3. Technical design of Wave Star

The WEC is designed for unmanned operation with remote monitoring of data. The commercial WEC is equipped with 20 floats, each float having a diameter of Ø5m. The floats are mounted on a 10 m long steel arm and these arms are hinged on the main tube, 10 on each side. The Roshage unit is a shortened section of the complete WEC; it has 2 floats of Ø5m placed on one side. The test section is fully equipped according to the complete WEC.

When the waves are moving a float and arm up and down the power is transferred to the Power Take Off (PTO) by a hydraulic cylinder.

The main tube is containing all equipment such as PTO and control systems in an interior climate environment which is ensuring a long life time of the components. The main tube is connected to a jacking sections at each end. These jacking sections contain the jacking system, which lifts the main tube along the four legs up to the storm protection level when necessary. During normal production, the jacking system maintains the main tube at a fixed production level. The four legs are standing on the seabed via four individual concrete foundations. All main structures are made of steel except for the floats which are made of fibreglass.

The WEC is designed to produce energy in waves with a maximum wave height H_{max} = 6 m which corresponds to a site specific significant wave height normally close to H_{max} / 2 = 3 m. At higher waves the arms are lifted out of the water and the WEC is jacked up to storm protection level, see Fig. 2. The commercial WEC is designed to be installed at 20 m maximum water depth under storm conditions (highest water depth) and it is designed to be in operation for minimum 20 years. Further details of technical data for the commercial WEC and the test section is outlined in Table 1. An artists impression of the commercial WEC is shown in Fig. 3.

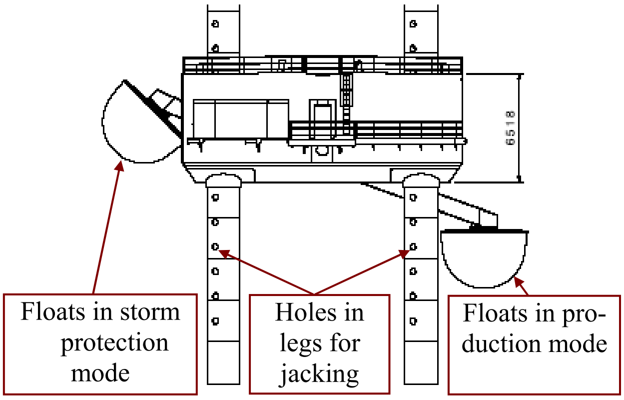

Figure 2: Wave Star storm protection concept.

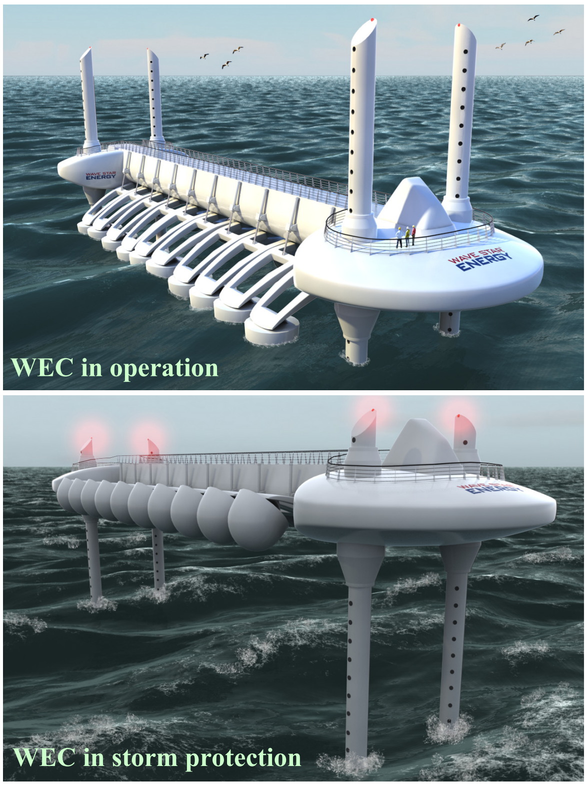

Figure 3: Artist impression of a commercial Wave Star WEC.

4. General about optimizing power

The general parameters influencing the yearly energy production are outlined in the following. Examples are given with respect to the Wave Star converter, but the issues are the same for any kind of WEC.

Wave climate

The power production is mainly influenced by the wave height, wave period and wave direction. Waves in nature are irregular in shape and therefore a “sea state” of several minutes is traditionally used to describe the waves. A sea state is normally defined by statistical parameters such as significant wave height, peak wave period, and mean wave direction. By far the most dominating parameter for the power production is the significant wave height, and therefore the power curves usually focus on this parameter.

Physical structural setup

The layout and size of the machine is important, e.g. such as: Number of floats - Size, shape and weight of floats - Position of individual floats in array relative to each other - Inclination of arms relative to water surface - Orientation of arms relative to wave direction. Also physical limits (e.g. limits on acceptable maximum motions) influences the potential harvested power. Structural strength and flexibility might limit the acceptable peaks and/or affect the harvested power.

The part of year in production

If the waves are higher than a certain limit the converter will be in storm protection and no electricity is produced. In addition, other environmental factors (such as low temperatures and/or extremely low or high water levels) will limit the time of operation. Additional reductions are due to repairs and maintenance.

Control strategy

More advanced control strategies can extract more power. However more advanced control strategies requires a more advanced PTO system which is more expensive and might also be less efficient.

PTO efficiency

Losses in mechanical, hydraulic and electrical components is described by an efficiency coefficient which can be between 0 and 100 %. If the efficiency is 100 % there are no losses.

PTO limits and capabilities

The PTO have certain limits on forces, velocities and power. The limits influences the harvested power and the produced electricity.

In order to get the most optimal design at a given site a full cost-optimization is ideally in general necessary taking all the above parameters into account.

The Wave Star C5-1000kW converter has a fixed physical structural design which is only slightly adjusted to a given site. The optimization of the power output therefore reduces to the interaction between the PTO components, the control strategy, and the actual wave climate at a given site.

5. Measured power by the Roshage unit

The first production from both floats with the full PTO in operation was performed on 15 January 2010, and the first electricity was delivered to the grid. On 27 January 2010 the first simultaneous measurements of wave climate and power production was acquired. The first part of 2010 has been used for manned operation with initial tests of the systems. Starting from May 2010 the converter is now running in unmanned continuous operation most of the time.

As outlined in Section 4 the power production depends on the wave climate and several other parameters. By far the most dominating parameter for the power production is the significant wave height, and therefore the power curves presented subsequent focus on this parameter. The power transferred from the water into the PTO is termed harvested power. Mechanical losses in the transfer from the motions of the float to the motion of the hydraulic cylinder is neglected (originally the harvested power comes from the water pressures on the float shell and the motions), i.e. losses due to structure flexibility and friction in bearings and cylinder are neglected. Hereby the harvested power is defined as equal to the hydraulic power leaving the hydraulic cylinder, which is subsequently flowing through the PTO, see Fig. 4.

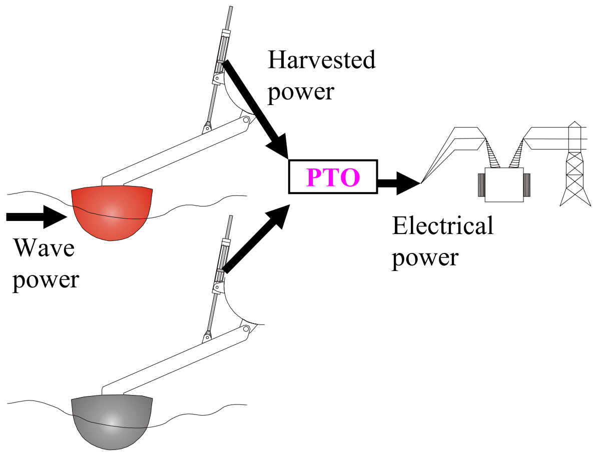

Figure 4: Overview of power transfer.

The harvested power is found from direct measurement of the pressure in the hydraulic system multiplied by the flow velocity. The flow velocity is found from direct measurement of the cylinder piston velocity multiplied by the piston area. The waves are measured directly at the location by an ultrasonic wave gauges.

In Fig. 5 the measured power production in May 2010 is shown by the black x-marks. The measurements show some spread, which is due to the dependence on other parameters besides the significant wave height (e.g. wave period, wave direction, control parameters, etc.).

Three curves are plotted in Fig. 5. The curves are the result of mathematical computer simulations using three different control strategies established for a typical wave direction and wave period. The measurements are seen to fit well in between the two lowest curves.

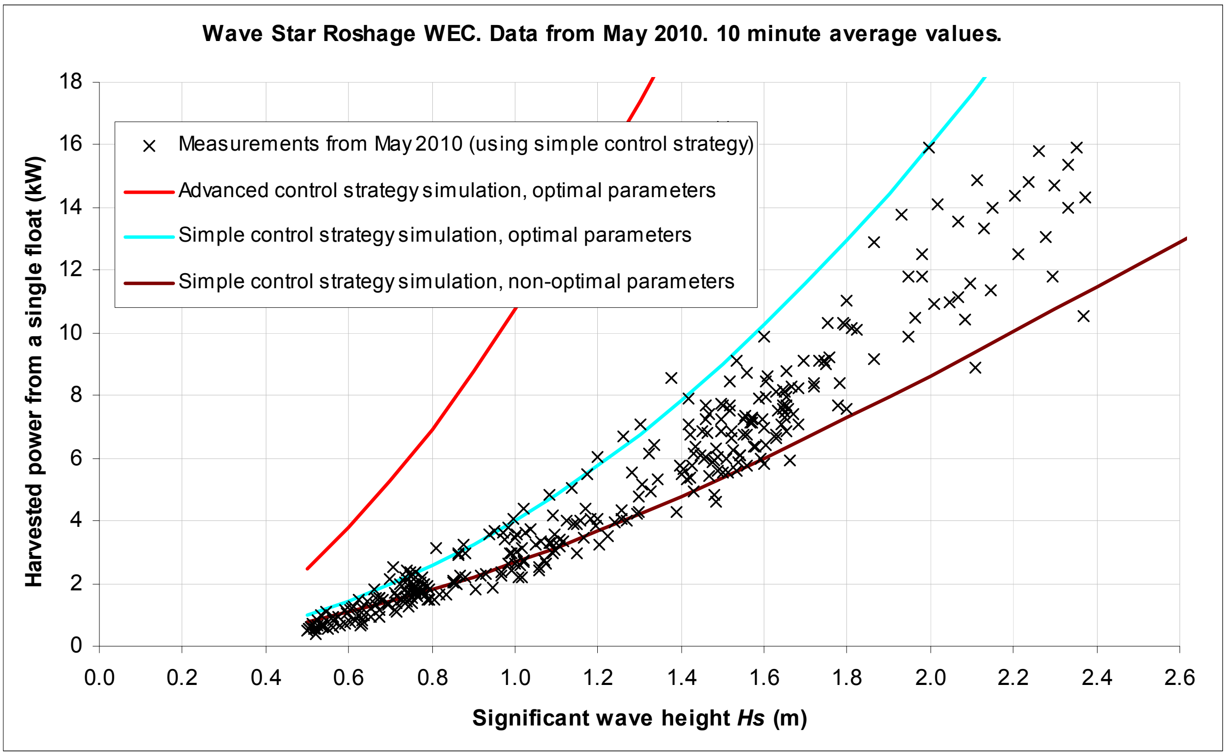

Figure 5: Power measurements from initial test period with Wave Star Roshage WEC. A simple control strategy was applied in the control software during the measurements.

6. Conclusions and future activities

The Wave Star test unit at Hanstholm was installed in September 2009. Starting from May 2010 the converter was running in unmanned continuous operation. The WEC has survived several storms with no damages and no service afterwards.

The first measurements of the power production are in agreement with the expectations. In order to minimize the risk of damages it was chosen to start the initial testing using a very simple control strategy. Hereby the peaks in forces, motions and powers would only apply moderate load to the PTO. A new and improved control strategy is under implementation. Calculations show that this will increase the power production significantly. The increase in power using the improved strategy has further been demonstrated in small scale in real sea in Nissum Bredning [6].

The converter at Roshage is an ideal test WEC for the further development of the Wave Star concept. Several activities are planned in order to demonstrate the future potential, e.g.:

- New control strategies will be implemented giving an expected increase in production.
- More tests will be performed in order to document and confirm the overall performance under a variety of sea and weather conditions.
- The efficiency of the PTO will be improved in order to minimize losses and thereby maximizing the electricity delivered to the grid.
- The time out of operation will be minimized in order to demonstrate the reliability of the systems and increase the total MWh production.
- New components are planned to be tested on the test-unit before inclusion in the commercial WEC.

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