Wavestar Demonstrator, monthly report for June 2013

Report for Energinet.dk, ForskVe 12110 “Increasing reliability and reducing maintenance on Wavestar wave energy plants in order to reduce the Cost of Energy”

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Background

In January 2013 the project titled *"Increasing reliability and reducing maintenance on Wavestar wave energy plants in order to reduce the Cost of Energy"* was initiated. The project is running over two years, January 2013 to December 2014. The project is subsidized by the Energinet.dk ForskVE program, project no. 12110. The project is an extension of the successful completion of the ForskVE project 2009-1-10305, which ended in December 2012. The previous project was spilt in two phases "Phase 1" and "Phase 2", and for this reason the new project is termed "Phase 3". An overview of the purpose for three phases is given below:

- **Phase 1**, May 2010 to September 2011: Focus was to demonstrate that the hydraulic power was higher than a specified target power performance curve. Phase 1 was finished in September 2011 where 14754 valid ten minute records with power production higher than the specifications, were recorded, documented and approved by EnergiNet.dk.
- **Phase 2**, October 2012 to December 2012 (three months): Emphasis was on the electrical energy. In phase 2 the capability of the machine to deliver the expected number of electrical kWh's in a three month period was documented. Phase 2 was completed after phase 1 was completed when the machine was ready for automatic continuous unmanned operation.
- **Phase 3,** January 2013 to December 2014 (two years). The purpose of the project is to continue operation and development of the Wavestar Demonstrator at Hanstholm with the focus on increasing the life time and reducing operating and maintenance costs, thus improving the overall Cost of Energy. This will be achieved through a targeted collection of statistics on maintenance and time consumption, and the subsequent replacement, testing and optimization of the critical components. The goal is to minimize the number of service calls and downtime on the upcoming full-scale machine in the open sea.

Every month since May 2010 Wavestar has published a monthly report with a summary of the achieved results and activities at the Wavestar demonstrator at Hanstholm. The monthly reports are supplemented by an Excel file containing data records with all the raw data presented in tables and figures.

References:

http://www.fi.dk/filer/publikationer/2010/energi_2010/html/kap03.htm

http://www.energinet.dk/DA/FORSKNING/ForskVE-programmet/Sider/ForskVE-udbud.aspx

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Ministry of Science Technology and Innovation

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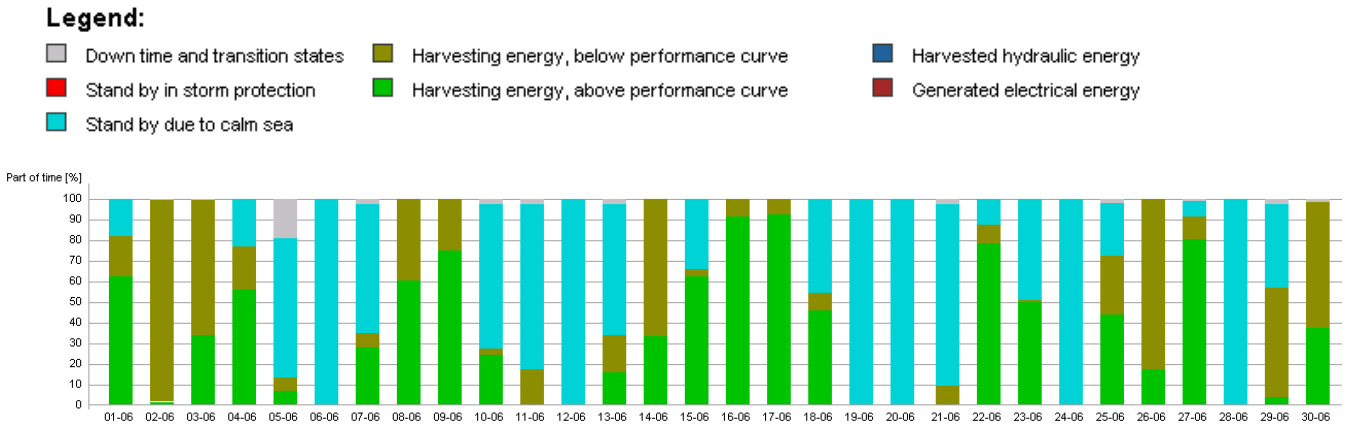
1 Activities and special events in present month

It has been a quiet month at the machine with a high operational time, ten groups of visitors, and a moderate wave climate.

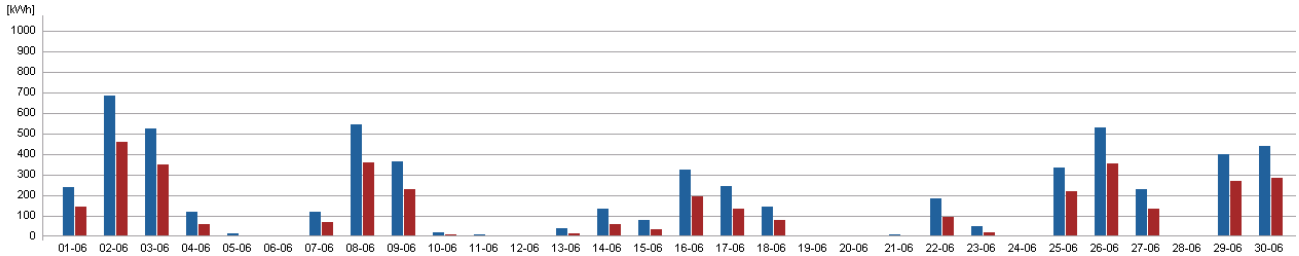
2 Performance in present month

This month the machine has been operational for 99.4% of the time of the month, and in production for 56.0% of this time.

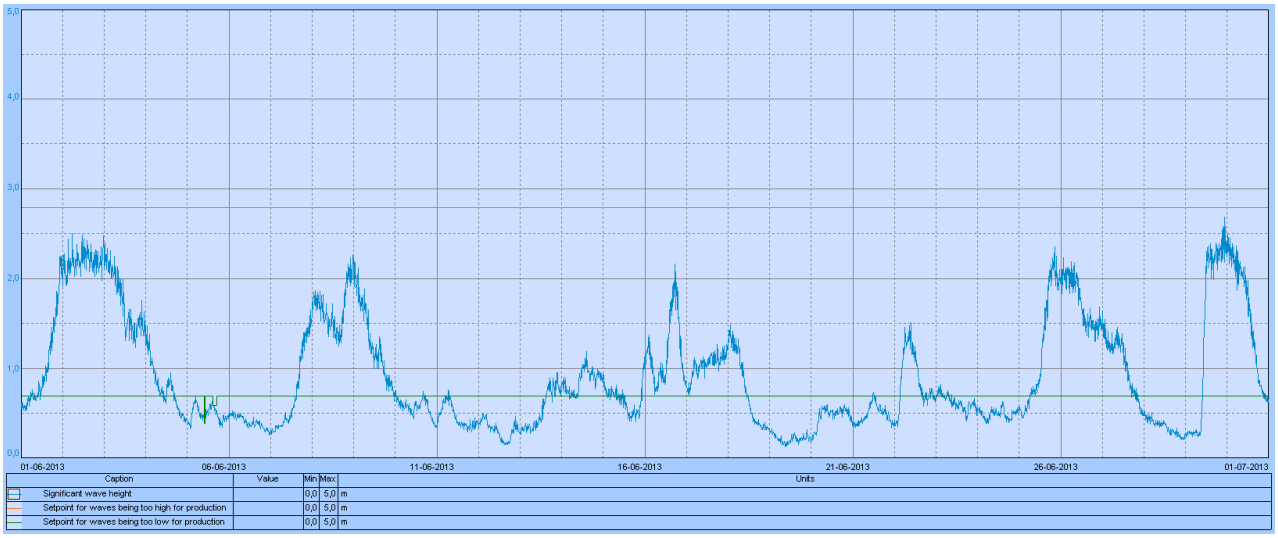
The operational status, the energy production, and the wave height for the month are displayed here below.



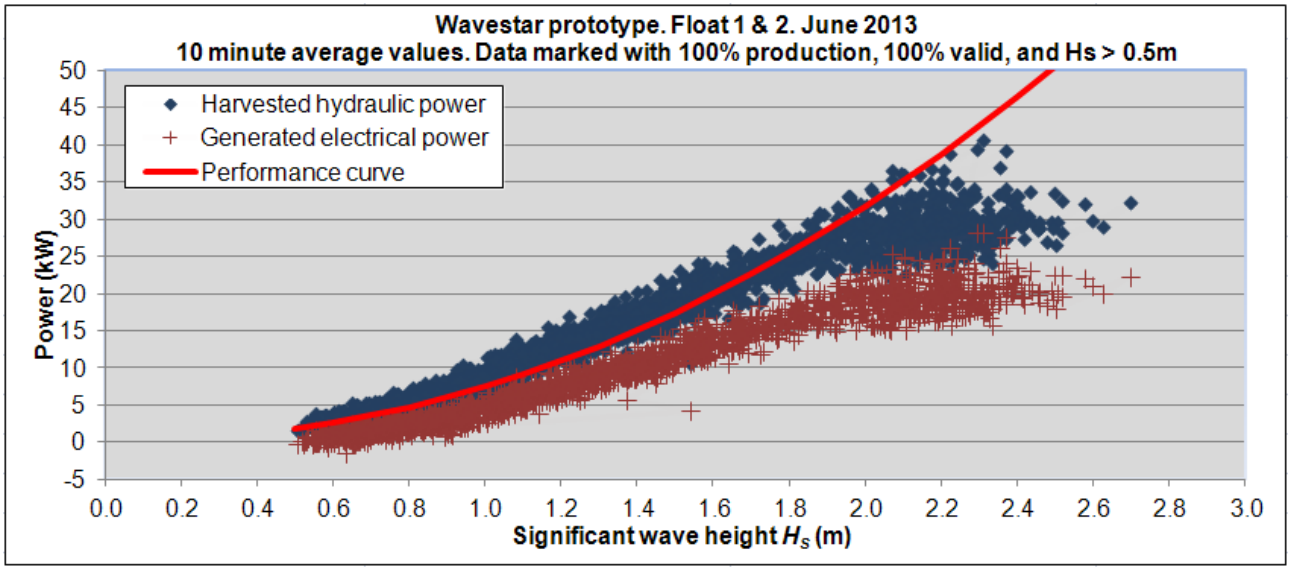
Operational status



Energy production



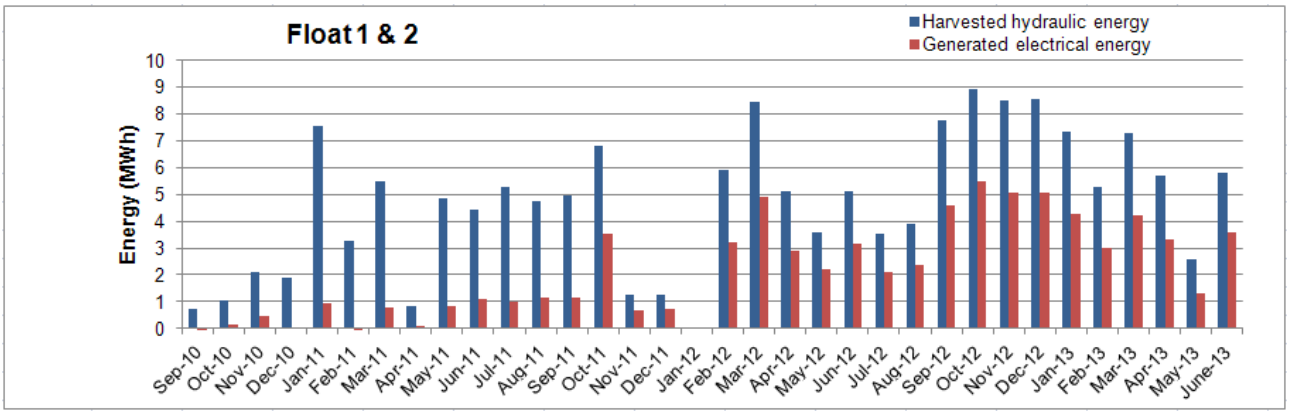
Significant wave height



10 minute average production registrations

3 Summary of performance since installation

Float 1 & 2									
Month	Operational time (of total time) [%]	Production [%]	Storm (of operational time) [%]	Calm sea (of operational time) [%]	Transitions (of operational time) [%]	Harvested hydraulic energy [kWh]	Generated electrical energy [kWh]	PTO efficiency [%]	Max generated electrical power [kW]
Sep-10	9.8	54.1	9.9	0.0	35.9	739	-69	-9.4	23.6
Oct-10	7.6	88.3	1.5	0.0	10.2	1064	149	14.0	22.9
Nov-10	14.4	73.7	6.1	7.3	13.0	2101	460	21.9	24.7
Dec-10	28.1	73.3	5.2	14.7	6.7	1880	43	2.3	23.4
Jan-11	81.7	80.6	0.0	18.3	1.1	7521	918	12.2	23.1
Feb-11	66.1	59.6	21.5	15.3	3.5	3265	-104	-3.2	25.0
Mar-11	64.1	61.7	3.9	32.4	2.0	5469	790	14.4	23.4
Apr-11	23.1	47.7	14.3	32.0	5.9	830	105	12.7	25.9
May-11	90.7	55.6	2.5	38.8	3.2	4859	827	17.0	25.8
Jun-11	92.3	44.8	3.2	49.8	2.2	4420	1111	25.1	23.2
Jul-11	90.3	71.7	0.8	24.7	2.7	5278	992	18.8	21.5
Aug-11	93.4	61.0	6.4	31.2	1.4	4721	1128	23.9	28.1
Sep-11	78.6	63.3	11.3	23.7	1.7	4941	1127	22.8	25.3
Oct-11	68.6	70.5	3.7	24.1	1.7	6790	3524	51.9	29.0
Nov-11	46.3	36.2	11.8	50.2	1.7	1256	666	53.0	15.9
Dec-11	16.7	73.4	12.7	0.1	13.8	1272	715	56.2	16.3
Jan-12	1.5	77.0	0.0	0.0	23.0	62	24	39.4	4.5
Feb-12	98.4	66.4	9.3	22.3	2.0	5915	3210	54.3	32.8
Mar-12	96.5	79.1	1.0	19.1	0.8	8465	4920	58.1	35.7
Apr-12	93.2	62.3	0.2	35.0	2.5	5131	2901	56.5	30.0
May-12	49.1	63.1	1.8	33.6	1.4	3582	2184	61.0	23.6
Jun-12	88.8	54.4	0.1	44.2	1.4	5129	3185	62.1	27.1
Jul-12	68.8	55.9	0.0	43.1	1.0	3534	2114	59.8	26.1
Aug-12	88.4	40.1	0.1	59.4	0.4	3881	2377	61.2	26.5
Sep-12	84.1	93.3	0.3	5.8	0.7	7752	4599	59.3	23.3
Oct-12	99.7	75.8	0.3	22.9	1.1	8943	5507	61.6	30.1
Nov-12	99.3	90.0	0.9	8.1	1.0	8475	5041	59.5	32.1
Dec-12	99.2	81.2	2.0	15.1	1.8	8544	5046	59.1	32.4
Jan-13	99.7	70.0	4.1	23.4	2.5	7328	4289	58.5	41.6
Feb-13	80.4	74.9	3.8	19.9	1.4	5254	3009	57.3	35.1
Mar-13	99.1	72.3	0.7	25.7	1.3	7261	4227	58.2	29.2
Apr-13	98.6	66.3	1.9	30.3	1.5	5690	3312	58.2	36.8
May-13	73.3	63.9	0.0	35.2	0.9	2582	1314	50.9	23.3
June-13	99.4	56.0	0.0	43.3	0.7	5784	3583	62.0	28.2



Period		Operational time [%]	Production time [hours]	Hydraulic energy [MWh]	Electrical energy [MWh]	PTO efficiency [%]
Sept-09 to Apr-10		-	149	0.8	0.2	18.0
May-10 to Sep-11	(phase 1)	45.8	3547	51.6	6.9	13.3
Oct-11 to Sep-12		66.3	3697	52.8	30.4	57.6
Oct-12 to Dec-12	(phase 2)	99.4	1805	26.0	15.6	60.1
Jan-13 to Jun-13	(phase 3)	91.8	2676	33.9	19.7	58.2
Total		63.7	11874	165.1	72.8	44.1

Summary of the measured energy production since installation in September 2009.

4 Downtime registration

Each time the machine or a single float leaves automatic operation it is automatically registered in the database.

- If it is due to a fault, the fault description is written.
- If it is due to the operator changing mode, the operator is requested to indicate the reason for this. The reason can be Demonstration, Inspection, Maintenance, Planned stop, or Development.
- If the reason is other than Demonstration, the operator is further requested to indicate which FDS (Functional Design Specification) area this stop regards, and an optional comment can be written.

When the float or the machine returns to operational state, the time is registered and the downtime duration is calculated.

As the machine is still half operational if only one float is operational a weighted downtime is calculated, where a single float only count half.

By accumulating the weighted downtimes, the number of minutes where the machine has been not operational is found. From this, the percentage of the month where the machine has been not operational is found.

The complete Downtime log can be seen in the Downtime log sheet in the Excel file of this report. An extract covering the present month is shown below.

Downtime log

Time for change to not operational	Downtime [min]	Area	Event	Reason	Detail	Comment
30-06-13 03:34:45	0.90	Float 2	Set into Manual mode	Maintenance	Floats	Refilling ballast water
30-06-13 02:39:54	52.05	Float 1	Fault	Fault	Tilt control faillure	
21-06-13 13:23:06	2.95	Float 2	Set into Manual mode	Not specified	Not specified	Demotest
18-06-13 10:03:33	1.13	Machine	Set into Manual mode	Demonstration	Control system General	Danwec
13-06-13 14:46:21	8.30	Machine	Not op. after power up	Fault	-	(Program error caused PLC stop)
13-06-13 13:12:37	3.00	Machine	Set into Locked mode	Developement	Control system General	Program download: New data structures
13-06-13 11:13:45	1.32	Machine	Set into Locked mode	Developement	Control system General	Modification to data structures for weather and wave data.
10-06-13 15:30:54	3.00	Machine	Set into Manual mode	Developement	Jacking Sections	Program download: Extensions to jacking sections
10-06-13 12:51:49	0.27	Float 1	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 12:50:50	0.23	Machine	Set into Manual mode	Not specified	Not specified	Test of Downtime log
10-06-13 12:50:07	0.23	Machine	Set into Locked mode	Developement	Control system General	Test of Downtime log
10-06-13 12:46:15	0.23	Machine	Set into Manual mode	Demonstration	-	Test of Downtime log
10-06-13 12:45:33	0.55	Machine	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 12:40:04	3.30	Machine	Set into Manual mode	Developement	Control system General	Program download: Corrections to new downtime log program
10-06-13 11:35:23	0.55	Machine	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 11:23:58	6.10	Machine	Set into Manual mode	Developement	Control system General	Program download: Corrections to new downtime log program
10-06-13 11:04:27	0.17	Machine	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 10:59:13	0.85	Machine	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 10:44:50	0.35	Machine	Set into Manual mode	Developement	Control system General	Test of Downtime log
10-06-13 10:30:13	9.60	Machine	Set into Manual mode	Developement	Control system General	Program download: Restructured program for downtime log
09-06-13 21:49:25	1.10	Float 1	Set into Manual mode	Maintenance	Floats	Refilling ballast
05-06-13 16:51:29	29.92	Machine	Set into Manual mode	Demonstration	-	Belgium visitors
05-06-13 10:03:49	166.87	Machine	Set into Manual mode	Inspection	Floats	Checking for leakage in floats
03-06-13 14:28:56	0.43	Float 1	Fault	Fault	Tilt control faillure	
03-06-13 14:23:29	3.97	Float 1	Fault	Fault	Tilt control faillure	
03-06-13 06:26:22	0.95	Float 1	Set into Manual mode	Maintenance	Ballast system	
03-06-13 06:25:25	0.87	Float 2	Set into Manual mode	Maintenance	Ballast system	
02-06-13 16:49:28	1.08	Float 1	Set into Manual mode	Maintenance	Floats	
02-06-13 16:48:31	0.82	Float 2	Set into Manual mode	Maintenance	Ballast system	
02-06-13 12:21:24	1.18	Float 1	Set into Manual mode	Maintenance	Ballast system	Refilling ballast water
02-06-13 12:19:35	1.55	Float 2	Set into Manual mode	Maintenance	Ballast system	Refilling ballast water
02-06-13 09:09:10	1.42	Float 1	Set into Manual mode	Maintenance	Floats	Checking ballast volumen
02-06-13 09:07:27	1.40	Float 2	Set into Manual mode	Maintenance	Floats	Checking ballast volumen
Accumulated downtime in month: 271.17 minutes, which is 4.52 hours, or 0.61 % of total time in month						

Through the first half of 2013 the machine or one of the floats has been in a state different from operational 178 times.
As these events are registered in the database with a number of parameters, it is possible by to group and sort the number of events and accumulated downtime per reason and detail. The result is shown here.

Downtime 1st half of 2013	
Events	Hours
178	352.66

Downtime reason	Events	Hours
Demonstration	25	22.51
Developement	58	2.49
Fault	40	307.10
Inspection	10	6.05
Maintenance	22	14.47
Not specified	2	0.03

Downtime due to developement per area	Events	Hours
Control system General	12	0.44
ICS Software	45	2.01
Jacking Sections	1	0.05

Downtime due to fault per fault type	Events	Hours
Booster system faillure	4	10.25
Fault on wave measurement	6	177.98
Float generator stopped	2	0.00
Hydraulic system not ready	5	109.31
Low A-port pressure	1	0.01
Machine not in expected position	1	0.28
Piston force control faillure	3	1.50
PLC fault	1	0.14
Servo system faillure	2	0.00
Tilt control faillure	15	7.62

Downtime due to inspection per area	Events	Hours
Ballast system	1	0.01
Float hydraulic system	1	0.09
Floats	7	5.94
ICS Software	1	0.01

Downtime due to maintenance per area	Events	Hours
Arms	1	7.84
Ballast system	5	0.04
Float hydraulic system	1	0.01
Floats	8	4.96
ICS Software	2	0.03
Jacking Sections	1	0.73
Main hydraulic system	4	0.85

The figures provide only little new information to the people following the daily operation of the machine, as the common faults and the major issues during the period are well-known.
But for a future machine it will be an important tool to document the operation and to identify problems.

Two types of faults account for the major part of the downtime. Common to these are, that when something fails, it is a combination of many factors:

- Fault on wave measurement.
  - The ultrasonic wave sensor became defective due to corroded cables.
  - The pressure sensor to detect waves became defective shortly after installation.
  - The wave buoy at Hanstholm Harbour was defective due to a collision with a ship.
  - The internet connection to the machine was lost due to a defective modem.
- Hydraulic system not ready.
  - New programs were written for the hydraulic system. By mistake the hydraulic system was reported not ready while the oil was cold, and then it could not start up to heat the oil.
  - This took place while waves were anyway too low for production, so with a brief view everything looked normal.
  - Half of the downtime happened over a weekend.
  - The other half happened while the operating staff at Wavestar was monitoring the machine sporadically from abroad.

5 Guest book

Registration of all visitors on the machine was started from January 1st 2013.

Visitors are grouped in the following categories: Politicians, Energy companies, Business partners, Journalists, Students, and Others.

The complete guest book can be viewed in the Excel file of this report. The visits in the present month are extracted and shown below.

Guest book					
Date	**Visitor**	**Contact person**	**Number of visitors**	**Category**	**Host**
30-06-13	Havneforum	Christian Nereus Grant	7	Others	clg
22-06-13	Nordisk Folkecenter for Vedvarende Energi	Jane Kruse	25	Others	clg
19-06-13	Havneforum	Christian Nereus Grant	2	Others	CLG
17-06-13	Bodil Jacobsen	Bodil Jacobsen	1	Students	mpe
16-06-13	Havneforum	Christian Nereus Grant	3	Others	clg
13-06-13	Visitors from Nemos	DanWEC	4	Energy companies	hjb
11-06-13	Switz tourists with an interest in energy production	Christian Nereus Grant	17	Others	clg
09-06-13	Nørrebygård Forening	Christian Nereus Grant	17	Others	clg
08-06-13	Croatian television journalists	DanWEC	3	Journalists	hjb
06-06-13	Folkecentret for vedvarende energi	Jane Kruse	20	Students	clg
06-06-13	PIL	Christian Nereus Grant	13	Others	clg
05-06-13	Belgian Delegation	Gerard Seghers	6	Business partners	mpe
05-06-13	GE electric, Michael Christensen (former ConverTeam)	Michael Christensen	1	Business partners	mpe
05-06-13	Andrew Zurkinden, AAU	Andrew Zurkinden	1	Students	mpe
01-06-13	Jens Riis	Christian Nereus Grant	20	Others	clg

In total, 675 people have visited the machine during the first half year of 2013. They are categorized as follows:

Category	Visitors
Business partners	38
Energy companies	135
Journalists	6
Politicians	15
Students	267
Others	214
Total	675

6 Economic data

Operation and maintenance activities are registered in the accounting system at the following accounts:

- Planned maintenance
- Unplanned maintenance
- Test and development
- Others (include insurances, direct cost like energy…)

The overview shown below will be updated as data becomes available.

cost €	planned maintenance	unplanned maintenance	test and development	others	total
2010					167351
2011					138964
2012					39476
2013 Q1	237			4273	4510
2013 Q2				1269	1269
2013 Q3					
2013 Q4					
total					**351570**

No detailed registration was made during the first three years. The first two years most expenses went to unplanned maintenance, while the expenses in 2012 mainly were for development.

7 Maintenance activities

Each time a maintenance operation on the machine is completed, it is registered in the database via the HMI faceplate of the component in question.

The complete Maintenance log can be seen in the Maintenance log sheet in the Excel file of this report. An extract covering the present month is shown below.

Maintenance log			
Time	**Component**	**Event**	**Action**
28-05-13 13:07:11	Control system General	Unplanned service	Correction of a program error: No automatic resetting of a booster pump alarm after a planned power cut test
23-05-13 11:18:26	Individual instrumentation	Unplanned service	New cables and reference sensor for Ultrasonic Wave sensor installed and testet. Pins in connector at the sensor has falled of during dismounting because the connector on the cable was corroded and sealing was thereby damaged.
22-05-13 11:23:02	Individual instrumentation	Unplanned service	New router and modem installed. AltiBox has changed the router for the fiber connection, and the RAM module in the Cisco router been exchanged. New Router also ordred and delievered. Cisco router repaired and configured by Jørgen Giversen.
08-05-13 15:59:22	Control system General	Test or developement	Maintenance log changed so that Maintenance log for a group displays events for all components of the group
06-05-13 15:13:44	Control system General	Test or developement	Error corrected in downtime registration: The user name from the last operator requested downtime event was logged with later alarms.
06-05-13 14:05:22	Individual instrumentation	Test or developement	Extracting, displaying, logging, and trending "Speed of sound" from ultrasonic sensor communication interface in order to test the reference sensor for errors.
06-05-13 12:19:58	Individual instrumentation	Unplanned service	Ultrasonic Water Level Detector has a failure in detecting water surfece level. It seems to be the reference sensor thats fails. and it was echanged with an other (old one from the pier). but not with the right result. It is informed from General Acoustic that the correct signal value from the ref. sensor is normally around C=34000. and with fail on the sensor typically around C=22900. which it is in our case. New cable and sensor has been ordred.

The complete maintenance log holds additional information like reference to the FDS (Functional Design Specification) that covers the component, and time and money spent on the operation.

In future status reports the maintenance operations will be grouped to show maintenance demand per FDS area and for evaluation of maintenance need for the machine as time, cost, and number of maintenance trips. The complete maintenance log will also serve as a valuable input to a future service manual.

On the following page, this is done for the first half of 2013.

Through the first half of 2013, 26 maintenance events have been registered at the machine.
As these events are registered in the database with a number of parameters, it is possible by one script to group and sort them in different ways. Here they are grouped per type and per FDS area:

Maintenance, 1st half of 2013			
Events	Internal hours	External hours	Material cost [DKr]
26	124.7	9.0	13120

Maintenance per type	Events	Internal hours	External hours	Material cost [DKr]
Planned service	9	2.7	0.0	240
Unplanned service	7	43.0	9.0	12880
Test and developement	10	79.0	0.0	0

Maintenance per area	Events	Internal hours	External hours	Material cost [DKr]
400V/230V Light	1	3.0	0.0	140
Ballast system	1	0.2	0.0	10
Compressed Air	1	0.0	0.0	0
Control system General	9	75.0	0.0	0
Individual instrumentation	4	40.0	9.0	12480
Jacking Sections	1	2.0	0.0	0
Jacking System	1	0.5	0.0	0
Lubrication system	2	2.0	0.0	205
Main hydraulic system	6	2.0	0.0	285

Data for half a year does not give a complete picture of the maintenance demand, but can be used to overview and evaluate the system for registering maintenance events.

The following table lists maintenance activities that are planned for the near future.

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Activity	**Description**	**Status**
Ladder repair	New ladder for float 1 float arm	Planned for spring 2013
Bearing repair	New rod end bearing for float 2, and repair of gyro suspension	Planned for summer 2013
Filter change	Hydraulic oil filter change, all systems	Planned for summer 2013
Hydraulic tank repair	Change of seals for hydraulic oil tank	Planned for summer 2013
Zinc anodes	Change of zinc anodes on legs	Planned for 2013
Bearing repair	New rod end bearing for float 2, and repair of gyro suspension	Planned for summer 2013
Test of essential sub-systems	Test of jacking system and diesel engine	Every second month

8 Development activities

The following table lists development activities that are planned for the near future.

Activity	Description	Status
Service log	Finishing of Service log to include components, that are not yet defined in the control system	Planned for 2st quarter 2013
Wave analysis	Software update with Wavelab	Planned for 2013
Load pin analysis	Software analysis and database update	Planned for 2013
Jack seals	Construction of a opening/closing mechanism for the new type of seals around legs	Planned for 2013
Reprogramming	Reprogramming of PLC programs for “Power systems” to current standard	Planned for spring 2013
New PTO test	Test new digital hydraulic high efficient PTO	Planned for 2014

Development activities are moved to the table below when completed.

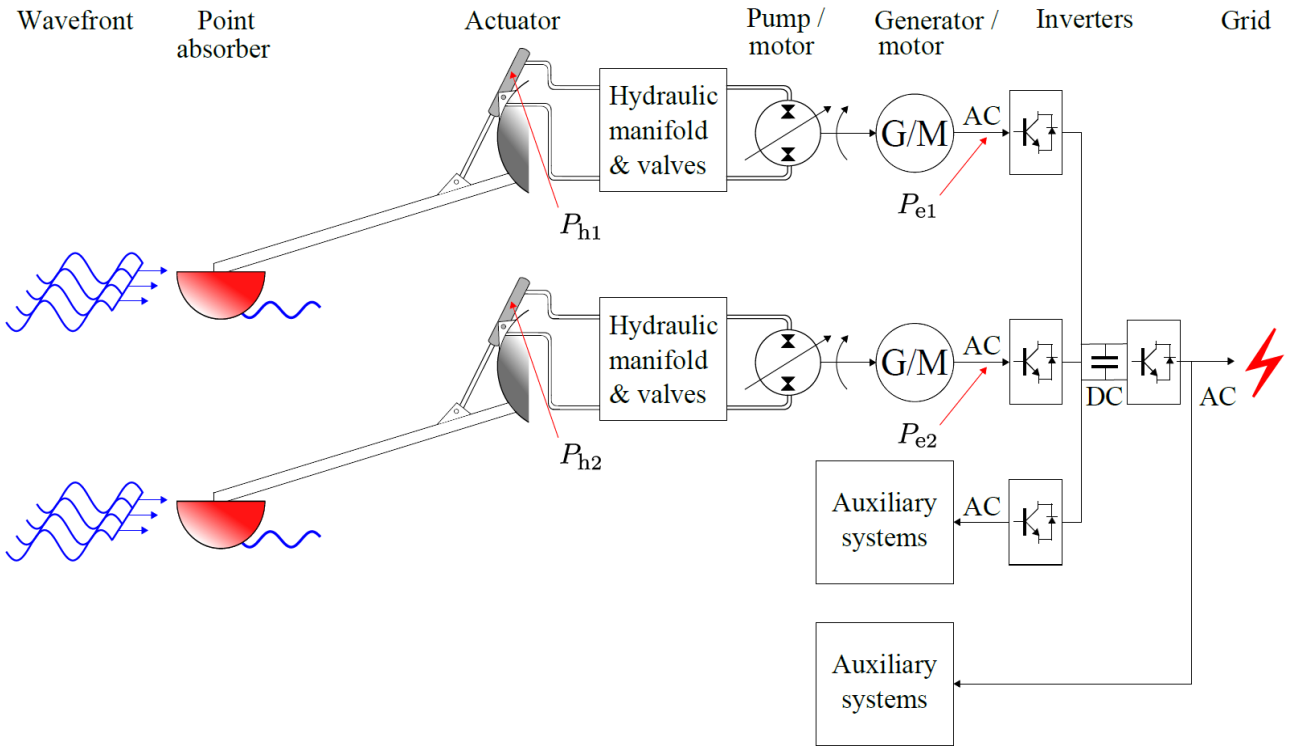
Activity	Description	Completed
Maintenance costs	Extraction of maintenance costs for 2010 to 2012 for display in the table in section 6, “Economic data”	January 2013
Guest book	It is defined how visitors on the machine are registered in the calendar system of MS Outlook. Information from here is extracted to the monthly Excel report.	February 2013
Downtime registration	Programming of the Downtime registration system has been finished. Final adjustments will be made concurrently.	February 2013
Reprogramming	Reprogramming of PLC programs for the area “Main machine control” has been updated to current standard	Marts 2013

Appendix A: Explanations on wave and power measurements

Waves and power production are measured directly on-board the Wavestar prototype. An ultrasonic wave sensor is providing wave recordings at the exact location of the device. The diagram below shows the different power conversion stages. Two definitions are important in the report.

Hydraulic power, P_h [W]: The hydraulic power is measured at the hydraulic actuator, calculated by multiplying of the pressure across the cylinder and the flow in the cylinder. The hydraulic power of the prototype is the sum of the hydraulic power of both floats, $P_h = P_{h1} + P_{h2}$. The hydraulic energy, referred to as E_h, is the integration of the instantaneous hydraulic power over time.

Electrical power, P_e [W]: The electrical and consequently generated power is measured at the output of the generator, calculated by multiplying the voltage and the current. The electrical power of the prototype is the sum of the electric power of both floats, $P_e = P_{e1} + P_{e2}$. The electrical energy, referred to as E_e, is the integration of the instantaneous electrical power over time.



Overview of energy conversion stages of the Wavestar Demonstrator at Hanstholm. The hydraulic power P_h[W] is measured at the hydraulic actuator (pressure across the cylinder multiplied by the flow in the cylinder). The electrical power P_e[W] is measured at the output of the generator (voltage multiplied by current).