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MARE-WINT:
New Materials & Reliability in Offshore Wind Turbines Technology

Improving the Reliability and Optimising O&M Strategies for Offshore Wind Turbines

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ABSTRACT

The aim of the European Commission funded MARE-WINT project is to 'reduce cost of energy, by improving reliability of [offshore] wind turbines (OWTs) and their components, and optimizing operation and maintenance (O&M) strategies' [1]. The project is divided into seven work packages (WPs), and between 15 Early Stage Researchers (ESRs), spread across 17 institutes [2]. This paper describes some of the current work being undertaken by a selection of ESR's in MARE-WINT.

1. Introduction

Improving the reliability of offshore wind turbines is currently an area of great research interest. Organizations such as the European Commission are funding various projects and researchers in the domain; MARE-WINT is one such project. The aim of MARE-WINT as mentioned above is essentially, to improve the reliability, and optimize the operation and maintenance of offshore wind turbines. In order to fulfill this aim, the research is carried out in the context of a reference wind turbine. The reference wind turbine under research in MARE-WINT is *the DTU (Technical University of Denmark) 10 MW Reference Wind Turbine (RWT)*.

Description	Value
Rating	10 MW
Rotor orientation, configuration	Upwind, 3 blades
Control	Variable Speed, Collective Pitch
Drivetrain	Medium Speed, Multiple Stage Gearbox
Rotor, Hub Diameter	178.3m, 5.6m
Hub Height	119m
Cut-in, Rated, Cut-out Wind Speed	4m/s, 11.4m/s, 25m/s
Cut-in, Rated Rotor Speed	6RPM, 9.6RPM
Rated Tip Speed	90m/s
Overhang, Shaft Tilt, Pre-Cone	7.07m, 5°, 2.5°
Pre-bend	3m
Rotor Mass	229 tons (Each Blade ~ 41 tons)
Nacelle Mass	446 tons
Tower Mass	605 tons

Table 1 – Specifications of the DTU 10 MW Reference Wind Turbine. Source [3]

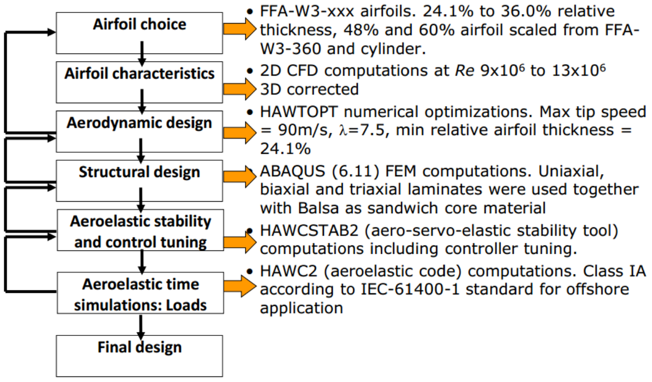


Fig.1: Method followed by DTU for designing the Reference Wind Turbine. Source: [4]

In MARE-WINT, the tasks of further optimizing various components of the wind turbine system are distributed between various researchers, with each researcher working in a specific Work Package (WP). The project's six work packages are structured as shown in the following figure. Since all the researchers are working on optimizing the same reference wind turbine, collaboration and cooperation between is an important core aspect of MARE-WINT.

As this conference paper has been prepared for an entire project, rather than an individual researcher, the structure of the paper is unorthodox. Instead of typical sections such as Introduction, Discussion, and Conclusion, the paper is divided into sections that detail the work under progress in each of the various project Work Packages 1 to 5.

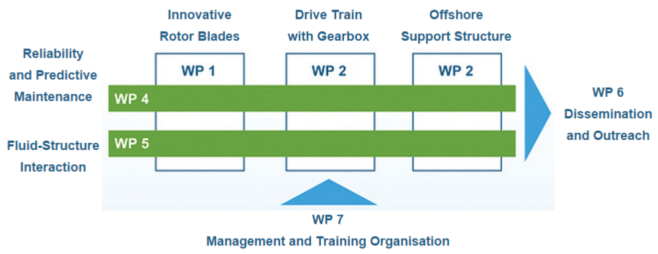


Fig.2 – The 'Structure' of the Work Packages in MARE-WINT. Source: [5]

2. WP 1 – Innovative Rotor Blades (ESR 1 & 2)

ESR 1's task includes *modelling of manufacturing defects in OWT blades*; the aim of ESR 1 is to develop the damage tolerance approach in wind turbine blade sub-structures, focusing on the crack growth mechanisms and detection methods. The trailing edge of the blade can develop damage in the composite material and adhesive interface. The delamination is accompanied by the formation of a crack bridging zone, where intact fibers connect the crack faces behind the tip thus increasing the energy required for crack propagation (Damage tolerance mechanism) [6]. A finite element model of the crack growth mechanisms in a double cantilever beam (DCB), representative of the trailing edge, was developed where different fracture modes were addressed. Experimental tests were conducted in order to fully characterize this structure and support the model. Then a crack monitoring technique was implemented using Fiber Bragg Grating (FBG) sensors in order to track the crack tip and its' propagation. This sensor approach was incorporated with the finite element model in order to predict the sensor output and extrapolate to a real trailing edge case. Experiments were conducted on DCB specimen crack growth with FBG monitoring under several fracture modes.

The focus of ESR 2 is on *CFD investigations of near-blade 3D flow for a complete OWT configuration*. The current work of ESR 2 is not covered further in this conference paper.

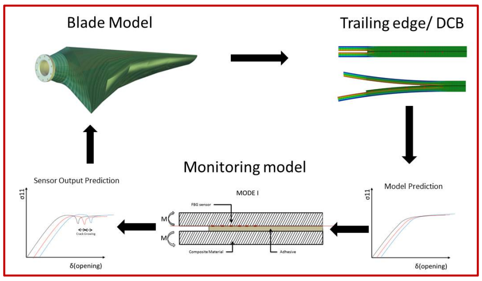


Fig. 3: Investigating the presence of damage in blades, understanding damage propagation mechanism & providing solutions for more reliable structure design using new materials, processes, and sensorisation. ESR 1

3. WP 2 – Drive Train & Gearbox (ESR 3 & 4)

The gearbox is one of the key subsystems in a geared wind turbine providing the task to transfer power from the low speed shaft connected to the rotor to the high speed shaft connected to the genera3or. As turbines become larger, more power is demanded and gearboxes with higher load capacity need to be designed. A deep knowledge into gearbox dynamics becomes of fundamental importance and noise and vibration measurements are demanded.

ESR 3's task involves *simulation & experimental validation of drive train loads for offshore specific conditions*. Like ESR 2, further details of this task are not covered in this paper.

The task of ESR 4 primarily involves the *derivation of a strategy for model updating based on experimental data from drive train test facility*. Since several components properties depend on the applied torque and on the rotational shaft speed, a validation in operational conditions needs to be performed. Building on existing techniques such as "Order Tracking" and "Operational Modal Analysis", a dedicated methodology is going to be developed, by ESR 4, for the analysis of operational gearbox dynamic behavior. Particular attention will be reserved to the separation between structural resonances and excitation orders.

Operational Modal Analysis (OMA) is used by ESR 4 to derive an experimental dynamics model from vibration measurements in operational conditions. It cannot be applied in a straightforward way due to the self-induced vibrations at several rpm-dependent frequencies (gear meshing orders). These frequencies can be wrongly considered resonance frequencies of the system. In order to face these problems, an extensive measurement campaign has been performed at ZF Wind Power on a 13.2MW test rig facility [1] (Fig.1). Accelerations have been measured at more than 250 locations on the test rig and for different load levels and operating conditions. For stationary conditions (at constant rpm) the gear meshing orders will give component discrete constant frequencies that need to be filtered out from the signal in order to determine the resonances. Run-up tests can be considered as a multi-sine sweep excitation and the resonances can be identified combining advanced order tracking methods with operational modal analysis by using a dedicated methodology, named Order-Based Modal Analysis (OBMA). The developed algorithms will be evaluated by means of flexible multi-body simulation models and real experimental data.

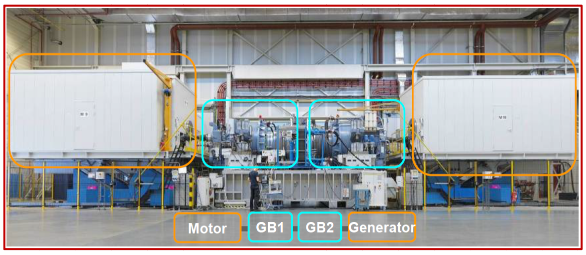


Fig. 4: Building further on existing Order Tracking & Operational Modal Analysis techniques, to develop a new method, and validate it by means of numerical models (flexible MBS model) & experimental data (test rig measurement). ESR 4

4. WP 3 – Offshore Support Structure Analysis (ESR 5 & 6)

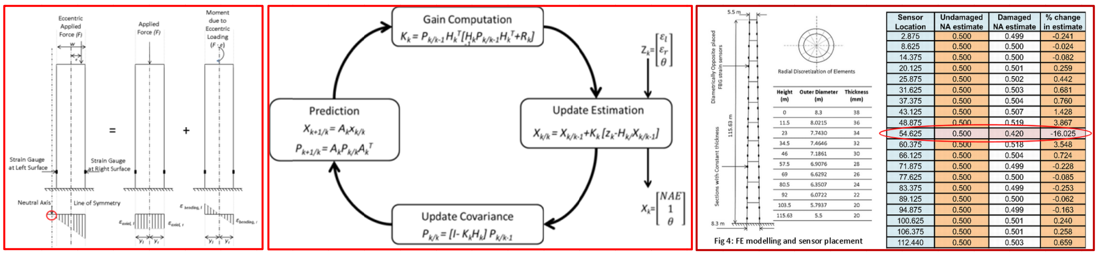
The task of ESR 5 is to develop dynamic modelling and analysis of a floating wind turbine concept, and to compare the results with laboratory test data or field measurements. ESR 6 by contrast, will focus on bottom fixed substructure analysis, model testing and design for harsh environment. A detailed description of the work carried out by ESR 5 & 6 is omitted from this paper.

5. WP 4 – Reliability & Predictive Maintenance (ESR 7, 8, 9, 10, 11a & 11b)

ESR 7 aims to address OWT condition monitoring based on acoustic emission and long range ultrasonic. ESR 8's research focuses on damage detection in metallic & composite structures through the use of Kalman Filter based Neutral Axis tracking. ESR 8's task tries to setup a damage detection strategy at the system level and hence encompasses the selection of the damage detection feature, optimisation of sensor placement to get optimal information using minima resources, signal processing and the damage detection.

Due to the different nature of the materials used in the structures two different damage detection strategies are proposed for the damage detection. The damage detection in towers is carried out using the change in neutral axis (NA) position as the damage sensitive feature while in blades the use of elastic waves is being investigated. The NA of a beam like structure is the property of the cross section of the structure and its condition, and hence is independent of the loading conditions thus through the use of strain sensors we can track the location of the NA accurately and any change in the location of the NA will be an indication of damage. In order to account for the change in the mass orientation of the wind turbine due to the yawing of the nacelle a data fusion strategy using extended Kalman filter (EKF) was proposed in [7]. The EKF yields robustness to the NA tracking even in the presence of measurement noise and temperature changes [8].

ESR 8's methodology was applied on a FE model of the 10MW DTU reference wind turbine and yields reasonably accurate damage detection. The use of EKF uses the strain measurements and yaw angle measurements as the input and yields the NAE location as an estimate. The use of EKF improves the prediction of the NA and as such gives robustness performance of the damage detection strategy in noisy environments and allows us to fuse data. The future plan is to incorporate the rotation of the wind turbine in the data fusion strategy to allow online damage detection in actual working conditions. The damage detection strategies for blades are slightly complicated due to the composite materials and the complex geometry. Furthermore embedding the sensors inside the blade is a problem, thus the use of IR thermography and using remote sensing is being investigated. The entire study undertaken in the task will focus on structural health monitoring for online damage detection. The proposed methodology will be validated on experimentally available data and FE models of the structure available.



Height (m)	Outer Diameter (m)	Thickness (mm)
0	8.3	38
11.5	8.0215	36
23	7.7430	34
34.5	7.4646	32
46	7.1861	30
57.5	6.9076	28
69	6.6292	26
80.5	6.3507	24
92	6.0722	22
103.5	5.7937	20
115.63	5.5	20

Sensor Location	Undamaged NA estimate	Damaged NA estimate	% change in estimate
2.875	0.500	0.499	-0.241
8.625	0.500	0.500	-0.024
14.375	0.500	0.500	-0.082
20.125	0.500	0.501	0.259
25.875	0.500	0.502	0.442
31.625	0.500	0.503	0.681
37.375	0.500	0.504	0.760
43.125	0.500	0.507	1.428
48.875	0.500	0.519	3.867
54.625	0.500	0.420	-16.025
60.375	0.500	0.518	3.548
66.125	0.500	0.504	0.724
71.875	0.500	0.499	-0.228
77.625	0.500	0.500	-0.085
83.375	0.500	0.499	-0.253
89.125	0.500	0.500	-0.062
94.875	0.500	0.499	-0.163
100.625	0.500	0.501	0.240
106.375	0.500	0.501	0.258
112.440	0.500	0.503	0.659

Fig. 5 (L to R): Flexural Strain Distribution over the beam cross-section subject to eccentric loading; Flow Chart for the implementation of KF; Numerical Model of the Tower. Initial investigations have shown promise in the technique to detect damage, & the metric is sensitive to even small extents of damage and shows robustness to presence of measurement noise. ESR 8.

ESR 9, through his research, aims to reduce wake effect fatigue loads using Large Eddy Simulations (LES). ESR 10's research has a focus on navigational risk assessment of vessels operating near OWTs, Lastly, ESRs 11a and 11b are carrying out research on overall OWT reliability modelling analysis. The work of these researchers is not covered in any further detail in this paper.

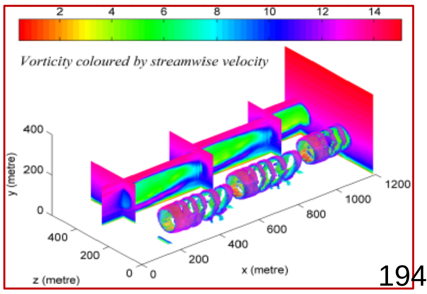


Fig 6: Using Large Eddy Simulation with Energy-Conserving Schemes to study wind farm wake aerodynamics towards predicting loading & fatigue on offshore wind farms. ESR 9

6. WP 5 – Fluid Structure Interaction (ESR 12, 13 & 14)

ESR 12's task involves RANS simulation for hydro-elastic floating substructure prediction. Horcas, et al. [9], summarize ESR 12's work as *'a new development aiming to deform multi-block structured viscous meshes during fluid solid interaction simulations. The focus will be put on the deformation of external aerodynamic configurations accounting for large structural displacements and 3D multimillion cells meshes. In order to preserve the quality of the resulting mesh, it was understood as a fictitious continuum during the deformation process. Linear elasticity equations were solved with a multi-grid and parallelized solver, assuming a heterogeneous distribution of fictitious material Young modulus. In order to improve the efficiency of the system resolution an approximate initial solution was obtained prior to the elastic deformation, based on Radial Basis Functions and Transfinite interpolators. To validate the performances of the whole algorithm, the DTU 10MW reference offshore wind turbine described by [10] is analyzed'.*

ESR 13's research focuses on analysis of a twist-coupled aero-elastic design for passive loads reduction on a full scale blade. Further details are not provided in the current paper.

ESR 14 is carrying out investigations into active flow control to improve aerodynamic performance using blade modelling & high quality grid generation. ESR 14 looks forward to achieve an aerodynamic performance improvement of wind turbine blades by decreasing the flow separation and associated noise in real time. This goal will be reached through the implementation into the 10 MW MARE-WINT wind turbine reference of a new rod vortex generator technology that in its MEMS configuration allows an active control. Due to the lack of experimental data for the reference turbine, the 2 bladed 10 m rotor diameter NREL UAE Phase VI wind turbine was selected for validation purposes. A considerable effort was put into the geometry modelling and grid generation for obtaining the high quality structured mesh adequate for the flow study. The upwind and downwind boundaries were located three blade radius away from the rotational plane. The farfield was situated at the same distance from the rotational axis.

In Fig. 7 below, the definition of the domain boundaries for the simulation can be found. At the inlet the static temperature and velocity were specified, meanwhile the static pressure was imposed at the outlet. The blade was defined as Navier-Stokes adiabatic wall.

The RANS simulations were done employing both, Spalart-Allmaras and SST k-w models. Good agreement was found between experimental and numerical data. In the figure 2 the Cp distribution along the chord for a couple of sections for a 7 m/s inflow speed are shown as example. Once validated through the numerical methods, the vortex generators will be implemented in the NREL blade and their aerodynamic and aeroacoustic effects studied.

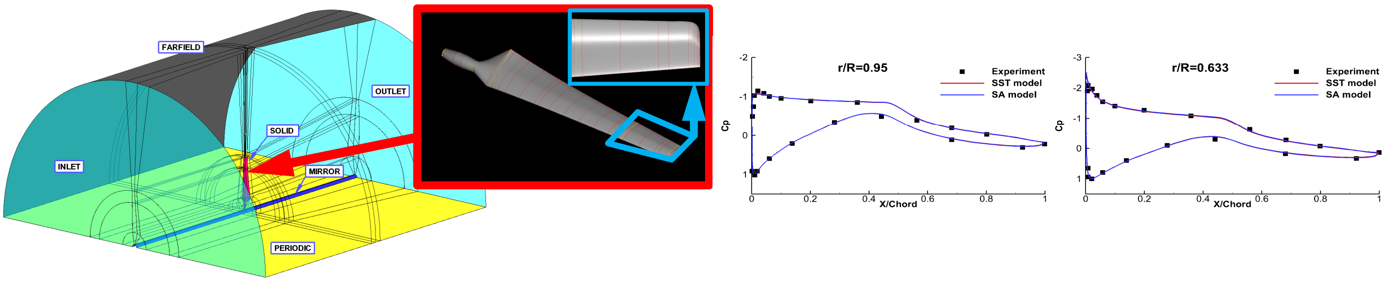


Fig. 7 (L to R): Grid domain; blade geometry with tip detail; Cp distributions along the cross sections 95% & 63% for 7 m/s. ESR 14

7. Conclusions

The work and research in MARE-WINT is on-going, with project deliverables due in September 2015 . This paper has presented the results of only a selection of the researchers and research activities. Even the limited results shown in the paper, however, indicate a promising level and quality of knowledge and information. There is utmost confidence that the current and future results from MARE-WINT will be used to improve the reliability of offshore wind turbines, and optimize the operations of the system as a whole.

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