Final report

1.1 Project details

Project title	XL-Blade
Project identification (program abbrev. and file)	64015-0086 EUDP 2015 I-II: ERA-NET Cofund DemoWind-1, XL Blade
Name of the programme which has funded the project	DemoWind
Project managing company/institution (name and address)	ADWEN Offshore, S.L. Avda Ciudad de le Innovacion 9-11, Sarriguren, SPAIN
Project partners	ADWEN Offshore S.L LM Wind Power A/S ORE Catapult Development Services Limited
CVR (central business register)	76490511
Date for submission	1/7-2019

1.2 Short description of project objective and results

[English]
Achieving the ambitious EU target of 27% renewable penetration by 2030 requires step-change technological innovations across all sectors of renewables, paving the way for industrialization and scale. Within this context, offshore wind has proven its viability as a mature utility-scale contributor to the EU energy mix, with substantial cost reductions achieved over the past decade, and a similar trajectory as onshore wind towards grid parity. Within an offshore wind turbine system, the rotor set is one of the most influential ways to reduce total cost of energy.

The overarching program objective of the consortium is to reduce the overall offshore wind cost of energy by merging the technological leadership of three offshore industry leaders across three participating countries to design, validate and deploy the world's largest offshore wind turbine blade.

Specific technological objectives are design, manufacturing and in-field validation of blade approaching 90m in length with aggressive weight targets:

- Definition of the optimum fiber, resin and laminating process with respect to structural properties, weight and cost.
- Tackling industry-plaguing issue of blade erosion through development of new coating and application systems.
- Characterization of offshore atmospheric conditions affecting blade erosion, to enable the development of new coatings.
- Defining real-scale laboratory tests that reproduce relevant environmental conditions over the operating lifetime of the blade.
- Demonstration of the blade technology readiness at the test bench level.
- Demonstration of project results via field validation in a full-scale offshore wind turbine prototype.

[Dansk] (review)
At nå det ambitiøse EU-mål om 27% vedvarende energi penetration inden 2030 kræver trinvise teknologiske nyskabelser på tværs af alle sektorer af vedvarende energi, hvilket baner vejen for industrialisering og opskallering. Inden for denne sammenhæng har havvinden vist sit potentiale som en moden energikilde som bidrag til EU's energimix med betydelige omkostningsreduktioner opnået i løbet af det sidste årti med en lignende tendens mod LCoE som landvind har gjort. Ser man på offshore vindmøller så er rotorsættet en af de områder der kan reducere de samlede energikostninger mest effektivt.

Konsortiets overordnede programmål er at reducere den samlede offshore-vind CoE ved at kombinere teknologiske lederskab fra tre af offshore-branchens ledere fra tre lande til at designe, validere og bygge verdens største offshore-vind turbine vinge.

Specifikke teknologiske målsætninger er design, fremstilling og validering af vinger der nærmer sig 90m i længden med aggressivt reduceret vægtmål:

- Definering af den optimale fiber-, resin- og lamineringsproces med focus på strukturelle egenskaber, vægt og omkostninger.
- Addressering af et i vindindustrien vedkendt spørgsmål om forkantserosion ved at udvikle nye coating og applikationssystemer.
- Karakterisering af offshore atmosfæriske forhold, der påvirker forkantserosion, for at muliggøre udvikling af nye beskyttelsessystemer.
- Definere laboratorieforsøg i skala, der representere relevante miljøforhold i løbet af bladets levetid.
- Demonstration af vingeteknologibesparelsen i test regi.
- Demonstration af projektresultater via feltvalidering i en fuldskala offshore vindturbine prototype.

1.3 Executive summary

LM has advanced carbon-glass mix, infusion resin and blade leading edge erosion technology from TRL 5 to TRL 7 by manufacturing an ultra-long wind turbine blade with the above technologies and optimized laminating processes and demonstrated the result in field validation in a full-scale offshore wind turbine prototype.

1.4 Project objectives

LM’s blade design will include a cost-efficient use of a mix of glass and carbon fibre fabrics resulting in significant blade weight reduction compared to state-of-the art glass fiber blade designs. LM will apply a Design-for-Manufacturing rationale suitable for production of large wind turbine blades in small series at competitive costs, while maintaining high quality and performance standards. A novel leading-edge protection system will be developed especially designed for the harsh offshore environment resulting in a tenfold improvement of protection against leading edge erosion compared to standard protective tapes.

Disadvantages:
The XL-Blade with a length approaching 90 m is significantly larger than the largest blade designed, manufactured and tested by the consortium’s partners. The mere size of the blade will provide result in new challenges in manufacturing and testing. Manufacturing process will have to be adjusted beyond known capabilities.
Further manufacturing and testing equipment will have to be re-designed to accommodate the ultra-long XL-Blade.

Technology Readiness Level (TRL). The XL-BLADE Project has advanced the proposed technologies from Technology Readiness Levels 5 to Technology

Readiness Levels 7.
o **TRL5:** Component and/or breadboard validation in a relevant environment.
• LM has already tested at coupon level the integration of carbon material with vinyl-ester resin and the compatibility with standard polyester
resin for the glass-fibre components. The new approach for the process handling and process-flow-chart distribution has also been tested and are at TRL 5.
o **TRL7:** system prototype demonstrated in an operational environment.
• The XL-Blades will be demonstrated in a full scale 8MW wind turbine from ADWEN.
• The testing procedures for large offshore blades (single axial and bi-axial fatigue testing) will be demonstrated by means of a real scale test on
LM's XL-blade

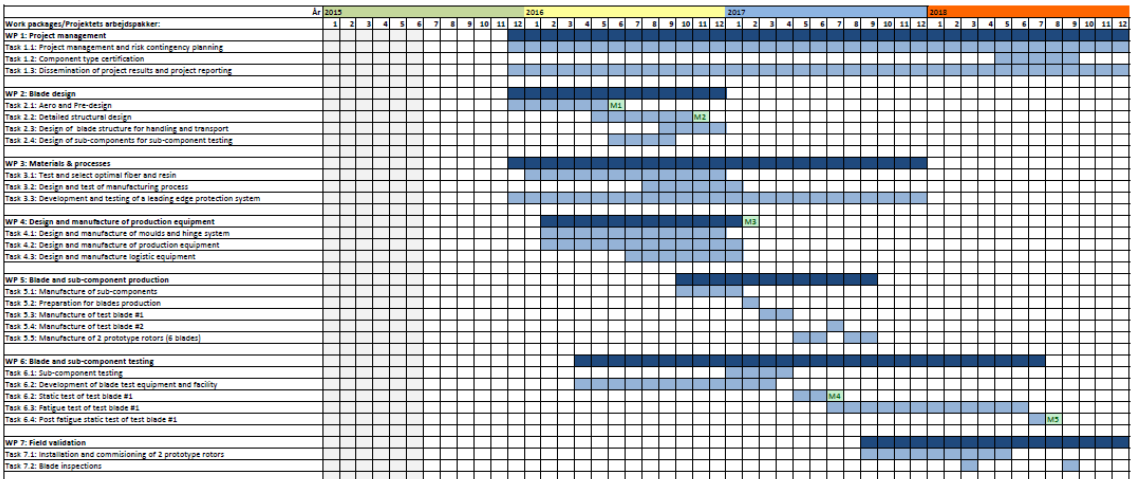
The **LM-XL-Blade** will be built with the newly developed hybrid carbon/glass fibre technology, which will lead blade weight of 32-35 tonnes and to a cost below a full carbon fibre technology. The main challenges to be solved:

- The optimal carbon/glass fibre blend
- The processability of the hybrid fabric and different resin systems.
- Design of the trailing edge geometry and the lay-up.
- Lightning protection of the hybrid carbon/glass main laminate structure.

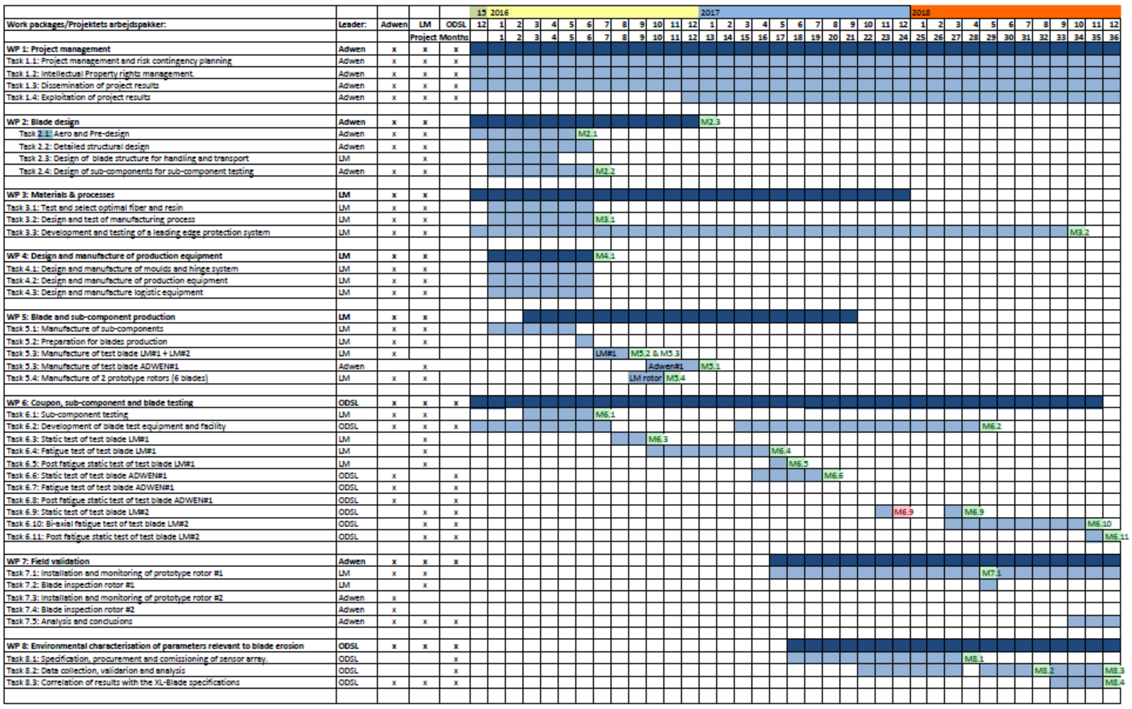
The mere size of the XL-Blade will provide challenges in manufacturing and testing. Manufacturing process will have to be adjusted beyond known capabilities.
Further manufacturing and testing equipment will have to be re-designed to accommodate the ultra-long XL-Blade. The detailed structural design will be performed following a Design-for-Manufacturing concept, which is the basis of standard LM designs. Sub-components with the specific structural details will be designed, manufactured and tested in order to find an optimal solution on a sub-scale level. Some of the manufacturing processes will be tested in real size test trails in order to secure performance.

A novel **leading-edge protection system** with superior lifetime performance compared to standard protective will be developed. The performance of the developed
protection system will be validated accelerated in a rain erosion tester simulating the harsh offshore environmental conditions. Further the final leading edge protection system will be tested in-field in a real offshore environment. The key challenge when **specifying the blade erosion** test is to determine the relevant testing
conditions representative of erosion in offshore environment. There is a lack of information on relevant parameters namely the droplet size distribution in relevant offshore wind environment, so test conditions specified in the erosion rig tests are largely speculative.

The initial project plan was updated in month 18 (see Figur 1and Figur 2) to reflect the actual task execution. The majority of the blade development tasks has been accelerated to secure blade readiness in due time for blade testing and prototype manufacturing.



Figur 1: Initial project plan



Figur 2: month 18 updated project plan

1.5 Project results and dissemination of results

Deliverable number	Deliverable name	Work package number	Lead Partner	Estimated delivery date	Means of verification (evidence of deliverable)	Completed (yes/no – new expected delivery date)
D3.1	Materials for the XL-BLADES.	WP3	LM	Month 25	Report	Yes
D3.2	Manufacturing process.	WP3	LM	Month 25	Report	Yes
D3.3	Leading edge protection system.	WP3	LM	Month 25	Report	Yes
D4.1	Moulds and hinge system.	WP4	LM	Month 15	Equipment (Mould with hinge system at manufacturing facilities)	Yes
D4.2	Production equipment	WP4	LM	Month 15	Equipment (Additional production equipment at manufacturing facilities)	Yes
D4.3	Logistic equipment.	WP4	LM	Month 15	Equipment (Logistic equipment at manufacturing facilities)	Yes
D5.2	Test Blade LM#1	WP5	LM	Month 17	Prototype: First test blade LM#1 delivered for bench testing	Yes
D5.3	Test Blade LM#2	WP5	LM	Month 20	Prototype: Second test blade LM#2 delivered for bench testing	Yes
D5.4	First prototype rotor.	WP5	LM	Month 19	Prototype: First prototype rotor delivered for field test.	Yes
D6.2	Commissioning report for new testing equipment.	WP6	LM	Month 17	Report	No new test equipment acquired
D6.3	Test specification & test report for LM#1 blade static test.	WP6	LM	Month 25	Report	Yes
D6.4	Test specification & test report for LM#1 blade fatigue test.	WP6	LM	Month 31	Report	Yes
D6.5	Test specification & test report for LM#1 blade postfatigue test.	WP6	LM	Month 32	Report	Yes
D7.1	Inspection of Rotor#1.	WP7	LM	Month 28	Report	Not avalible

1.6 Utilization of project results

Link to LM 88.4P press release:
http://cws.huginonline.com/L/160830/PR/201606/2021942_5.html

Link to LM Wind Power – LM 88.4P promotion web page
https://www.lmwindpower.com/en/products-and-services/blade-types/longest-blade-in-the-world

Flyer from ORE Catapult – Bi-axial test capability and cooperation with LM Wind Power on test of LM 88.4P

BI-AXIAL BLADE
FATIGUE TESTING

CATAPULT
Offshore Renewable Energy

CASE STUDY

BLADE TESTING THAT IS MORE REPRESENTATIVE OF REAL-WORLD OPERATING CONDITIONS, REDUCING OVERALL TEST DURATION AND COST

ORE Catapult's blade experts are developing a bi-axial testing method to address the challenge of reducing the duration and costs of blade testing, also making it more representative of real-world operating conditions. This joint industry and academic collaborative aims to reduce the overall test program duration by up to 25% and fatigue test duration by almost 50%.

ORE Catapult's bi-axial testing method involves understanding the theoretical fatigue damage of a blade during its service life. This is done using fatigue analysis software, developed by ORE Catapult and certified by DNV-GL, ensuring that the physical test loads replicate the service life damage over as much of a blade as possible. With data from the analysis, a bi-axial test can be designed and undertaken, exciting the blade in the flapwise and edgewise directions simultaneously to more accurately represent the fatigue that a blade in the field would experience over its lifetime.

Bi-axial moves away from conventional methods of testing, and can also be presented to a certification body. Having attracted significant interest from industry, the bi-axial testing programme is now set to be upscaled to become part of the XL-BLADE DemoWind project, alongside project partners ADWEN and LM Wind Power, validating one of the world's longest offshore wind blades at 88m.

"The collaboration with a world-class research and test institution such as ORE Catapult cements our position as an offshore industry leader and enforces our commitment to innovation"
Alexis Crama, VP Offshore, LM Wind Power

25%
Reducing overall test times by up to 25% ensures more cost effective testing, reducing the levelised cost of energy.

Bi-axial fatigue testing can be designed to represent the damage that the blade is predicted to see in service.

1/2
Bi-axial testing reduces fatigue test duration by almost 50%, increasing speed to market for OEM client blades.

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1.7 Project conclusion and perspective

During the project it was shown that a +88 meter wind turbine blade can be manufactured and by combining innovative materials and methods two of the industry hurdles has been addressed.

- ☐ Reducing leading edge erosion by developing a protection system including application process
- ☐ Keeping blade weight at an acceptable level in this case within range of 32-35 ton by introducing new material technology with optimized blend of carbon and glass fibre along with a new resin system

During the project a new manufacturing setup was developed to enable the production of the blades. A prototype rotor set was manufactured by LM Wind Power and installed on prototype turbine by ADWIN.
Two LM88.4P test blades were manufactured and tested according to IEC-61400-23 to obtain component certificate.
Finally, one LM88.4P test blade was delivered to OREC, UK and fatigue tested in a bi-axial test setup as part of development of a setup and evaluation SW tool.