1: Project summary

The Wave Dragon is a slack-moored wave energy converter of the overtopping type. It is by far the most powerful wave energy converter and at the same time one of the most energy efficient and economic devices under development today. Since March 2003 a 20 kW scale 1:4.5 prototype of a 7 MW Wave Dragon has been tested as the world's first floating grid connected wave energy converter. The project will develop the Wave Dragon technology further from the tested all steel built 20 kW prototype to a full size composite built 7 MW unit and by comprehensive testing validate the technical and economic feasibility. The RTD-part of the project will:

- Develop Wave Dragon's energy absorbing structure, the low head turbine power take-off system and the control systems. An additional reservoir placed above the existing reservoir level will also be developed. The result of these changes to the overall design will be a significant increase in power production and a reduction in O&M cost. The development of the 7 MW unit will be based on the knowledge base established through the tests with the 20 kW prototype and the design process will comprise several innovative elements utilizing the O&M experience from the 20 kW prototype tests.
- Develop cost effective construction methods and establish the optimal combination of in situ cast concrete, post-stressed reinforcement and pre-stressed concrete elements.
- Develop new supplementary environmental friendly water hydraulic power take-off systems.
- Demonstrate reliable and cost effective installation procedures and O&M schemes.
- Establish the necessary basis for design codes and recommendations for floating multi MW wave energy converters.

The quantitative objectives are referring to a 24 kW/m wave climate:

- Higher energy production of each unit to a total of 10 GWh/y resulting in from a total improvement of 12% where 5% is from improvement by better control system and 7% is from the new power take off system
- A reduction in the overall installation capacity cost of 5% compared to the state of the art
- A reduction of operation and maintenance cost of 5%

The test program will demonstrate the availability, power production predictability, power production capability and medium to long term electricity generation costs at €0.052/kWh in a wave climate of 24kW/m, which could be found relatively close to the coast at the major part of the EC Atlantic coast.

2. Project objectives

Overall objectives

A 20 kW scale 1:4.5 prototype of a 7 MW Wave Dragon has since Marts 2003 been tested as the world's first floating grid connected wave energy converter. The project is a European project supported by EC and the development of and research on a full scale Wave Dragon is the next logical step towards commercialisation.

The project will develop the Wave Dragon technology further from the tested all steel built 20 kW prototype to a full size composite built 4-7 MW unit and by comprehensive testing validate the technical and economic feasibility. The RTD-part of the project will:

- Develop Wave Dragon's energy absorbing structure, the low head turbine power take off system and the control systems. An additional reservoir placed above the existing reservoir level will also be developed. The result of these changes to the overall design will be a significant increase in power production and a reduction in O&M cost. The development of the 7 MW unit will be based on the knowledge base established through the tests with the 20 kW prototype and the design process will comprise several innovative elements utilizing the O&M experience from the 20 kW prototype tests.
- Develop cost effective construction methods and establish the optimal combination of in situ cast concrete, post-stressed reinforcement and pre-stressed concrete elements.
- Develop new supplementary environmental friendly water hydraulic power-take-off systems.
- Development of a cost effective 250-440 kW hydro turbine system.
- Demonstrate reliable and cost effective installation procedures and O&M schemes.
- Establish the necessary basis for design codes/recommendations for offshore multi MW devices.

The dimensions of the device are as shown on the figure and table:

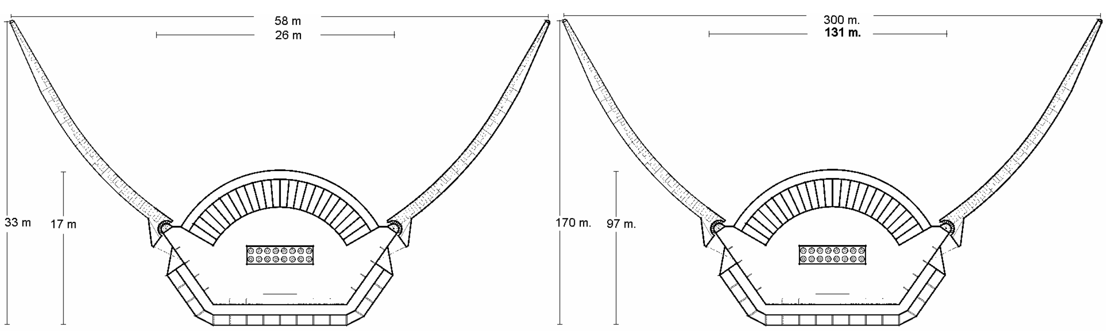

Figure: Wave Dragon in scale 1:4:5 (0.04 kW/m wave climate) compared with the scale 1:1 (36 kW/m wave climate) full scale device.

Table: Dimensions of the 7 MW Wave Dragon compared to the demonstration unit tested 2002-2005 in Nissum Breding, Denmark.

Rated Power	**7 MW**	**0.02 MW**
Sea state	24-36 kW/m	0.04 kW/m
Scale	scale 1:1	scale 1:4.5
Device Width	300m	58m
Height	17m of which 3-6m above sea level	3.6m
Length	170m	33m
Reservoir size	7000m^3	55m^3
Water Depth	>25m	6m
System Weight	33,000 tons incl. ballast	237 tons incl. ballast
Rated Power[1]	7 MW	0.02 MW

[1] Deployment will take place at a 16 kW/m wave climate a few miles from the shore, but after 3-5 years the device will be moved to a more exposed climate approximately 10 miles from the shore

The test program will demonstrate the availability, power production predictability, power production capability and medium to long term target electricity generation costs at €0.052/kWh in a wave climate of 24kW/m (€0.04/kWh in a wave climate of 36kW/m), which could be found relatively close to the cost at the major part of the EU Atlantic cost.

Quantitative objectives

The improvement to be obtained during the project can be summarised as followed for a 4MW unit in a 24kW/m North Sea reference wave climate, where the base is the expected performance based on the present design again based on the expected performance of the Nissum Bredning prototype.

Improvement	**From**	**To**
Overall energy production	8.9 GWh/y	10.0 GWh/y (+12% of total)
Energy production based on improved control		+0.45 GWh/y (+5% of total)
Energy production based on new hydraulic PTO		+0.62 GWh/y (+7% of total)
Availability	NA	> 85%
Reduction in overall installed cost	2,540 €/kW	2,415 €/kW (-5%)
Reduction in hydro turbine cost	1,200 €/kW	900 €/kW (-25%)
Reduction in operational cost	0.04 €/kWh	0.03 €/kWh (-25%)

The actual target of a power production at the selected test site (16 kW/m) is expected to be 6.7 GWh (4MW) and 7.6 GWh (7 MW) and will be followed up by monthly reports based on the measured performance (best values found during the period) at different sea states. This actual performance will also be interpolated to 24 and 36kW/m reference wave climates.

Specific objectives

Minor design changes to the Wave Dragon energy absorbing structure will be developed primarily to improve the stability in roll and pitch. State of the art computer programs will be used in the optimisation process. Standard program packages can however not take the influence from the compressed air in the open bottomed buoyancy chambers into account. New computer codes will therefore be developed during the design process.

Comprehensive tests at Aalborg University have shown that an increase of the power absorption capability for an overtopping device of app. 20% is possible if more than one reservoir level is used. The project will develop a combined wave damper for the existing reservoir on top of which an additional reservoir is placed with a crest level between 1 – 2 meters above the existing ramp crest. Tests will be performed to establish the optimal crest level of this reservoir, and the possible gain in efficiency will be calculated based on measurements of the overtopping to the upper reservoir.

The full-scale low head turbine will be developed in line with the model size turbines used in the 20 kW prototype. The most significant change will be that the cylinder gate on the on/off turbine will retract to a stationary tower, whereas, in the present design, the whole tower or hood around the upper part of the turbine and the generator is lifted when the model turbine is started. This will lower the power consumption of the gate operation significantly (more than 50%).

The PLC programme and the programme imbedded in the AC/DC converters that controls the operation of the turbines, i.e. the number of active turbines and their speed, will be further refined to minimize spill from the reservoir and losses of head for the turbines due to unnecessary low water level and at the same time minimizing the number of on/off operations. The control system for the floating level of plant, i.e. the ramp crest height, will likewise be refined based on measurements of significant wave height and peak period. The system will also compensate for wind speed and direction in order to minimise the power consumption of the air compressors in the buoyancy system. Optimisation of the control systems will increase the power production significantly (more than 10%) and at the same time reduce operation & maintenance costs (25% reduction).

The target lifetime for the WD structure itself is 50 years, which advocates for thorough investigations of the benefit of using corrosion resistant reinforcement like coated steel, stainless steel or fibre reinforced composite bars in the most critical and exposed parts of the structure. The possibility of utilizing high strength concrete of the CRC-type in joints between pre-cast elements will also be investigated. Cost effective construction methods will be developed in the design process.

New design of the joint between main body and reflector arm:
A new joint, tested in 2005 in an already funded project (Danish PSO), with 3 degrees of freedom (all rotational) will therefore be developed to full-scale for the prototype. The new developed spherical joint will have water lubricated PTFE sliding bearings much like the types used for bridges. The new joint construction means, that the reflectors will be locked to the main body and thus their draught will vary like the main body. This will have the positive side effect of increasing the reflectors efficiency whenever the freeboard is below the highest level.

The redesigned joint will be equipped with a damping device in the form of hydraulic rams. The damping of the movements between the main body and the reflectors reduces the wear of the bearings. The hydraulic power in the rams will be utilized in hydraulic motors which drive generators – a system similar to the power take off in the 2 degree of freedom joints on the Pelamis wave energy converter. To avoid the risk of oil spillage water will be used as hydraulic fluid. The system will be of the same type as already in use at the 20 kW prototype where it operates the cylinder gates for the turbines.

Supplementary hydraulic power take-off in the mooring system:
Taking out power by means of hydraulic rams can lower the forces in the mooring lines.
A water hydraulic system similar to the system in the redesigned joint will be developed.

The combined effect of damping movements of the main body and the reflectors, and utilizing the power in the damping systems is expected to yield up to 30% additional power in certain sea states.

It should be noticed, that the redesigned joint and the new hydraulic power take off systems will be tested in model scale and at the 20 kW prototype with public Danish support (PSO-funding) prior to the development of the full scale prototype is initiated.

3. Participant list

Part. Role	Part. no.	Participant name	Partic. short name	Country	Date enter project**	Date exit project**
CO	1	Wave Dragon ApS	WD	Denmark	Month 1	Month 36
CR	2	NIRAS AS	NIR	Denmark	Month 1	Month 36
CR	3	Aalborg University	AAU	Denmark	Month 1	Month 36
CR	4	Kössler Ges.m.b.H	KOS	Austria	Month 1	Month 36
CR	5	Technical University Munich	TUM	Germany	Month 1	Month 36
CR	6	ESB International Ltd	ESBI	Ireland	Month 1	Month 36
CR	7	Balslev AS	BAL	Denmark	Month 1	Month 36
CR	8	Warsaw University of Technology	WUT	Poland	Month 1	Month 36
CR	9	University Wales Swansea	UWS	United Kingdom	Month 1	Month 36
CR	10	Dr. techn. Olav Olsen	OO	Norway	Month 1	Month 36
CR	11	Wave Dragon Wales Ltd	WDW	United Kingdom	Month 1	Month 36

CO = Coordinator   CR = Contractor

Web side:

www.wavedragon.net