at the grid interface. The improvements on the harmonic performance are achieved on the expense of some additional circulating currents.

A fact common to all three topologies is that the highest conversion efficiency is achieved with the use of low voltage semiconductors. Out of the IGBT blocking voltage classes under investigation (1700V, 3300V and 6500V), the 1700V IGBTs offer highest conversion efficiency and lowest semiconductor losses. 1700V IGBTs can be operated at a higher switching frequency compared to 3300V and 6500V devices. This reduces the filtering requirements in order to comply with the applicable grid standards. However from the point of view of total system cost there is a tendency to aim at voltages as high as possible because transformer cost and conductor cost could be decreased.

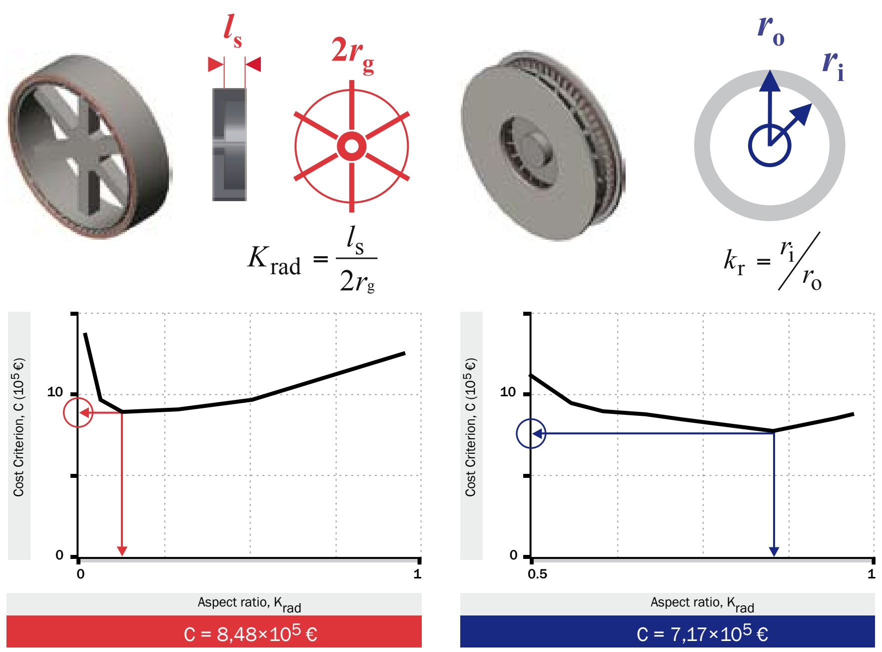

Figure 4: Simulation results for axial and radial flux PM machines.

SIXTH FRAMEWORK PROGRAMME

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Transmission and Conversion

THE CHALLENGE

This work package (WP) covers the entire drive train including mechanical and electrical components. The overall purpose is to develop the technology necessary to overcome the present limitations in turbine size, power and efficiency and to increase predictability and reliability. The WP is divided into the three sub-tasks: mechanical transmission, generators and power electronics.

THE RESEARCH ACTIVITIES; RESULTS AND EXPECTATIONS

MECHANICAL TRANSMISSION

In terms of reliability the drive train today is the most critical component of modern wind turbines. Nowadays the typical design of the drive train consists of an integrated serial approach where the single components, such as rotor shaft, main bearing, gearbox and generator are as close together as possible with the aim of compactness and mass reduction. Field experiences throughout the entire wind industry show that this construction approach results in many types of failures (especially gearbox failures) of drive train components, although the components are well designed according to contemporary design methods and all known loads. It is assumed that the basic problem of all these unexpected failures is based on a basic misunderstanding of the dynamic behaviour of the complete wind turbine system due to the lack of a ready-to-use integral design approach. This approach should simultaneously integrate the structural nonlinear elastic behaviour with the coupled dynamic behaviour of multi body systems together with the properties of electrical components. The following different system parts need to be addressed within one coupled "integral" model:

- Wind field simulation;
- Aero-elastic interaction at blades;
- Nonlinear flexibilities of fibre blades;
- Linear flexibilities of metal components of e.g. drive train;
- Nonlinear behaviour of drive train components e.g. gears, bearings, bushings;
- Electro-mechanic behaviour of generator;
- Electrical behaviour of power electronic converter and grid.

Within this WP three main issues for the construction of future large-scale wind turbines are addressed:

- In-depth and realistic simulation of the complete system behaviour for the design of reliable and cost effective components;
- Systematic analysis and test of gearboxes to ensure and verify a desired lifetime and at the same time reduce noise emission;
- Verification of common load assumptions for drive train design through long-term measurement technique and development of low-cost down counting technique of remaining drive train life-time due to actual measured stresses.

WP1A1
WP1A2
WP1A3
WP1B1
WP1B2
WP1B3
WP1B4
WP2
WP3
WP4
WP5
WP6
WP7
WP8
WP9

To overcome the actual limitations in design and reliability, it is necessary to develop and verify new and enhanced simulation tools. A Multi Flexible Body Dynamics (MFBD) simulation tool based on the pre-existing non-linear Finite Element Analysis (FEA) code SAMCEF Mecano is used, adapted and verified for detailed analyses of drive train behaviour.

A customized Open Computer Aided Engineering software platform based on plug-in techniques for wind turbine application is also being developed. It contains the pre-defined or user defined models developed and validated during the project, with focus on drive train. Figure 1 shows the Graphical User Interface of this professional software environment that can also be used for various kinds of analyses and post-processing. It is open to be extended towards specialised computation software to cover the whole design process from concept level to detailed component analysis.

The tool and the model have to be validated by comparison with experimental results. Measurements have been taken on a 1.5 MW class turbine and compared to simulation results, with emphasis on drive train behaviour. It could be shown that specific behaviour of drive train components can be simulated, matching the observations. Figure 2 shows exemplarily the movement of the gearbox torque arms during an e-stop event.

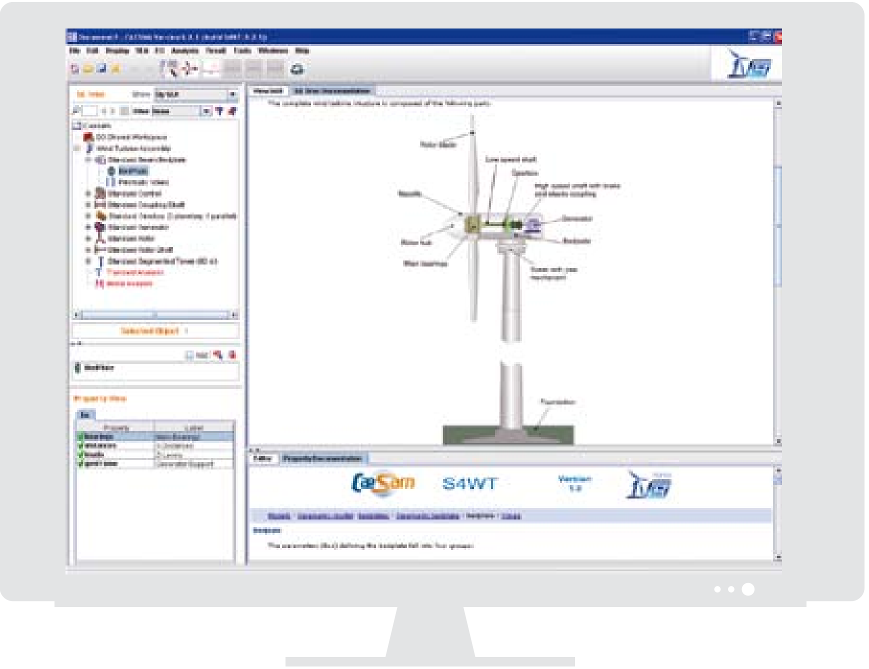

Figure 1: Graphical User Interface.

Further enhancements to the multi-body simulation tools are studied with regard to gear mesh behaviour. Normally the gear stiffness (for MFBD) is defined as a constant value or an analytic function in dependency of time, but for detailed gearbox analysis these assumptions are too simplistic. It is proposed to use realistic time varying stiffness gained via FE-simulation. Using a 3D model of the gear also considering modifications of the teeth like e.g. crownings constitutes a challenge as well. Also it has to be expected that for different torques different stiffnesses do result. To take account of these boundary conditions the mesh stiffness shall be computed using tooth contact analysis software. Thus the mesh stiffness can be won in accordance to the applied torque, the rolling position of the gears and the gear deflection in a static mode. The challenge of this task is the coupling with the MBS model of the wind turbine. Figure 3 shows the proposed methodology for integrated tooth contact analysis.

Depending on the specific location of a wind turbine, the actual loads on the components can be quite different from the design loads. Therefore the availability of a long-term measurement technique is the necessary tool to provide load cycle analysis for all turbine conditions and for different turbine locations. The same technology can be used for development of a low-cost drive train load monitoring system, which enables to down-count the proposed and designed lifetime according to the actual measured load cycles. The measured load cycles for specific conditions will be compared to simulation results. Thus the commonly used assumptions for component design can be verified and enhanced towards future large-scale wind turbines. Preliminary simulations and measurements have indicated that there is a significant dynamic coupling between the generator and the wind turbine structure beyond the drive train, and that this coupling can cause oscillations in the drive train and tower. The interaction between the mechanical system and the generator will be studied further. The proposed drive train measurement system for long-time measurements will particularly use generator power and angular rotor speed with high accuracy both in time resolution and with appropriate dynamical performance. The aim is to demonstrate that the drive train conditions can be measured in a simple and robust way. In order to ensure sufficient bandwidth, the generator power is derived by measured 3-phase generator AC current and voltage.

GENERATORS

The main objective of this task is to find the most suitable generator system for the wind turbine for the year 2020. Currently, there are three main generator systems used in wind turbines: constant speed with gearbox and squirrel cage induction generator, variable speed with gearbox and doubly-fed induction generators, and variable speed direct-drive generators without gearbox. Each concept has its typical weaknesses. A thorough comparison of these and other possible generator concepts based on cost models and energy yield models is the focus of this task.

During the last two decades, various wind turbine concepts with different generator systems have been developed and built to maximize the energy capture, to minimize costs, to improve power quality, and others. An overview of wind turbine technologies and a comparison of different generator topologies based on literature and market supply review has been performed. Secondly, promising direct-drive permanent magnet (PM) machines, which include the axial flux (AF), radial flux (RF) and transverse flux (TF) machines, have been surveyed in literature to find the most suitable generator type for direct-

drive large scale wind turbines. The advantages and disadvantages of each type are investigated and discussed, and comparison of different generator topologies based on the technical data and market aspects have been mapped using appropriate comparison criteria.

Promising PM machines, such as AFPM, RFPM and TFPM, have been surveyed more in depth, as PM machines are more attractive because they possess higher efficiency and power-to-weight ratio compared to electrically excited machines. In case of RFPM machines, the electromagnetic design and optimisation with general topology have been discussed in a number of publications. It can be concluded that the machines are almost optimised electromagnetically, so that it is hard to reduce the active material weight and cost of the machines significantly. The disadvantages of the AFPM machine must be solved, because it causes the machine cost to increase and manufacturing to be difficult. TFPM machines also have disadvantages such as low force density in large air-gaps, complicated construction and manufacturing, and low power factor although the machines have advantages such as high force density and simple winding with low copper losses. However, in a number of publications, various topologies of TFPM machine have been proposed to solve or improve the existing drawbacks, since the machine is more flexible and attractive to design.

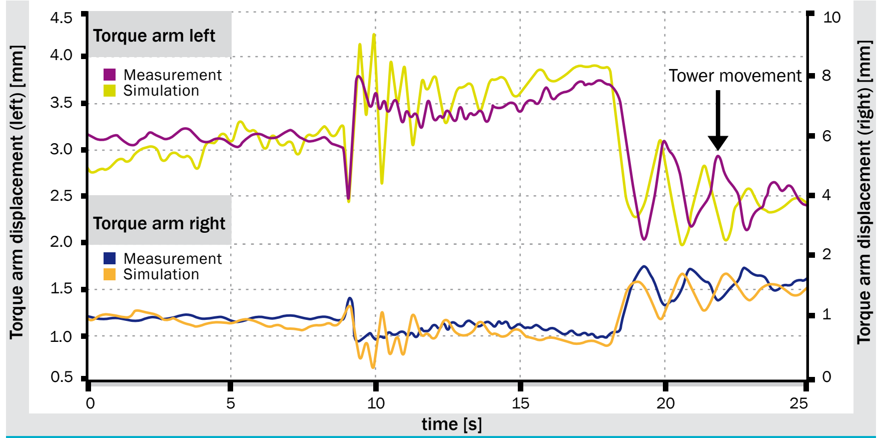

Figure 2: Torque arm displacement - longitudinal.

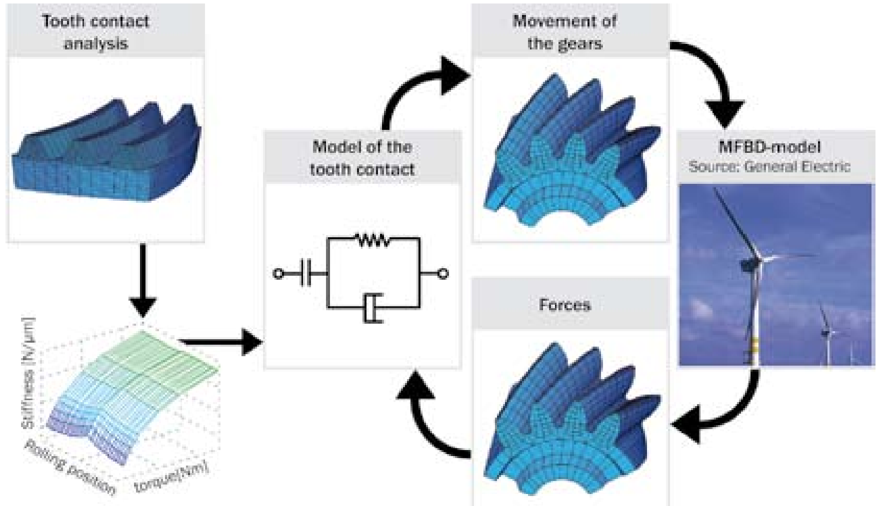

Figure 3. Methodology for integrated tooth contact analysis.

One aim of this task is to evaluate the most cost-effective wind turbine generator systems by applying design optimisation and numerical comparison. The following generator topologies were investigated: the squirrel cage induction generator, the doubly-fed induction generator, the electrically excited synchronous generator and permanent magnet synchronous generator. The fourth picture shows simulation results for axial and radial flux PM machines, with optimum choice of diameter to length ratio for lowest cost.

POWER ELECTRONICS

While acknowledging that doubly-fed induction generators are a sort of standard today, the UpWind research focuses on full converter solutions for synchronous generators. This project task anticipates the market pull for the second next level of offshore wind turbine power of around 5-7 MW. Three different approaches to increase the power rating to the required level will be analysed in detail. An example design per approach including power device selection, selection of switching frequency, filter design, efficiency curve, volume estimates and control scheme will be provided with the final report. These concepts comprise the matrix converter, the 3-level neutral point clamped (NPC) converter and the parallel interleaved converter. The concepts are benchmarked in terms of conversion efficiency, number of semiconductor devices and filtering effort.

As a result of the benchmarks it can be noted that all topologies are potential candidates for next generation wind turbines and can serve the desired power conversion rating. The matrix converter is the topology offering the most potential for future developments. Currently the lack of tailor made power semiconductors is a small drawback. The 3-level NPC is a well established converter topology for the desired output power range, and it supports different output voltage levels. The parallel interleaved converter topology provides very good harmonic performance