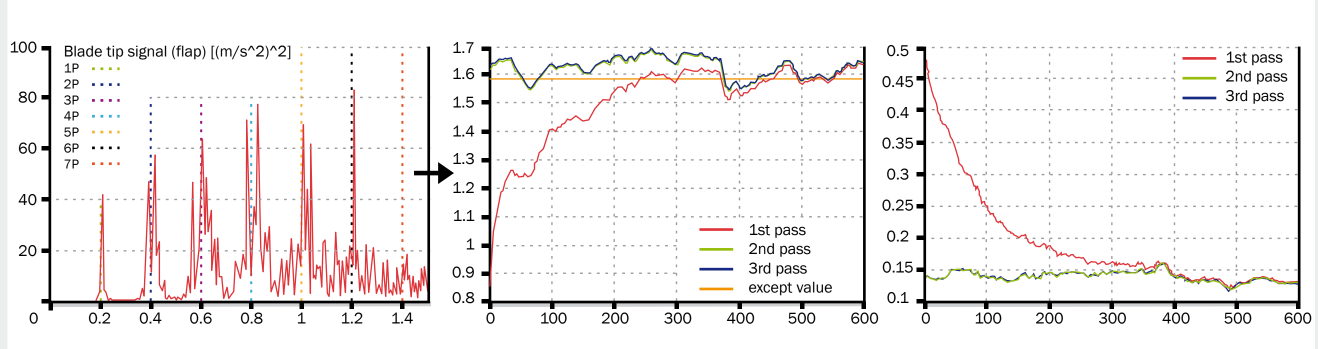

Figure 7: Performance of a Kalman Filter for identification of wind turbine blade structural oscillation parameters stiffness and damping.

reliability and remaining life time curves of wind turbines and their major components. With a growing number of fault statistic data sets, the results of the PLP can be used to estimate the remaining life time of a component. This will allow the improvement of offshore wind turbine O&M strategies, e. g. the performance of the condition based maintenance approach.

RESULTS AND EXPECTATIONS

Some practical results of the work done so far include:

- A state of the art report about condition monitoring for wind turbines. This report describes the required measurements and the related sensor technology to perform condition monitoring and fault prediction tasks. The basic data evaluation and fault prediction algorithms are presented. A description of the basic condition monitoring functionalities and the integration of these items into international standards complete the report. The report is available on the UpWind project web site;
- In close co-operation with the WP3, first laboratory tests have been started. Within these tests, the stress and fatigue behaviour of the GRP material itself and of the applied FBG sensors is being determined simultaneously. Another laboratory test has been carried out to demonstrate the principle functionality of the FBG sensors to be installed in the N-80 test turbine;
- First investigations of the “Flight Leader Turbine” concept have been applied to a simulated 5 x 5 wind turbines offshore wind farm. The fatigue damage has been estimated for the individual turbines;
- With the fault statistic data bases identified so far, first evaluations have been performed. These evaluations should deliver a ranking for wind turbine components according to their fault and reliability relevance. Furthermore, the interdependence of the wind turbine concept and its reliability has been analysed;

All in all the R&D activities of WP Condition Monitoring will lead to an O&M cost optimisation concept for the next generation of offshore wind turbines with power outputs of up to 20 MW. The results will be fed into the integration work of other WP’s. Basic scientific and technical results will be made available in international publications and conference presentations as well as education material for WP Education and Training. Technical knowledge will be communicated to relevant international standardisation working groups.

UpWind

SIXTH FRAMEWORK PROGRAMME

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- Smart Fibres Limited (SmartFibres)

www.upwind.eu

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Condition Monitoring

THE CHALLENGE

The main challenge of the work package (WP) Condition Monitoring is supporting the incorporation of new condition monitoring, fault prediction and operation & maintenance approaches into the next generation of wind turbines for offshore wind farms, leading to improving the cost effectiveness and availability of offshore wind farms.

THE RESEARCH ACTIVITIES

The WP is divided into four subtasks:

OPTIMISED CONDITION MONITORING SYSTEMS FOR USE IN WIND TURBINES OF THE NEXT GENERATION

With increasing size and innovative features of the next wind turbine generation, new approaches for measurement equipment as well as for signal acquisition and evaluation is required to perform condition monitoring and fault prediction. This subtask investigates the required improvements and new developments of the condition monitoring systems (hardware and software) for wind turbines.

‘FLIGHT LEADER’ TURBINES FOR WIND FARMS

The planning of operation and maintenance (O&M) measures and the estimation of its cost requires extensive knowledge about the load applied to an individual turbine in a wind farm during its life time. Instrumentation of all the turbines in a wind farm is too costly. Therefore, the idea is to equip selected turbines, the so called “flight leader turbines”, at representative positions in the wind farm with the required load measurement sensors. Flight leader (a term used in aircraft technology) turbines are subject to higher, or at least similar, loads as other turbines in a wind farm. The probability that failures occur first to the flight leader turbines is higher than the other way around. This provides an opportunity to take measures to avoid similar damage to the whole population of wind turbines. Other applications of the Flight leader concept include rational O&M planning. From the measurements at the flight leader turbines, the load for all turbines in the wind farm will be estimated. With these data, a comprehensive O&M scheduling and cost estimation at reasonable cost for sensor and data acquisition is possible.

FAULT STATISTICS

Fault statistics will be used as a starting point for investigations in new diagnostic methods, materials and wind turbine models. They are essential to identify weak points in the design of wind turbines and their components and to establish new O&M strategies, for instance condition based maintenance. Within this subtask, available fault statistic data bases will be analysed. Based on this, improvements and extensions of the data bases will be discussed and possibilities for combination and consolidation of the different data sets will be assessed.

STANDARDISATION

During the last years, several national, European and international standards have been established or are currently under development. Within this task, the implementation of the standards will be observed and the results of the WP will be included as far as possible into the standards by participation of WP7 members in the respective standardisation working groups.

RESEARCH STRATEGIES

The major route for research in WP7 is to combine theoretical investigations, like physical modelling, combined with laboratory and field measurements for verification and testing. The details will be described below.

MODELLING

Mathematical models of sensor behaviour due to bending forces at the roots of the blades will be implemented. The models will be used to estimate the sensor's dynamic response and the expected range of the output signals. Furthermore, approaches for the system identification using the blade's oscillations in the flap wise plane will be investigated by use of numerical models. The derived parameters will be used to retrieve information about the structural health of the blade. In an iterative process, the models will be verified and optimised with the measurements from both laboratory and field tests.

A different modeling approach is used for the flight leader concept. In a first step, the concept will be evaluated by wind farm model calculations, including wake effects and loads to translate measured data of a reference unit into data representing the degree of degradation of other turbines in the wind farm. Based on the simulation results, a model for the estimation of O&M costs in offshore wind turbines will be designed.

LABORATORY AND FIELD TESTS

As mentioned above, the laboratory and field test results will be used to refine the physical and mathematical models. The following hardware installation and testing is planned:

1. Material testing of fibre optic strain sensor: In co-operation with WP3 on Rotor Structures and Materials, Fibre Bragg Grating (FBG) fibre optic sensors, which use the "Bragg Grating Principle" to generate strain measurement signals, are tested. For this, samples (coupons) of GRP blade material will be stressed over longer periods with high numbers of load cycles. The test stress will represent a real blade's load exposure over the designed life time. Two types of sensors are tested: FGB patches, which will have a carrier material for the fibres. The carrier will be glued to the surface of the coupon. Second type under test is the inline sensor, where the optical fibre is directly incorporated in the matrix of the GRP coupon during manufacturing.

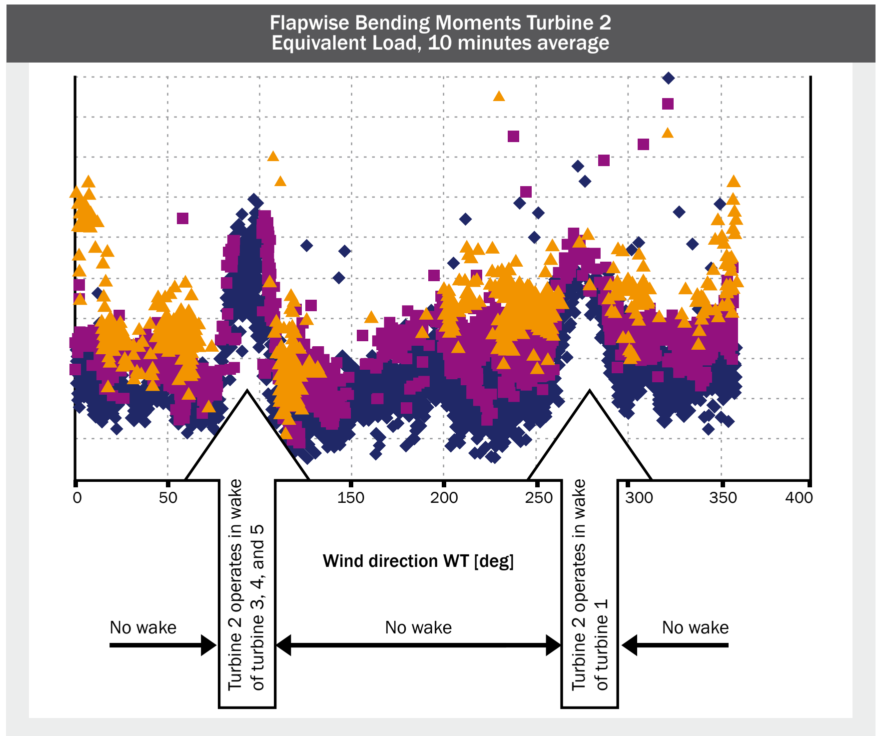

Figure 1: Wake analysis by measured data of the flapwise bending moments for the wind turbine 2 in ECN's test field in Wieringermeer, NL.

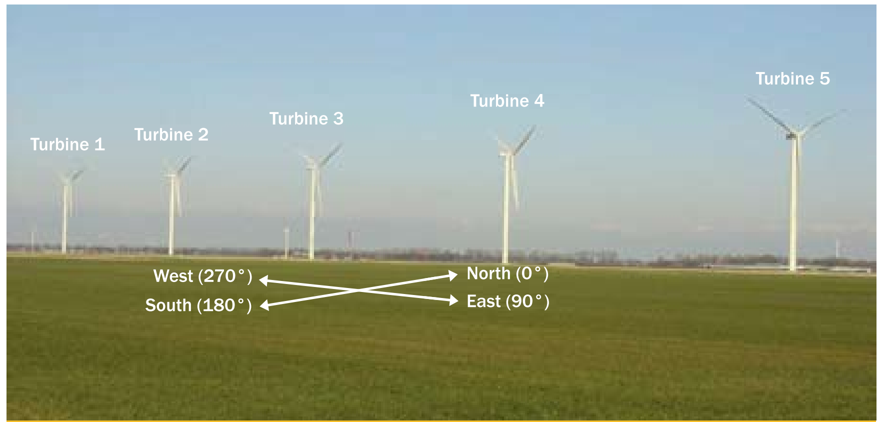

Figure 2: Configuration of ECN's wind turbine test field in Wieringermeer, NL.

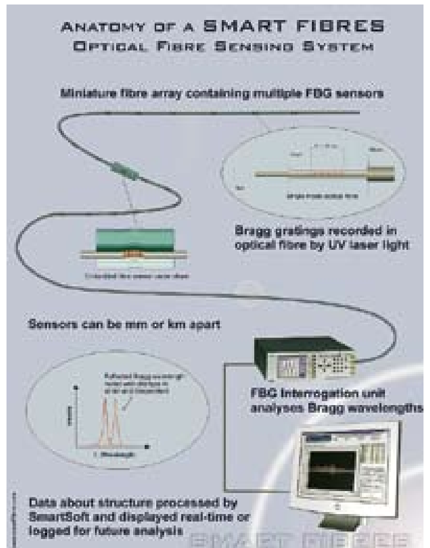

Figure 3: Fibre Brag Grating (FBG) optical strain measurement system.

2. Installation of FBG strain sensors in the blades of an N-80 wind turbine: To test the performance of the sensors in the real world, a set of 12 FBG patches will be retrofitted into the blades of a Nordex N-80 machine in the wind turbine test field of partner ECN in Wieringermeer, NL. The patches will be glued to the surface of the inner blade walls to measure the flap wise and edge wise blade bending. Two sensors on opposite positions will be installed for one measurement direction. A so called interrogation unit will be installed in the hub of the N-80. This unit acquires sequentially the strain measurement signal from the FBG sensors. It has four channels, whereas each channel will be attached to the sensors in one blade.

3. Installation of accelerometers in one blade: The remaining input channel of the interrogation unit will be connected to FBG accelerometers, which will be installed in one blade. These sensors measure the oscillation of the blade in the flap wise plane at four positions. Each two pair of sensors will be attached to the inner web structure of the blade near to leading and trailing edge in a distance of about 8 m and 16 m respectively from the rotor axis. The acceleration signals will be used as input for the parameter identification algorithms mentioned above.

4. Installation of accelerometers in the nacelle and strain sensors in the tower base: To analyse the structural oscillation behaviour of the tower of the N-80, two additional accelerometers will be installed to detect the nacelle's oscillation in axial and transverse direction (related to the rotor axis). Additionally, FBG strain measurement sensors will be installed in the tower base. These sensors will measure tower torsion and the tower bending in two axes. To acquire the data, a second interrogation unit will be installed in the tower base.

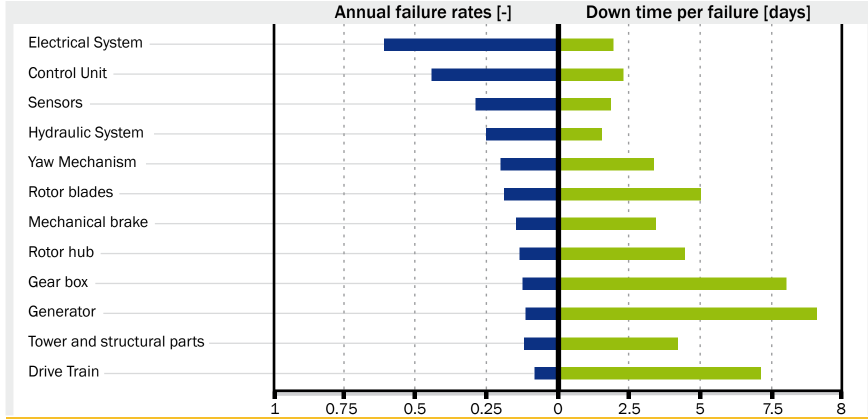

Figure 4: Comparison of wind turbine components according to thier annual failure rates and resulting downtimes.

Figure 5: Comparison of different O&M strategies for wind turbines in offshore wind farms.

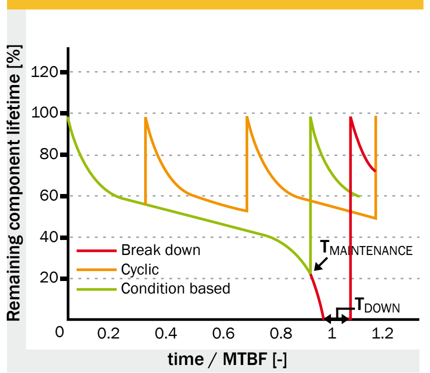

Figure 6: FBG sensor patches and 4channel interrogation unit to be installed in the test wind turbine.

NUMERICAL DATA EVALUATIONS

The measured structural oscillation data resulting from the fibre optic strain and acceleration sensors will be evaluated by extended numerical spectral analysis algorithms. These algorithms are further developed on the basis of the common numerical Fast Fourier Transform (FFT). Required extensions to the FFT will be the adaptation of the algorithm to the very low rotational and structural oscillation Eigen frequencies of the next generation of wind turbines. Another point is the variable speed of the turbines, which requires an RPM tracking of the FFT algorithm, the so called order analysis.

For extracting basic information from the fault statistic data bases, the standard statistical algorithms (averaging, correlation, etc.) will be used. To refine the results, new statistical algorithms will be developed. A promising approach seems to be the Power Law Process (PLP) model. This allows modeling the typical shape of