Technical report

Project title	Upgrading and relocation of the Wavestar prototype
Project identification (program abbrev. and file)	Energinet.dk project no. 2009-1-10306
Name of the programme which has funded the project	ForskEL
Project managing company/institution (name and address)	Wave Star A/S
Project partners	
CVR (central business register)	29838879
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The Wavestar wave energy converter (WEC) was installed in the North Sea in 2009 and produced electricity to the grid nearly 4 years from 2010 to 2013.

In 2013 it was decided to pause the WEC as all possible test had been made on the current configuration of the machine. Rebuilding and relocation of the machine was necessary to move to the next phase of the development of the technology. A more energetic site, development of a higher performing Power Take-Off (PTO) and reducing Cost of Energy by testing alternative components and new materials.

The existing location, close to a pier in Hanstholm Harbour, could only provide 7-8 m water depth and had a high turbulence because the waves broke on the pier.

The first part of the project included the placing of WEC into the harbour of Hanstholm for refurbishment, installation of a new developed PTO. Since the plan was to relocated it around 1,3 km from of the harbour to a water depth of around 18m giving higher and more regular waves resulting in higher energy production.

The phase 1 of the project gave Wavestar the opportunity to move the WEC from the existing location to the Harbour of Hanstholm:

The entire plant was placed on a barge, and the foundation was removed with dynamite:

Then it was toyed to the harbour:

And placed on a foundation inside the harbour:

The second phase included the design of the future prototype which the following components:

- Two more floats going from a diameter of 5 m to 6 m.
- Two new arms going from a length of 10 m to 12 m.
- Analysis of using a new developed concrete float
- A new designed PTO with a higher efficiency

In the project a new float of 6m has been designed based on the experience acquired from the prototype in Hanstholm. Forces on the shell had been measured and analysed, which has to been secured for the future (2 floats were destroyed in June 2010 due to weakness in the shell reinforcement).

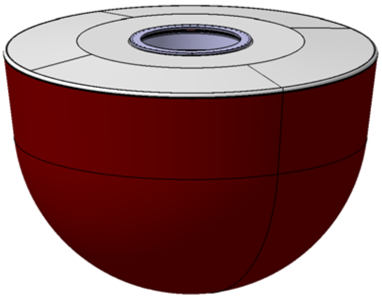

Fig 1: existing float design

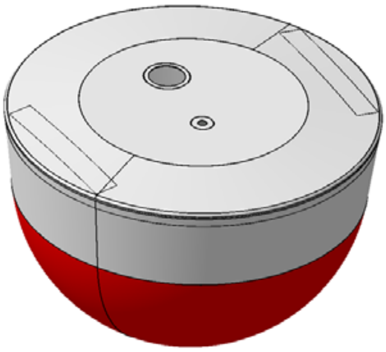

Fig 2: new float design

In the new design, the anchor point has been moved to the side, with the goal of simplifying the design. By moving the structural loads on the side of the shell, the will not have to be transferred in the middle to the arm fixing point. This makes the float lighter and less expensive to build, and also distribute the load on the entire shell spread and not on a specific point.

A new arm of 12 m has been designed for the machine:

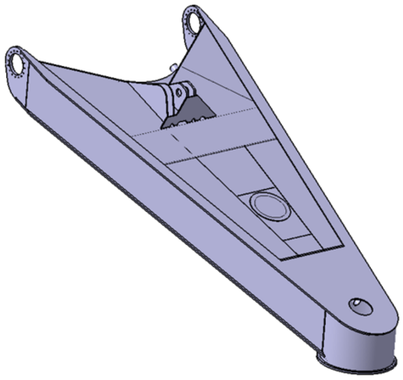

Fig 3: existing arm design

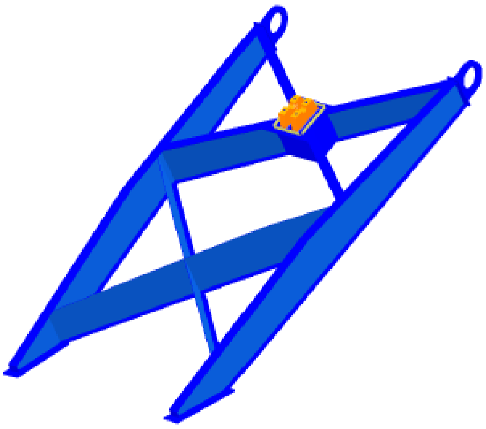

Fig 4: new arm design

This arm design is simpler to build and lighter compared to the original design. This was in line with the strategy to make the main parts of the machine less expensive. The anchoring points are now moved to the side of the float as described previously.

The use of CRC (composite reinforced concrete) for a new 6m float has been evaluated and designed:

Fig 5: float in CRC, arm in steel

A complete arm/float model has been developed for the WEC in Hanstholm by Aalborg University (AAU) based on the work conducted on the FLOAT2 project containing the design of a CRC arm and float. This design is quite different from the existing design as the weight of the entire system is lower and placed differently on the structure. The main weight is given by the float, which requires a larger cylinder to move the float/arm system out of the water. The dynamic of the system is also quite different and requires another control strategy as the point of gravity is placed differently giving another resonance in the system.

A new PTO has been developed in the project period, based on the experience conducted on a test bench at AAU focussing on making a unique high efficient system.
The test bench allows the development of one cylinder, which is transferred to a complete system with four floats (two of 5m in diameter and two of 6m in diameter)
A constant development has been made on the test bench, to find the right components where different type of valves has been used. But also to develop the most optimal control strategy according to the component used as the dynamics of these has a lot of influence on the results.

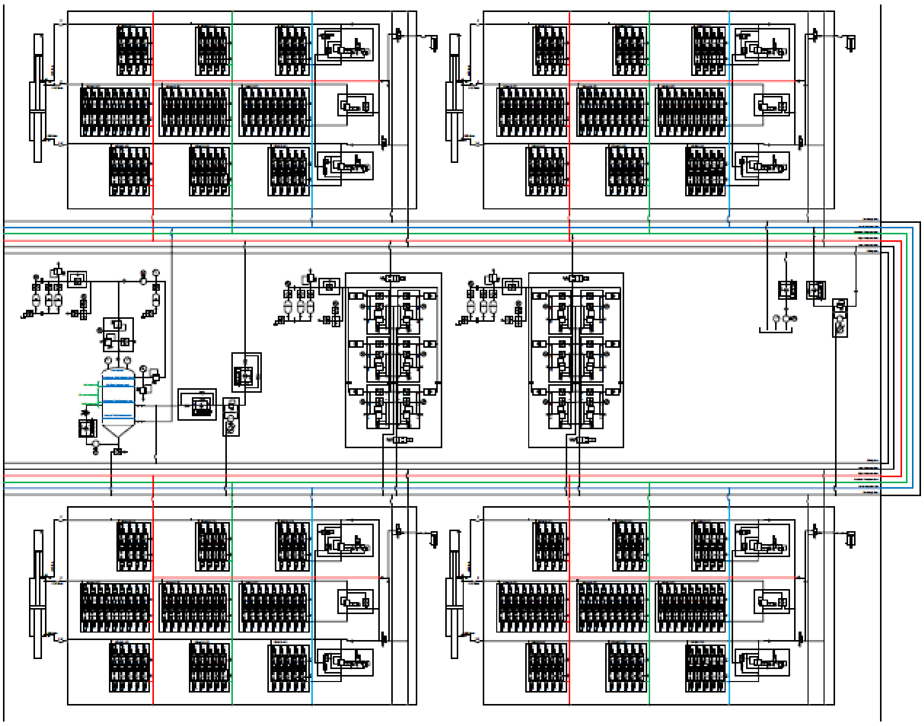

Fig 6: The four cylinder configuration with pressurized tank.

A complete PTO has been designed for the 4 floats, including a new developed pressurized tank (EUDP project). The goal was to build and test the complete new PTO on the machine for final development of the commercial machine.
A complete model has been developed to simulate the operation in different sea states according to the Hanstholm configuration.
The model and the simulation allow us to configure the component to be used for the machine: size of cylinder, size of manifold (flow speed and volume), size of accumulator (volume) and size of the pressurized tank.

The existing Parker valves have been replaced by new developed on/off valves from Bucher, capable of taking high flow and having a response time of less than 15ms. The reason of changing the Parker valves with the Bucher is the save energy in the system as the Parker valves are very energy consuming.
We obtain the same results with the Bucher valves as with the Parker[1]:

[1] AAU testbench report – 2015 09 29

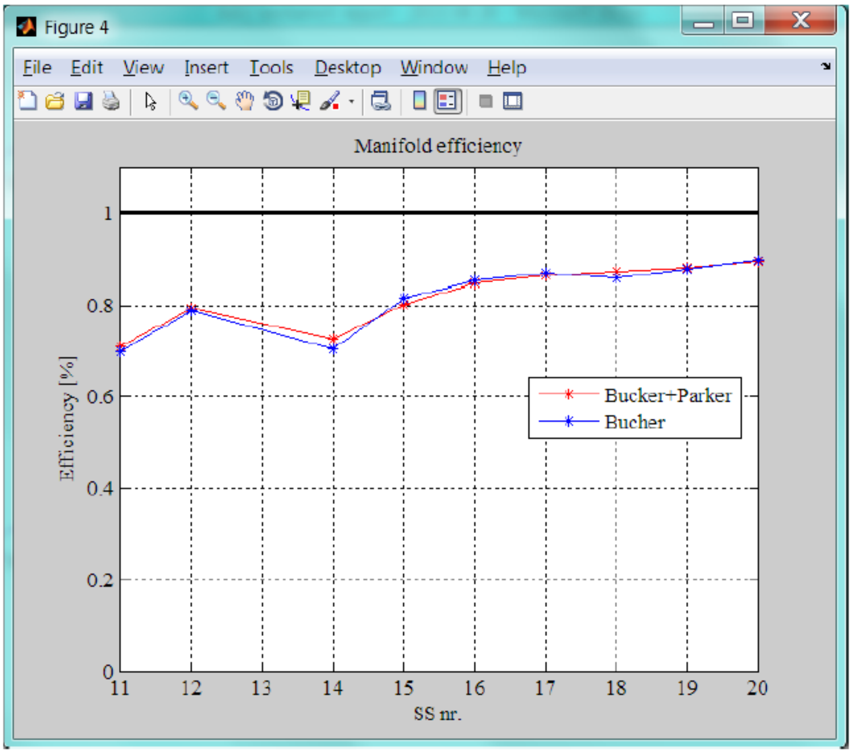

Fig 7: comparison of the use of Parker and Bucher valves for Digital hydraulic PTO.

The efficiency of the manifold has been tested with the new valves configuration together with the cylinder efficiency and a new control system.

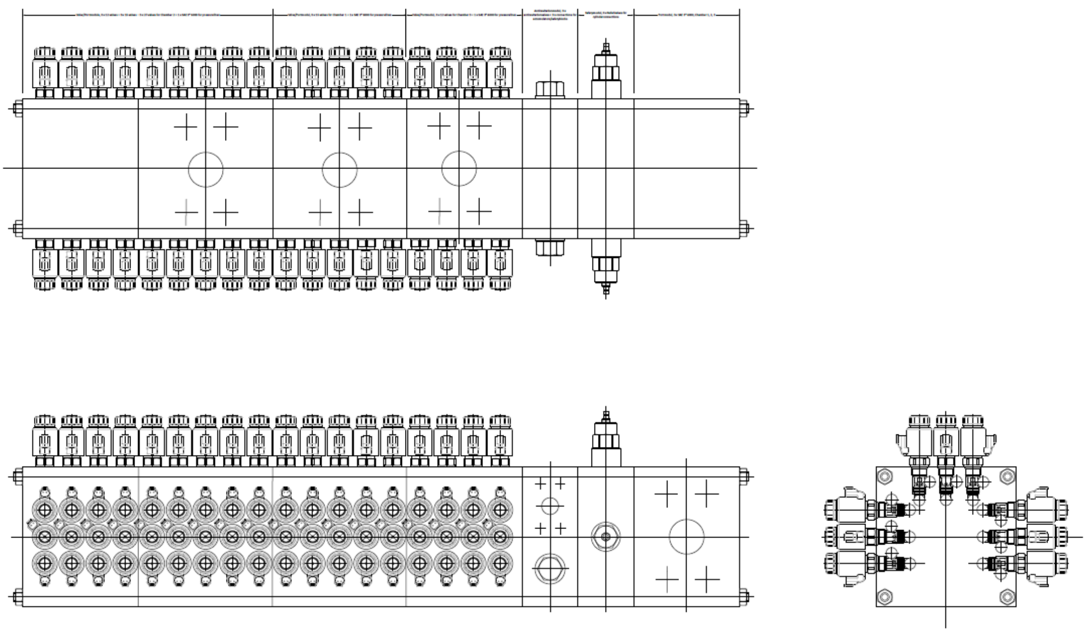

Fig 8: New manifold design with Bucher high speed valves.

The difference from the original hydraulic system is a complete change of operation. The new PTO is working digitally (on/off valves) with three different pressure lines: low (20bars), middle (100bars) and high (200 bars), which adjust itself to reach the highest efficiency independent of the sea state.

A series of tests have been performed with different sea states on the test bench; the sea states models are based on the data recorded from the machine in Hanstholm and are in that way very representative of the sequences that the machine will face in the sea.

The results show a very efficiency of the system, where an average efficiency is noted to be around 84%[2]

eta[%]		T0,2		
		3,5	4,5	5,5
Hm0	0,25	-	-	
	0,75	70	70	
	1,25	79	81	
	1,75		85	86
	2,25		87	88
	2,75			90

Fig 9: Efficiency results for different sea states.
Efficiency of the system depending on wave height (Hm0) and time period (T0,2), the efficiency is given in %

Parallel to this, experience has been conducted in the wave basin at the AAU to prepare the development of the control strategy and to measure the loads absorbed by the arm and float system.
The PTO test with the new control settings have been repeated in the configuration in the basin where a complete set of measurement has been recorded. These measurement form the basis for a complete analysis of the data (efficiency, loads transfer, adjustment of parameters). Papers regarding these tests results were submitted to EWTEC 2015.
In the future extended test with a series of float (5) needs to be done providing an analysis of interaction between float and test of new control strategies. For example the predictive control, which allow increasing the energy absorbed by between 15 to 50% depending of the sea state[3]

[2] AAU testbench report - 2015 09 29
[3] Wavestar Energy Production Outlook, AAU

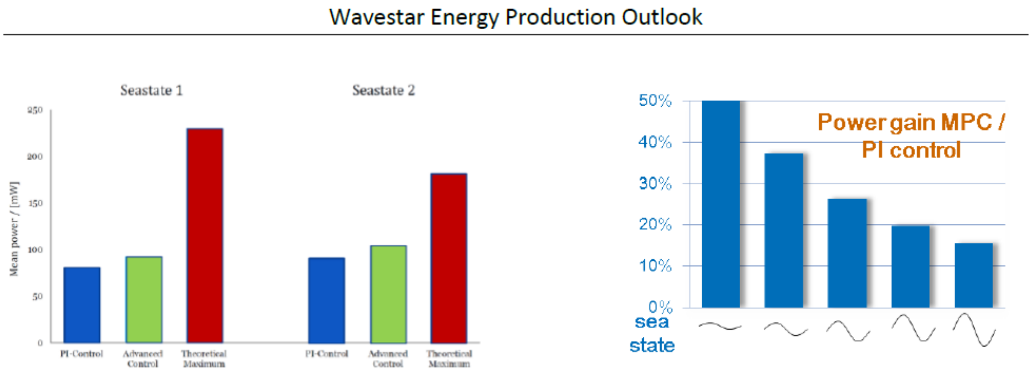

Figure 2: Results of control and power measurements on a single small scale Wavestar float in the wave basin at AAU. Left figure is from [35], right figure is from [26].

A complete study has been done for a Ph.D. thesis by Morten Møller Jakobsen based on the work performed in the AAU basin.[4]

In parallel to this, a study has been made to define the influence of the loads on the structure and on the PTO. The result of this study would allow us to adjust the control system to minimize the influence of the loads and to design the right component to be used on the machine.
The study made by Simon Ambühl, is the results of data from the existing machine, measurement by loads and acceleration cells on the test bench and measurement from loads cells on the float in the wave basin. An article has been published for the EWTEC 2015[5].

Project conclusion and perspective

The project has succeed to go through different phases for the design of the new digital PTO system, model simulation, basis for the control system, measurement of the loads to prepare the basis design and design of the different components both for the hydraulic (manifold, valves, accumulators) and for the structural ones (float and arm).
This work gives definitively the basis for the design of the future full scale machine. A complete test of the new refurbished and installed machine on a more energetic site would have provided the last necessary experience to improve the control strategy and validate the value of the structural loads for the end design.

Unfortunately, the project did not reach the final goal, since it has been decided to stop all activities in Wave Star A/S as of April 1, 2016 for financial reasons. However, it is our belief and hope that other wave energy developers will benefit from the experience and research and development, which Wavestar through time has presented.

[4] Wave-Structure Interactions on Point Absorbers an experimental study , Morten Møller Jakobsen 2015
[5] Different Reliability Assessment approaches for Wave Energy Converters, Simon Ambühl, Morten Kramer, John Dalsgaard Sørensen, AAU 2015