Book of abstracts

9th PhD Seminar on Wind Energy in Europe

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PREFACE

The wind energy field is becoming more and more important in relation with future challenges of switching the world energy system to renewables. Therefore it is of high importance that tomorrow's researchers in the field from all over the word meet and discuss future challenges.

The 9th annual EAWE PhD seminar is in 2013 organized by Uppsala University Campus Gotland. This is a very suitable place for this event since it combines a unique historical environment with a sustainable profile and a long tradition of wind energy. Today about 45% of the energy consumption is locally produced by wind energy.

Uppsala University Campus Gotland also has more than 10 years experience of teaching and research in the field with a focus on wind power project development.

The aim with this seminar is to improve the international communication and information sharing of ongoing activities as well as simplify contact building between young researchers. It is also a perfect opportunity for PhD students to practice and improve their presentation and discussion skills.

Associate Professor Stefan Ivanell
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TABLE OF CONTENTS

ROTOR & WAKE AERODYNAMICS

AERODYNAMIC LOADS AND AEROELASTICITY

TURBULENCE, ABL & MEASUREMENTS

TURBINE MODELING AND CONTROL

TURBINE OPERATION, PERFORMANCE AND MAINTENANCE

MICROSCALE, MESOSCALE AND ENERGY

ROTOR & WAKE AERODYNAMICS

UNDERSTANDING THE WIND TURBINE BREAKDOWN MECHANISM WITH CFD

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ABSTRACT

Accurate prediction of the wind turbine wake is important for the performance analysis of the turbine as well as the optimal positioning of wind turbines within tightly-spaced wind farms. In this work CFD is used to explore the breakdown of the wake downstream of the blades and assess the capability of CFD in predicting the correct physical mechanism of the breakdown.
In the past, CFD was considered a tool confined to the near-wake analysis due to the inherent numerical dissipation of CFD solvers. With progress, however, in numerical methods and mesh density, CFD is emerging as the best tool for the analysis of the wakes since it can accurately capture the development of core instabilities that will lead to the wake breakdown. It is the purpose of this paper to demonstrate how CFD can be used for the analysis of the wake, and at this instance the Multi-Block CFD solver of Liverpool University [1] is used.

The solver has so far been validated for several cases including the NREL experiments [2] as well as the pressure and PIV data of the MEXICO project [3]. This last case is used for this paper where the wake is resolved on a fine mesh able to capture the vortices up to 8 radii downstream the blades. At a wind speed of 15m/s, the main frequency is the blade rotation (21. 4Hz) and is present in the CFD signals for up to 4 radii downstream the rotor plane, where the vortex cores fall on a perfect spiral, as can be seen in “fig.1”. Between 4 and 5 radii downstream, a sinusoidal behaviour is observed, due to a higher frequency content, which indicates the onset of instabilities. This instability results in vortex pairing, which was also reported in [4], and can be observed in the vorticity contours of “fig.2”.

The encouraging results obtained for 15m/s suggest that the wake instability of wind turbines can be predicted with CFD methods. Additional results at different speeds have also been obtained. A detailed presentation of the results and stability analysis are presented in the full paper.

REFERENCES

[1] Gomez-Iradi, R. Steijl and G.N. Barakos, Development and Validation of a CFD Technique for the Aerodynamic Analysis of HAWT, J. Solar Energy Engineering-Transactions of the ASME, 31(3):031009, 2009.

[2] Hand, M. M., Simms, D. A., Fingersh, L. J., Jager, D.W., Cotrell, J. R., Schreck, S., and Larwood, S. M. Unsteady aerodynamics experiment phase VI: wind tunnel test configurations and available data campaigns. Technical report TP-500-29955, NREL, December 2001.

[3] H. Snel, J.G. Schepers and B. Montgomerie, The MEXICO project (Model Experiments in Controlled Conditions): The database and first results of data processing and interpretation.

[4] S. Ivanell, R. Mikkelsen, J.N. Sorensen, D. Henningson, Stability analysis of the tip vortices of a wind turbine, Wind Energy, 13 (2010) 705–715.

A multi component hot-wire probe and its application and feasibility in wind turbine wake measurements

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ABSTRACT

The aim of the present project is to map the turbulent wind turbine wake for the purpose of extracting information useful for numerical modeling. Numerical modelers have previously been invited to compare their data to the experimental results in the NOWITECH/NORCOWE blindtest [1]. To reach this goal a measurement technique with both a high temporal and spatial resolution is needed. One such technique is hot-wire anemometry. In this paper the feasibility of applying multi component hot-wire anemometry to wind turbine wake measurements is investigated. For this investigation a four-wire probe is used which is capable of measuring all three velocity components simultaneously and thus all the turbulent stresses and the turbulent kinetic energy (Figure 1). Such a probe faces several challenges in a wind turbine wake. The biggest ones are large flow angles and large velocity gradients across the probe volume. This is especially true in the tip vortex region. To ensure that the probe is capable of handling large flow angles great care has been taken in mapping the angular response of the probe. Several approaches to handling the angular response have been attempted revealing large differences in performance, from Bradshaws simple cosine law [2] to the more elaborate look-up tables (Figure 2.) as suggested by Döbbeling [3] and others. The probes sensitivity to velocity gradients will depend on its geometry and size. The performance of the chosen geometry is tested by modeling the probes response in Matlab and exposing it to wake like conditions in a manner similar to that done by Vukoslavčević [4]. The virtual experiment show that the high gradients in the tip region will affect the accuracy of the results.

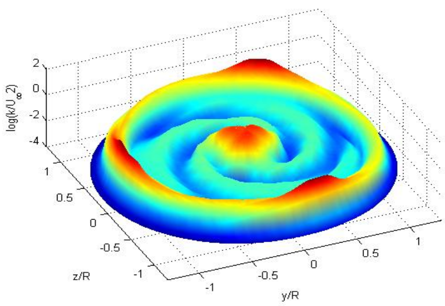

Figure 1: Logarithm of phase locked averaged turbulent kinetic energy at 1D for λ=6

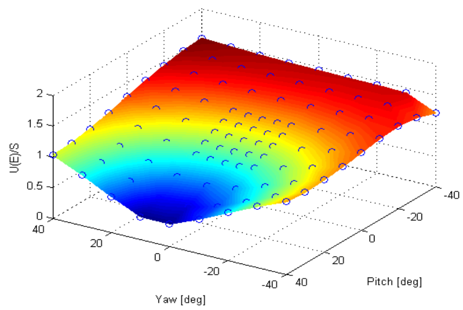

Figure 2: Calibration map for a single hot-wire.

REFERENCES

[1] P-Å.Krogstad, P.E.Eriksen "Blind test calculations of the performance and wake development for a model wind turbine" , Renewable Energy, 50 (2013) pp. 325-333.

[2] P. Bradshaw, "An introduction to turbulence and its measurements", Pergamon Press, (1971)

[3] K.Döbbeling et al, "Computer-aided calibration and measurements with a quadruple hotwire probe", Experiments in Fluids, 8 (1990) pp. 257-262.

[4] P.V.Vukoslavčević, "A hot-wire probe configuration and data reduction method to minimize velocity gradient errors for simultaneous measurements of three velocity components in turbulent flow", Exp Fluids, Springer-Verlag, 2012.

Implementation of actuator methods in ANSYS-CFX

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ABSTRACT

Currently actuator methods are employed by a number of different researchers in the field of energy generation in order to design turbines with increased efficiencies. These predominately use in-house or specifically developed codes instead of those available commercially. The aim of the study described in this paper was to implement the actuator disk and actuator line methods in the commercially available optimized Computational Fluid Dynamics (CFD) code viz. ANSYS-CFX. This study describes the process required to implement the aforementioned actuator methods using the ANSYS-CFX expression language (CEL). Both methods implemented in this study show good agreement when qualitatively compared to previous theoretical (one-dimensional momentum equation) and numerical studies evident in the literature. Whence negating the use specially developed codes to implement the actuator disk and actuator lines during the design and analysis of turbomachinery.

Experimental analysis of the re-energising process of a wind turbine wake

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ABSTRACT

The mixing properties of the self-induced flow in a horizontal axis wind turbine wake are studied. The wake of a 60-centimetres horizontal axis wind turbine has been measured with stereo particle images velocimetry in order to investigate a relationship between the wake recovery and the evolution and instability of the tip-vortex helix [3]. The process of wake re-energising is studied and its dependency on the wake flow structures and stability is shown. Unconditioned and phase-locked sampling of the velocity field have been conducted up to 4 diameters downstream in order to show the average field as well as the evolution of the tip vortices and their pairwise interaction. The main observation is a clear dependency of the onset of the instability on the value of TSR according to [1] and a strong influence of the leapfrogging event on the re-energising process of the wake. The finding is in accordance with the hypothesis of [2] who stated that the near wake tip-vortices are acting as a shield preventing the wake to mix with the outer flow. As last it is shown how the transport of the mean flow kinetic energy in the wake shear layer changes after the wake breakdown. A thorough estimation of the energy transport at wake scale and the modelling of its dependency on the turbine characteristics would be a first step towards a rotor design process which does not only take into account the aerodynamic and power optimisation of the rotor itself, but also the re-energising properties of the wake, namely the "design of the wake".

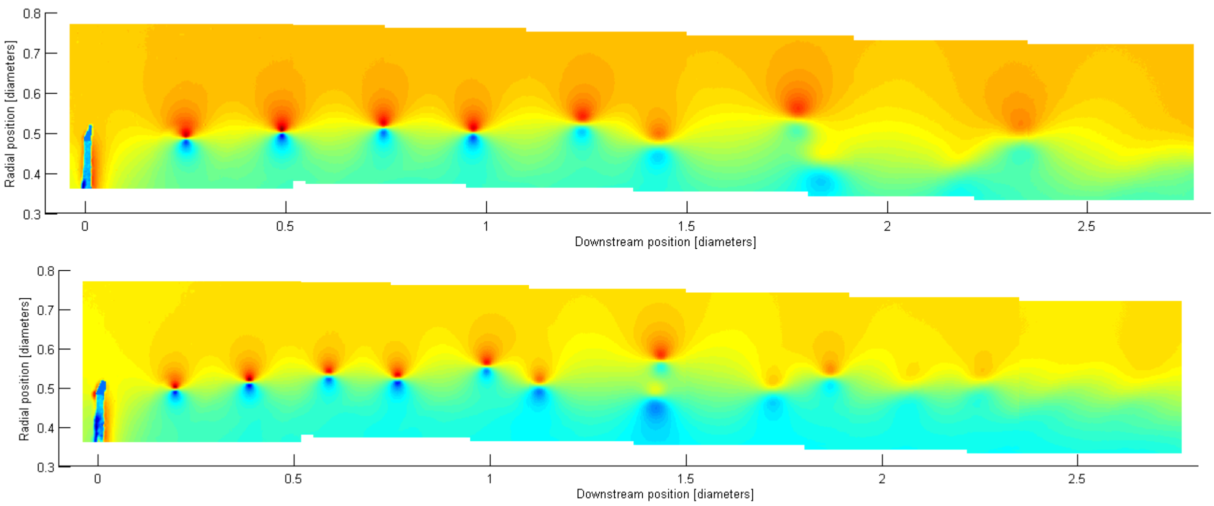

Figure 1: evolution and instability of tip vortex for TSR = 4 (a) and 6 (b) till 2.3 diameters

REFERENCES

[1] Felli, M., Camussi, R., Di Felice, F., 2011. Mechanisms of evolution of the propeller wake in the transition and far fields. Journal of Fluid Mechanics 682, 5-53.

[2] Ivanell, S., Mikkelsen, R., Sørensen, J.N., Henningson, D., 2010. Stability analysis of the tip vortices of a wind turbine. WIND ENERGY 13, 705-715.

[3] Medici, D., 2005. Experimental Studies of Wind Turbine Wakes – Power Optimisation and Meandering, Mechanics. Royal Institute of Technology (KTH), Stockholm.

LES of the Lillgrund wind farm using a torque based power controller

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The aim with the study is to quantify the effects of using an active power controller when performing large-eddy simulations (LES) combined with an actuator disc (ACD) method.

Large-eddy simulations are performed using the EllipSys3D Navier-Stokes solver developed at DTU/Risø by Michelsen [1][2] and Sørensen [3] to compute the power production and the wake effects of the wind turbines in the Lillgrund offshore wind farm. Lillgrund is ideal for wake studies thanks to its layout which is characterized by a small internal turbine spacing. The turbines in the farm are modeled using an actuator disc (ACD) method, Mikkelsen [4]. The ACD method models the rotor with body forces determined from drag and lift coefficients which are tabulated as functions of the angle of attack. As the boundary layer over the blades is not resolved, this approach greatly reduces the computational costs compared to simulations involving the modeling of the full blade geometry. The atmospheric conditions are modeled using pre-generated synthetic turbulence, Mann [5], and a prescribed boundary layer in order to save computational costs. The simulations are performed both with a recently implemented power controller, see Nilsson [6], which forces the turbines to adapt their rotational speed to the conditions they are operating in, and without any controller, where all turbines are given a fixed rotational speed. The relative power predicted from the different simulations are compared with measurement data as depicted in Figure 1. In this figure it can be seen that both the simulations with and without the power controller are predicting the measured production very well. There is however a tendency that the controlled simulations are performing slightly better than the uncontrolled ones in comparison with the measurements.

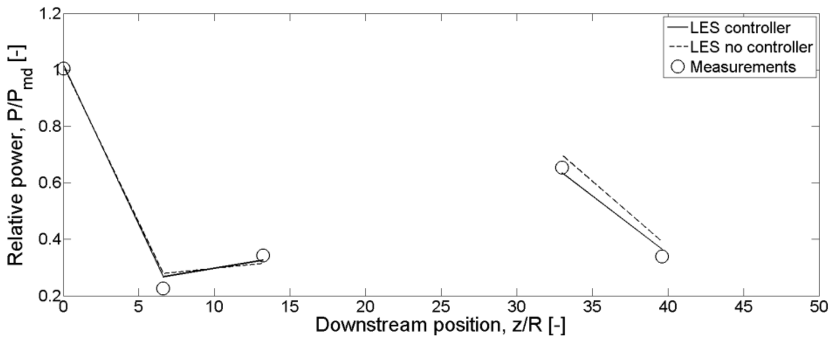

Figure 1: Relative production for a row of turbines in the farm

[1] Michelsen JA. Basis3D - A Platform for Development of Multiblock PDE Solvers. *Tech. Rep. AFM 92-05* 1992; DTU
[2] Michelsen JA. Block Structured Multigrid Solution of 2D and 3D Elliptic PDE's. *Tech. rep. AFM 94-06* 1994; DTU
[3] Sørensen NN. General purpose flow solver applied to flow over hills. *PhD th. Risø-R-827-(EN)* 1995; Risø
[4] Mikkelsen R. Actuator Disc Methods Applied toWind Turbines. *PhD thesis MEK-FM-PHD 2003-02* 2003; DTU
[5] Mann J. Wind field simulation. *Probabilistic Engineering Mechanics* 1998; 13; 269-282
[6] Nilsson K. Numerical computations of wind turbine wakes and wake interaction. *Lic.th. TRITA-MEK 2012:18* 2012; KTH

Modelling of a wind turbine wake in a uniform, turbulent flow using LES and comparison with wind tunnel measurements

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ABSTRACT

The assessment of the effects of turbulence of wind turbine wakes on downstream turbines plays a central role in the estimation of loads and in the analysis of production of parks. Hence, the physical representation of turbulence becomes a determinant factor in the accuracy of the predictions. In this regard, RANS models have been shown to be reasonably accurate while being computationally economical [1], which makes them the first choice for industrial applications. However, a detailed study of the turbulence characteristics requires a model capable of reproducing the transient velocity fluctuations of the flow field. Consequently, LES models are employed for such investigations.

In this work we evaluate the modelling of the inflow turbulence as well as the turbulent wake produced by a porous disk. To this aim, we perform LES calculations to reproduce the features of the wind tunnel measurements of [2]. Our model also involves the reproduction of the grid turbulence used in the experiments by a homogeneous, non-sheared turbulence field, obtained by means of the Mann model [3]. The characteristics of the turbulence field produced following this approach are compared with those of the experiment. Preliminary results show a very good agreement between our computations and the experimental results (see “Figure 1”).

In a similar study [1], results of RANS calculations compared very well to the same experimental measurements. For that reason, this study presents an opportunity to evaluate the pertinence of following a more complete but expensive approach such as LES as opposed to the simplified methods of RANS, with respect to the features that one attempts to reproduce.

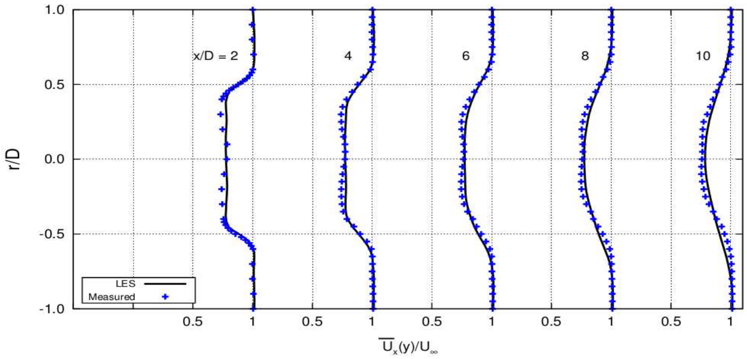

Figure 1: Comparison of predictions of velocity deficit profiles behind an actuator disk of $C_T=0.43$ in a turbulent flow with 3% turbulence intensity (measured in the absence of the disk).

REFERENCES

[1] J. Sumner, G. Espana, C. Masson and S. Aubrun, “Evaluation of RANS/actuator disk modelling of wind turbine wake flow using wind tunnel measurements”, Int. J. Engineering Systems Modelling and Simulation, Vol. 5 (2013), pp. 1-3.

[2] G. Espana, Étude experimentale du sillage lointain des éoliennes à axe horizontal au moyen d'une modélisation simplifiée en couche limite atmosphérique, PhD Thesis (2009), Université d'Orléans.

[3] J. Mann, “Wind Field Simulation”, Prob. Engng. Mech., Vol. 13, No. 4 (1998), pp. 269-282.

A Coupled Wind Turbine Model at Different Aerodynamical levels

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ABSTRACT

The increasing of the size of wind turbines poses the question about the accuracy of the simplified design models. Large rotor blades require more accurate and efficient tools to correctly predict aerodynamic loads and performance of wind turbines. One of the most renown methods to simulate wind turbines is the Blade Element Momentum theory (BEM). It constitutes the basis for many aerodynamical models used in wind turbine design software. Nevertheless, several experimental and advanced numerical studies show that BEM based codes are not sufficiently accurate and reliable for predicting aerodynamical loads acting on the wind turbine blades. It is therefore necessary to implement and use more accurate tools.

Several difficulties can arise when modeling the aerodynamical behavior of rotor blades. These difficulties are attributed to complex flow phenomena, which can appear even in the simplest inflow conditions. These phenomenas are, to cite just a few: flow separation, secondary flow, vortex shedding at the leading, trailing, and at the tip of the blade, added to this are the 3D effects. A simplistic approach to these phenomena, as it is the case when using simple BEM methods, can lead to fatal consequences for the design process and might reduce the effectiveness of the wind turbine and thus the expected energy output. One very common example is the applicability of 2D airfoil polars in the design process of wind turbines. The flow around a wind turbine blade being highly 3D, a correction is needed to account for the 3D effects on the dynamical behavior of the blades. The corrections can be obtained by conducting 3D Computational Fluid Dynamics (CFD) simulations to obtain a more realistic flow behavior and thus a better prediction of the loads on the blades. It is therefore essential to conduct more complex and realistic simulations in order to capture all the important phenomena, which play a role in the correct modeling of wind turbines.

The main goal of this PhD work is to develop a coupled aerodynamical model for wind turbines. This model will be able to simulate the dynamics of the wind turbine and to account for the wind field configuration in the wind turbine simulation code OneWind [2]. For some aspects of the simulation, like load changes caused by 3D effects, flow detachment at the blade tip or the changes in the profile geometry at the transition sections of the blade, Computational Fluid Dynamics (CFD) simulations are going to be conducted. This will be achieved using the open-source simulation package OpenFOAM [3]. These simulations will be de-coupled from the BEM simulations performed in OneWind. Through an iterative process, the results of the CFD simulations will be integrated in the OneWind wind turbine simulations. This will be part of a coupled, automatized aerodynamic tool for advanced wind turbine design. Furthermore, a 3D automatized grid generator, BEM simulations with frontal and yawed inflow conditions with OneWind on the MEXICO-Rotor [4] are planned. The model constructed is going to be tested by comparing the simulation results with the experimental data available from the MexNext project [4]. This PhD is part of the Smart Blase project.

REFERENCES

[1] M. Pepe. CFD study of thick flatback airfoils using OpenFOAM. Master thesis, Department of mechanical engineering, Technical University of Denmark, 2011.
[2] OneWind. http://www.onewind.de/.
[3] OpenFOAM. The open source computational fluid dynamics toolbox. http://www.openfoam.com/.
[4] The MexNext project. http://www.mexnext.org/

ADJOINT SOLVER FOR OPTIMIZATION OF WIND TURBINE AIRFOILS IN OPENFOAM®

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ABSTRACT

Common aerodynamic design tools for wind turbines are based on the Blade-Element-Momentum theory (BEM), which are fast to compute, but less accurate than Computational Fluid Dynamics (CFD). Due to the high computational cost of CFD simulations, we propose here to use the adjoint method as optimization tool for wind turbine airfoils.
The adjoint method for aerodynamic optimization has widely been used [1, 2, 3]. It can be divided into three steps: solving the Navier-Stokes equations, the calculation of the adjoint system and the use of the adjoint variables within the optimization process. In the second step the adjoint variables are chosen in such a way that the optimization process is independent from the solution of the Navier-Stokes equations, which leads to a fast computation. Furthermore, the adjoint method gives a mathematical optimized solution by definition (Lagrange optimization). However, more time is previously needed for the derivation of the cost function and the adjoint equations. The CFD code used in this work is the open source toolbox OpenFOAM, which is written in C++ and expandable by each customer [4].
A time averaged solver provided by Othmer et al. [5] already uses adjoint equations for internal flows (*adjointShapeOptimizationFoam*). In this work, this solver is extended to external aerodynamics with a moving boundary and deforming mesh. As a first cost function the drag force is chosen, which means the shape ends into a flat plate. This corresponds with the theoretically expected solution and therefore shows the correct implementation of the solver.
The cost function will be redefined in order to minimize the drag at a constant lift force with given constraints (e.g. minimum thickness). The corresponding boundary condition for the airfoil will be implemented.

REFERENCES

[1] A. Jameson, "Aerodynamic shape optimization using the adjoint method," Lectures at the VonKarman Institute, 2003.
[2] W. K. Anderson and V. Venkatakrishnan, "Aerodynamic design optimization on unstructured grids with a continuous adjoint formulation," AIAA Paper, 1997.
[3] R. Löhner and O. Soto, "On the computation of flow sensitivities from boundary integrals," AIAA Paper, 2004.
[4] "OpenFOAM finite volume programming environment for CFD", www.openfoam.com.
[5] C. Othmer, E. d. Villiers, and H. G. Weller, "Implementation of a continuous adjoint for topology optimization of ducted flows," AIAA Paper, 2007.

A Simple Nonlinear Eddy Viscosity Model applied to Wind Turbine Wakes

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ABSTRACT

Wake effects in wind farms can lead to an energy loss of 10-20% [1] and higher wind turbine loads due to increased turbulence levels. Therefore, accurate and practical modeling of wind turbine wakes is important. In the present research, a Reynolds averaged Navier-Stokes code is employed in which two different turbulence models are tested, namely, the linear k-ε eddy viscosity model and a proposed simple nonlinear eddy viscosity model that is inspired by the work of Apsley and Leschziner [2]. Both turbulence models are applied to single wind turbine wake simulations. Results are compared with field wake measurements of the wind turbine test site of ECN [3] and large eddy simulations (fig. 1). The comparison shows that the wake deficit and the Reynolds-stresses, predicted by the nonlinear eddy viscosity model, are much closer to the ones calculated by the large eddy simulation and the ones observed in the measurements, with respect to the linear k-ε eddy viscosity model.

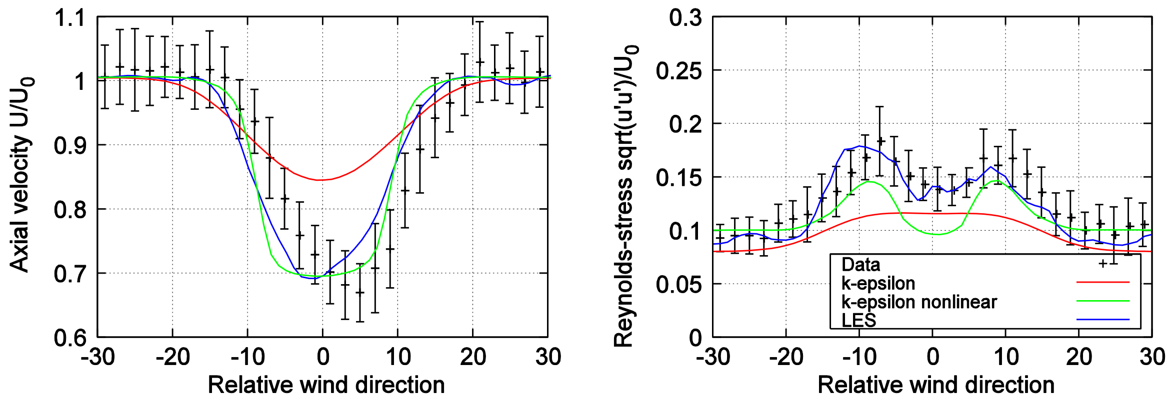

Figure 1: Wake deficit (left) and stream-wise Reynolds-stress (right) at a downstream distance of 3.5D. D=80 m, U_0=10.7 m/s. Error bars include one standard deviation.

REFERENCES

[1] R. J. Barthelmie, S. T. Frandsen, N. M. Nielsen, S. C. Pryor, P.-E. Réthoré , and H. E. Jørgensen, "Modelling and measurements of power losses and turbulence intensity in wind turbine wakes at middelgrunden offshore wind farm," Wind Energy, vol. 10 (2007) pp. 217–228.
[2] D. D. Apsley and M. A. Leschziner, "A new low-reynolds-number nonlinear two-equation turbulence model for complex flows," International Journal of Heat and Fuid Flow, vol. 19 (1998) pp. 209–222.
[3] J. G. Schepers, "Analysis of wake measurements from the ECN wind turbine test site wieringermeer, EWTW," Wind Energy, vol. 15 (2012) pp. 575-591.

Validating of a transition model for the DU91-W2-250 airfoil

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ABSTRACT

One possible reason which caused the discrepancy between CFD results and experimental data for wind turbine was a lack of transition model in MexNext project [1]. For the simulations, most turbulence models used assumed fully turbulent flow, while in the wind tunnel experiment, there is transition from laminar to turbulent flow. When a suitable transition model for wind turbine simulation is implemented, the predictions are expected to be more accurate.

This research aims to validate a transition model implemented in an open source code OpenFOAM with the ability to predict the aerodynamic characteristic for the wind turbine airfoil DU91-W2-250. DU91-W2-250 airfoil is one of three different aerodynamic profiles used for the MEXICO rotor blades in MexNext project. In this paper a Reynold-Averaged Navier Stokes simulation with k-omega SST turbulence model and kklomega transition model is implemented. Streamlined and post stall flow at two different angles of attack at $Re=1.0x10^6$ are considered. A comparison is made between numerical results and experimental data measured in Low Speed Low Turbulence wind tunnel in TUDelft. The numerical results show good agreement with the pressure distribution along the airfoil measured in the experiment. In the next step, this transition model will be applied in three dimensional complex flow codes for MEXICO rotor.

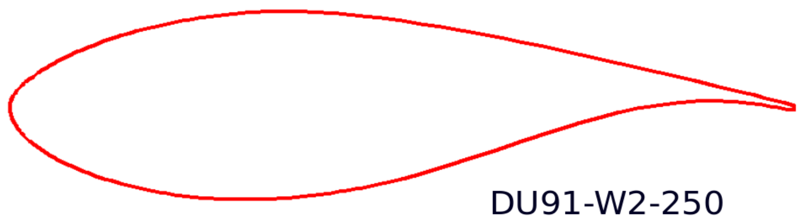

Figure 1: DU91-W2-250 airfoil.

REFERENCES

[1] Bechmann, A., Srensen, N. N., and Zahle, F. “CFD simulation of the MEXICO rotor”, Wind Energy, vol.14 (2011) pp.677-689.

AERODYNAMIC LOADS AND AEROELASTICITY

VORTEX METHOD APPLICATION FOR AERODYNAMIC LOADS ON ROTOR BLADES

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ABSTRACT

The aerodynamics of a wind turbine are governed by the flow around the rotor where the prediction of air loads on rotor blades in different operational conditions and its relation to rotor structural dynamics is crucial for design purposes. Therefore, one of the most important challenges in wind turbine aerodynamics is to predict the forces on the blade accurately where the blade and wake are modeled by different approaches such as Blade Element Momentum (BEM) theory, vortex method and Computational Fluid Dynamics (CFD).
In this paper, the application of vortex method for wind turbine aerodynamic performance is used. The main purpose is to calculate the wind load and study the wake behavior by using vortex panel method. Two approaches of vortex panel method, prescribed wake and free wake have been studied. The results are compared with the BEM method and GENUVP code. Fig.1 shows the comparison between the geometric and effective angle of attack seen by blade.

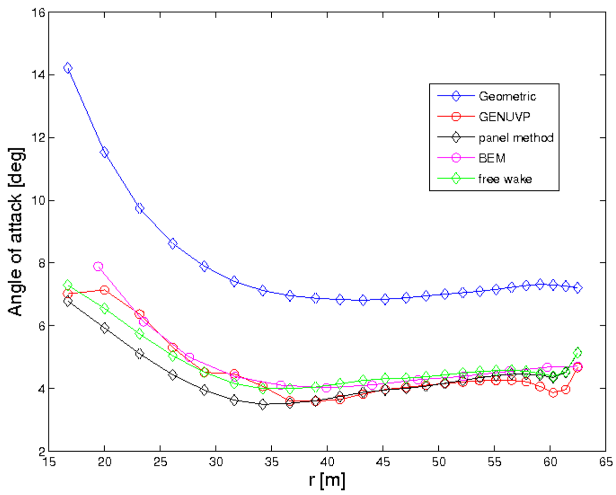

Figure 1: Effective angle of attack.

REFERENCES (Centered, 12 Points, Bold)

[1] Katz, J., and Allen Plotkin, 2001. Low-Speed Aerodynamics, 2nd ed. Cambridge University Press.
[2] Voutsinas, S., 2006. "Vortex methods in aeronautics: how to make things work". International Journal of Computational Fluid Dynamics, 20, pp. 3–18.

ACTIVE MICRO-TABS FOR WIND TURBINE LOAD CONTROL

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ABSTRACT

Modern large wind turbine blades are affected by strong local and unsteady wind conditions such as wind shear, gusts and blade-tower interaction which induce fatigue loads and further lead to an overall reduced turbine lifetime. To alleviate dynamic loads locally on the blade the proposed work investigates an electro-mechanical micro-tab system under dynamic conditions. A static micro-tab placed on the pressure side of an airfoil and close to the trailing edge can enhance the local lift, whereas a placement on the suction side leads to reduced lift (see fig. 1).

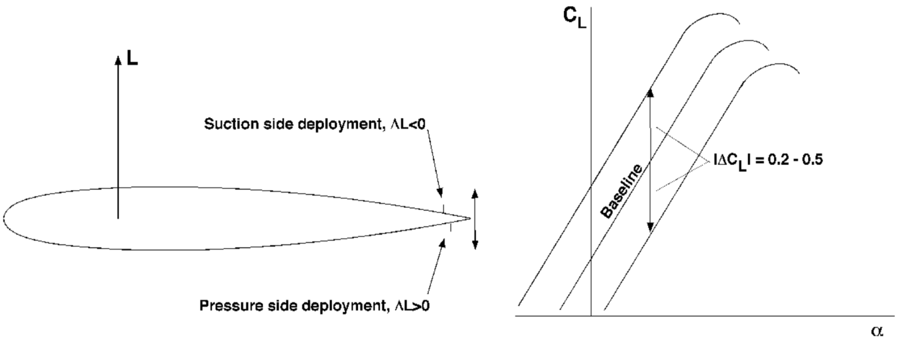

Figure 1: Static load control concept with micro-tabs [1].

In reality, wind turbine sections are highly affected by unsteady inflow and changing angle of attack. Hence, transitional effects of active load control techniques play an important role [2]. This work aims at providing a deeper insight in the aerodynamics of active deploying or retracting micro-tabs under various conditions, such as the Reynolds number or the tab deployment time. Transient responses of lift and moment coefficients obtained from time resolved surface pressure measurements will be presented. The transient lift as well as the moment show a certain time delay, implied by a vortex emerging behind the deploying micro-tab [3]. The dependency of this time delay is analysed and shall be further discussed.

REFERENCES

[1] J.P. Baker, K.J. Standish and C.P. van Dam, "Two-Dimensional Wind Tunnel and Computational Investigation of a Microtab Modified S809 Airfoil", 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 2005.
[2] D. Yen, C.P. van Dam, R. Smith and S. Collins, "Active Load Control for Wind Turbine Blades Using MEM Translational Taps," Proc. ASME Wind Energy Symposium, Reno, NV, 2001.
[3] R. Chow and C.P. van Dam, "On the Temporal Response of Active Load Control Devices," J. Wind Energy, 2012, Vol. 13, pp.135-49.

Assessment of Fatigue Load Reduction of HAWT using Smart Rotors

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ABSTRACT

During the last years smart rotors have gained popularity in wind turbine research. These rotors exploit active aerodynamic devices, such as trailing edge flaps, to modify the flow around the blade. Besides power generation, maximum load control and tip deflection control, fatigue load alleviation is one of the most investigated problems.

Originally being designed to reduce the fatigue load of blades, the added aerodynamic damping due to the flap motion also impacts the loads on other wind turbine components. For this paper a set of aeroelastic simulations has been run with load cases according to IEC specification for fatigue loads in DU-SWAT, an in-house tool specifically developed to assess smart rotors. One set of simulations is the baseline analysis of the NREL 5MW reference turbine, while the other simulations include individual flap control (IFC) [1]. Usually the effect of flaps on the aeroelastic vibrations of the rotor are studied. A good measure for this is the dynamic behaviour of the blade root bending moment. Besides this standard measurement, also the internal forces and moments in the hub, on the shaft on the tower top and the tower bottom were monitored as shown in fig. 1, thereby presenting for the first time a complete study of the full turbine.

It was found that the aerodynamic damping introduced by the flaps lead to an overall lower vibration level which translates into a fatigue load reduction of more than 34 percent for the out-of-plane blade root moment. While also the in-plane bending moment experiences a decrease of 7 percent, the torsional moment increases by 27 percent. The tower, shaft and hub experience a reduction in loading for practically all load cases between 5 and 15 percent. In an effort to further quantify the impact of smart rotors, the simulations are extended to extreme loads such as 50 year gust or the 180 degree change of wind direction.

Figure 1: Monitored locations

REFERENCES

[1] L.O. Bernhammer, R. De Breuker, G.A.M. van Kuik, J.-W. van Wingerden, J. Berg, "Model Validation and Simulated Fatigue Load Alliviation of SNL Smart Rotor Experiment", Proceedings of 51st AIAA Aerospace Sciences Meeting, Grapevine 2013.

Extreme gust loads for novel wind turbines

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ABSTRACT

In the scope of the INNWIND.EU project, future “beyond state-of-the-art” wind turbines are envisioned that could easily extend above an altitude of 150 m. To accomplish this, it is important to properly cover the atmospheric conditions in the design phase of the turbine. One of these aspects is finding and modeling the extreme operating gust with a 50-year recurrence period in order to assess its effect on such large turbines (see fig. 1). This encompasses finding a suitable model with a physical basis that is also easy to handle during the early conceptual design phases. One such candidate is *constrained stochastic simulation* [1], which will be refined using high-frequency LIDAR measurements.

Determining return levels is traditionally done by extrapolating an extreme value distribution. However, predicting a 50-year gust based on only several years of measurements brings along a high degree of uncertainty. Finding ways to deal with such uncertainty is therefore a crucial aspect of this project.

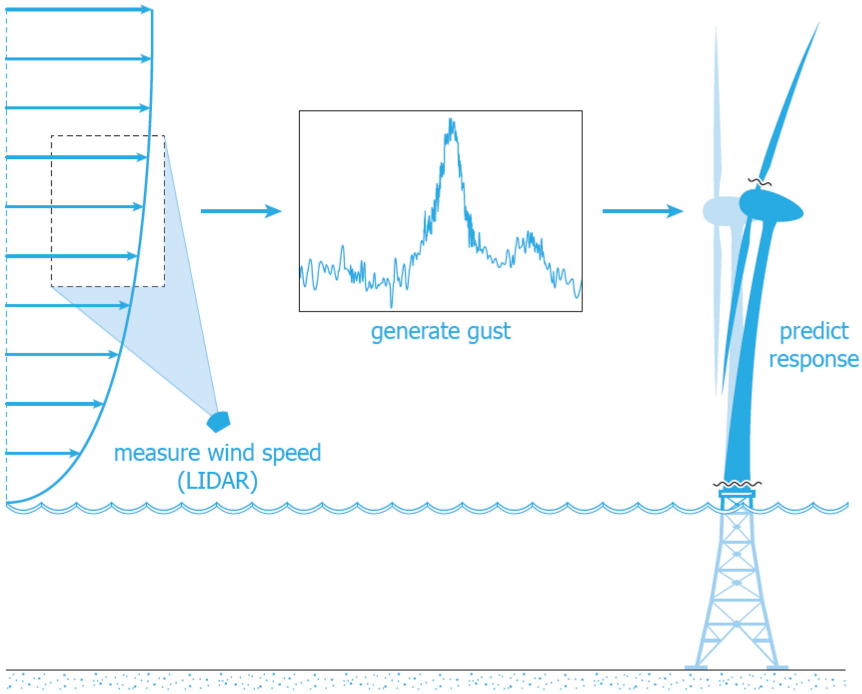

Figure 1: Predicting extreme gust loads of a wind turbine.

REFERENCES

[1] W.A.A.M. Bierbooms, “Constrained stochastic simulation – generation of time series around some specific event in a normal process”, Extremes, vol. 8, no. 3 (2005), pp. 207–224.

DESIGN OF A THIN AIRFOIL FOR DOWNWIND TURBINES

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ABSTRACT

Introduction: An airfoil was designed for large scale downwind turbines for offshore application. The blade for a downwind rotor can be more slender than for the upwind configuration. As a consequence the turbine at megawatt scale can be lighter, with advantages both structurally and economically. Moreover in offshore conditions salt and dust can deposit and modify the blade surface roughness, hence the airfoil performances should not be strongly affected by it. For these reasons and to optimize the power output the airfoil should be thin, with high Lift/Drag ratio for a wide range of angles of attack, have a smooth stall characteristic, and be insensitive to roughness. In the present study an airfoil with the above characteristics was designed and tested in the wind tunnel at NTNU.

Methodology: The airfoil was designed using the full-inverse design routine of Xfoil. The initial airfoil geometry was obtained from a pressure distribution at the design angle of attack computed using Stratford and Liebeck theories for high Lift/Drag airfoils [1]. The airfoil was subsequently modified in order to achieve also the other characteristics. Thus the airfoil was simulated with Xfoil [2] at different Reyonolds numbers (Re) and Turbulence Intensities (T.I.) to verify the performances. Lift and Drag coefficients (C_l and C_d) obtained for the external conditions of Re and T.I. achievable in the wind tunnel are compared with the experimental results.

The airfoil model consists of a 2D wing, provided with pressure taps around the surface at the symmetry plane, such that the pressure distributions at different angles of attack were measured and compared with the simulations. The wing was attached to a six components balance such that Lift and Drag were also measured directly.

Results: In figure 1 the measured pressure distribution is compared with the simulation from Xfoil, for an angle of attack of 5.1deg. Both results were obtained for Re=9.35e5 and T.I.=0.3%. The lift coefficient calculated with Xfoil is C_l=1.06, and the one obtained by integrating the measured pressure distribution is C_l= 1.03, thus 3% lower.

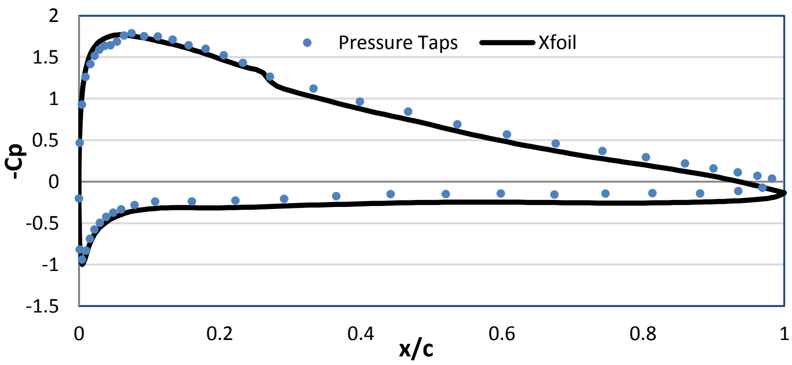

Figure 1: pressure distribution for α=5.1deg

REFERENCES

[1] R.H. Liebeck, "A class of airfoils designed for high lift incompressible flow", Journal of Aircraft, Vol. 10, No. 10. (October 1973), pp. 610-617

[2] M. Drela and H. Youngren, XFOIL 6.9 User Primer, 2001

Fluid-structure response of wind turbine airfoil to gusts using CFD

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ABSTRACT

There is a trend towards designing wind turbines with smart (active) control to reduce fatigue loading, decrease the tip deflection and/or increase performance. Feasibility studies on active trailing edge flaps (TEF) have shown that a significant reduction of the root bending moment can be obtained when an appropriate controller is used [1]. Active control can reduce the loads when extreme conditions are encountered by the wind turbine, especially during local gusts [2].

However, such a complex mechanism of Fluid-Structure-Control-Interaction (FSCI) needs to be analysed in more detail compared to a common BEM method. The increasing size and complexity of wind turbines seems to make responses to extreme wind conditions more important. As a first step the fluid-structure response of a wind turbine airfoil to a gust is analysed using CFD. The aim is to understand the interaction between gust and structural response and vice versa.

Several gust shapes are analysed: 1-cosine gust, Mexican hat and a more realistic extreme gust event based on long time series of stochastic flow [3]. In fig.1 the aerodynamics and structural response of a typical wind turbine airfoil are shown for a vertical 1-cosine gust.

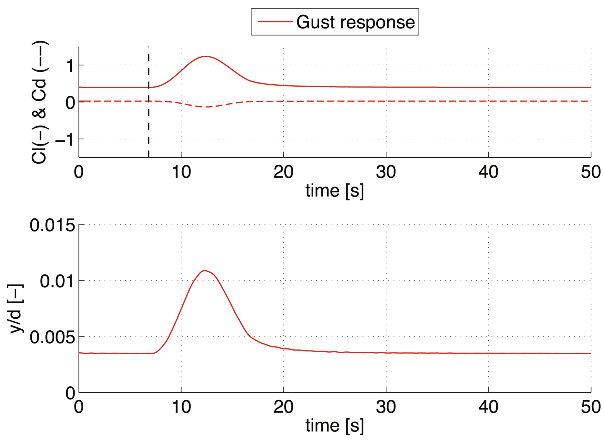

Figure 1: Aerodynamic and structural response to a vertical 1-cosine gust

The results will be compared to a BEM model widely applied in wind turbine simulations. From these results it will be analyzed how important the realistic modeling of the gust shape is for CFD simulations, and how interaction between structure and gust affects the loading on the wind turbine.

REFERENCES

[1] T.K. Barlas and G.A.M. van Kuik, “Review of state of the art in smart rotor control research for wind turbines”, Progress in Aerospace Engineering, vol.46 (2010) pp. 1-27.
[2] M.A. Lackner and G.A.M. van Kuik, “The performance of wind turbine smart rotor control approaches during extreme loads”, Journal of Solar Energy Engineering, vol.132 (2010) pp. 1-8
[3] W. Bierbooms, “Investigation of Spatial Gusts with Extreme Rise Time on the Extreme Loads of Pitch-regulated Wind Turbines”, Wind Energy, vol. 8 (2005) pp. 17-34

AEROSTRUCTURAL OPTIMIZATION OF WIND TURBINES

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ABSTRACT

The present project aims at the development of automated design procedures for the combined aerostructural optimization of wind turbines, and it represents an improvement and evolution of the tools described in Refs. [1] and [2].

In the current work, the design approach is based on the constrained mimization of the cost of energy, modelled according to Ref. [3]. However, whenever possible, scaling relationships are avoided in favour of a direct physical modeling of the cost items. Currently, detailed physical models are implemented for the rotor blades and the tower, an important step towards a comprehensive physics-based approach to design.

The design procedures are based on a two-level modeling approach, depicted in Fig. 1. From the blade and tower sectional geometry, a complete aeroservoelastic multibody model of the whole machine is generated, and used for the simulation of all relevant desing load cases (DLCs). The model is complemented by the control laws that are necessary for covering the entire operating envelope of the wind turbine. After a first optization performed at the level of the aeroelastic model, a verification of the design is performed using detailed finite element models of the blade and tower. Iterations are performed between the aeroelastic and FEM levels until convergence, as shown in Fig. 1.

The design degrees of freedom at present include aerodynamic blade parameters, and structural blade and tower parameters. The approach is capable of capturing the effects that changes in the aerodynamic shape have on performance and loads and, consequently, on the structural sizing. Ultimately, these coupled effects are felt on the cost of energy, this way enabling the identification of the solutions of best compromise the realize a minimum for the figure of merit.

The paper will illustrate the performance of the tools on the design of a modern 10MW wind turbine.

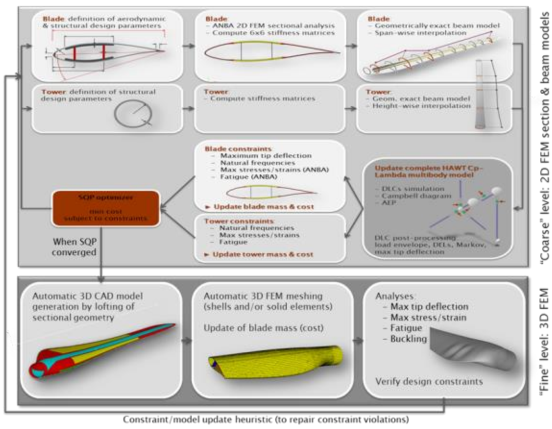

Figure 1: Aerostructural optimization procedure

REFERENCES

[1] C.L. Bottasso, A. Croce, F. Campagnolo, Multi-Disciplinary Constrained Optimization of Wind Turbines, Multibody System Dynamics, vol 27 (2012), pp 21-53
[2] F. Gualdoni, Cp-Max: A Blade Design Optimization Environment, 8th Phd Seminar on Wind Energy in Europe, 12th-13th September 2012
[3] L. Fingersh, M. Hand, and A. Laxson, Wind Turbine Desing Cost and Scaling Model, Technical Report NREL, December 2006

HIGHER-ORDER LIFTING-LINE THEORY FOR EQUAL FIDELITY AEROELASTIC ANALYSIS OF WIND TURBINE BLADES

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ABSTRACT

This paper presents research that has been carried out in the framework of a Delft University wind energy project. The aim of this project is to develop a fast aeroelastic design code for the design of composite wind turbine blades by coupling equal and low fidelity aerodynamic and structural models. In a later stadium control flaps will be added to trade off passive and active load control methodologies. This abstract focuses on the development of an aerodynamic model that matches the accuracy of the structural model, which is a sophisticated beam model, to obtain an equal fidelity aeroelastic model. Since nonlinear beam elements are used, it is required that the aerodynamic model consists of deformed line elements as well. For the steady aerodynamic forces, Weissinger's method is used. However, according to van Holten [1], Weissinger's method is not valid for unsteady flow. Therefore a higher-order lifting-line method that allows unsteady flow conditions as well is needed.

The following actions are undertaken:

1. van Holten's matched asymptotic expansion theory [1] was translated into vortex theory, as shown in figure 1, and the shape of the lifting vortex line is adapted to fit the structural shape of the blade,
2. the theory was modelled numerically for the steady case and compared to the results from Weissinger's method.

The results show that the steady case of the higher-order lifting-line theory matches Weissinger's ¾-chord theory for wind turbine blades. The validated steady higher-order lifting-line theory will then be extended to an unsteady theory. This demonstration of feasibility of an unsteady lifting line model for the preliminary design of wind turbine blades is very important for arbitrary shape and stiffness optimisation of flexible wind turbine blades.

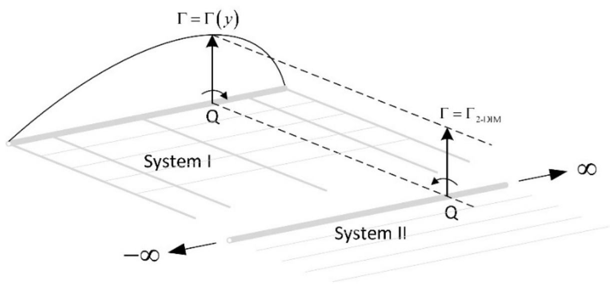

Figure 1: Exploded view of the vortex systems resulting from conversion of pressure theory to vortex theory: 3D vortex system plus local vortex line.

REFERENCES

[1] T. van Holten, "Some notes on unsteady lifting-line theory", Journal of fluid mechanics, vol.77 (1976) pp. 695-706.

ADVANCED AERO-ELASTIC MODELING OF 2-BLADED WIND TURBINES USING MULTIBODY SIMULATION

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ABSTRACT

In this work the motivation, methodology and advancements of the aeroelastic analysis of an innovative 2-bladed wind turbine design is presented. Given the current interest in alternative wind turbine concepts - especially for offshore applications - the use of 2-bladed turbine designs can significantly reduce the overall cost of energy, due to lower turbine weights and therefore higher rotor diameters and lower erection and maintenance cost [1].

The aim of this project is the analysis and reduction of the typical transient loads of a 2-bladed rotor, using high efficient numerical simulation tools that can capture the transient, nonlinear interaction of the turbine with the highly turbulent inflow. As part of a this project, the integration of an additional (active or passive) degree of freedom into the system shall be investigated, resulting in the design of an active load reduction control system.

Using a high fidelity multibody model in SIMPACK the principle load cases of a rotating 2-bladed turbine can be analysed, including the impact of a flexible blades design and various operational parameters (rotational speed, wind load, yawing rate etc.) [Fig. 1]. Due to continuously changing relative moments of inertia as well as the modal responses of the blades and wake-blade interaction, complex transient loads are exerted on the turbine structure at any time [Fig. 2]. A methodology focusing on the understanding of the aeroelastic behavior by the use of a coupled free wake-multibody simulation environment has been deployed.

The paper comprises a description of the wind turbine model as well as the results of the principle load case simulation. The use of a free wake solver for the simulation of a 2-bladed wind turbine will be discussed with regard to its computational effectiveness and its physical representation. Based on the presented simulation results the use of a passiv or active control of a tilted 2-bladed rotor system will be discussed.

Fig. 1: Multibody model (SIMPACK) of a 2-bladed wind turbine (Source: Skywind).

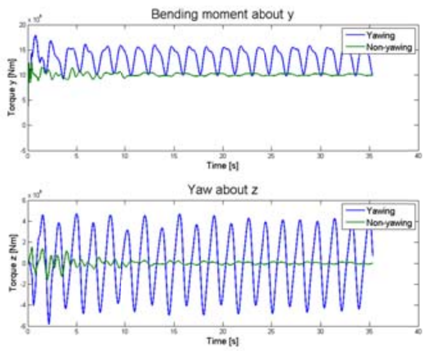

Fig. 2: Transient loading on a yawing, non-tilting 2 bladed wind turbine at $n = 17\ rpm$

REFERENCES

[1] Buliga, Andrei. *Aeroelastic comparison of two and three bladed wind turbine rotors.* Section of fluid mechanics, Technical University of Denmark. 2011. Master's thesis

Large-Eddy Simulation for wind turbine fatigue load calculation in forest regions

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ABSTRACT

There is a strong incentive for placing wind turbines in forest regions, motivated by, for example, easier maintenance compared with off-shore wind turbines. Since larger wind turbine towers are used, wind turbines can operate efficiently even in the flow above forests. However, the wind in forest regions is characterized by strong wind shear and increased turbulence levels. As a consequence of that, wind turbines in forest regions are exposed to strong fluctuating aerodynamic loads, which will affect their fatigue life and maintenance requirements.

In the present project, the turbulent flow over a forest is to be predicted with the help of Large-Eddy Simulation (LES). The forest is accounted for in the lowest part of the computational domain as shown in fig.1. In that region, a momentum sink term is added to the momentum equations [1]. The sink term can be understood as an additional, height-dependent drag force that can be tuned to represent different kinds of trees.

Turbulence is first extracted from the LES and then used as input for wind turbine load calculations.

As a first result, the mean velocity profile is given in fig.2. The solid blue line represents the computed velocity, while the red squares denote measurement data from the Ryningsnäs test site in Sweden. The dashed horizontal line indicates the top of the canopy. Simulation data show good agreement with the measurements and also the presence of the forest is clearly shown in the velocity profile.

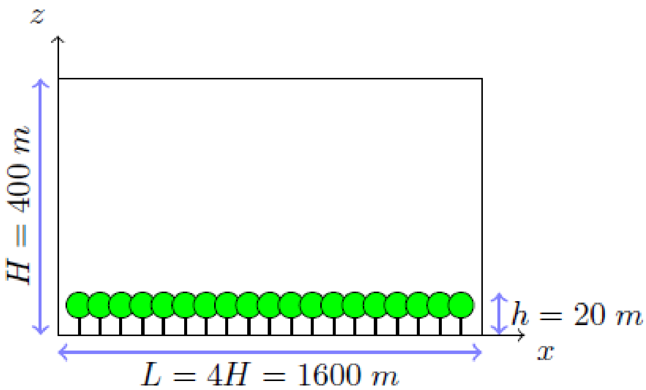

Figure 1: The computational domain

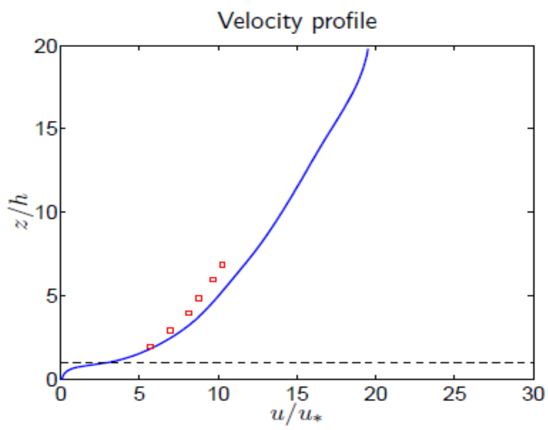

Figure 2: Mean velocity field

REFERENCES

[1] R.H. Shaw, U. Schumann. "Large-Eddy Simulation of Turbulent Flow above and within a Forest". Boundary-Layer Meteorology 61: 47 – 64, 1992

AERODYNAMIC DAMPING OF NONLINEARILY WIND-EXCITED ROTOR BLADES

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ABSTRACT

In designing support structures of offshore wind turbines, knowledge of the wind-structure interaction is important. Besides a loading component, an added damping contribution – so-called aerodynamic damping – is often distinguished. The size of the aerodynamic damping varies with the angle with which the effective wind flow approaches the turbine, the angle of attack. Besides, both mean wind velocity and turbine state – operating or idling – affect the amount of aerodynamic damping.

In current support structure design, aerodynamic damping is only taken into account for operating turbines, excited in the fore-aft direction. The estimated damping is based on a linearized load formulation, while the mutually affecting response of the rotor and the combined tower and support structure is decoupled [1]. This research aims at constructing a simple model for preliminary support structure design, taking into account different turbine states and multidirectional wind loading. The specific goal of this paper is the derivation of wind-direction-dependent damping coefficients for the rotor as a whole, including the nonlinear quadratic drag term in the wind force formulation.

In order to estimate the actual aerodynamic damping, an individual turbine blade is modeled as a mass-spring system with two degrees of freedom (see fig.1). The wind flow vector represents both the magnitude of the relative velocity and the angle of attack. Both drag and lift are considered. Due to the structural response, the angle of attack is a function of the feedback velocity of the blade. The evaluation of the wind-structure interaction is done using Volterra series expansion, which can be seen as an extended Taylor series expansion, applicable for time dependent systems. Volterra series expansion allows for frequency response respresentation of the nonlinear loading [2]. Turbine characteristics are adopted from the NREL5-MW turbine [3].

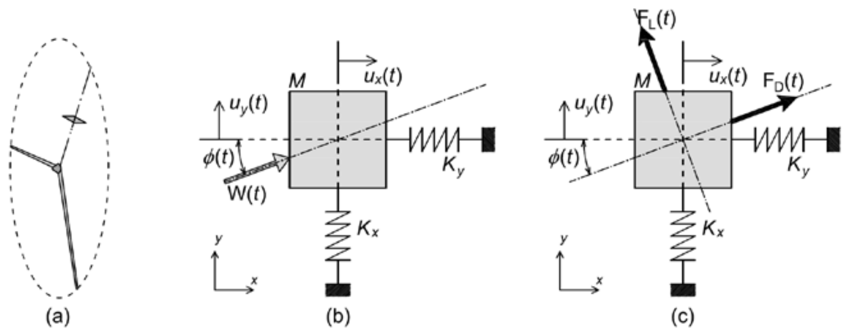

Figure 1(a) blade representation by concentrated mass, (b) wind flow and mass-spring system interaction, and (c) lift and drag force excitation.

REFERENCES

[1] T. Burton, N. Jenkins, D. Sharpe, and E. Bossanyi. "Wind Energy Handbook, Second Edition" John Wiley & Sons, Ltd., West Sussex (2011).
[2] L. Carassale and A. Kareem. "Modeling nonlinear systems by Volterra series", Journal of Engineering Mechanics, vol. 136 (2010) pp. 801-818.
[3] J. Jonkman, S. Butterfeld, W. Musial, and Scott G. "Definition of a 5-MW reference wind turbine for offshore system development." Technical Report NREL/TP-500-38060, National Renewable Energy Laboratory, Golden, Colorado (February 2009).

Fatigue load monitoring of wind turbines in a wind farm based on standard signals

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ABSTRACT

It is foreseen that offshore wind energy will be generated by larger wind turbines located far from the shore. The lower accessibility of such sites over the year represents a challenge for their operation and maintenance (O&M). Therefore, increasing their reliability is a necessary step to improve the cost of energy by reducing their O&M costs. Additionally, the loading history of wind turbines during operation is normally not known, load measurement campaigns are mostly limited to prototypes or to very limited periods of time. Finally, actual loads at a given site are hard to predict [1].

The objective of the research addresses the need for a system that monitors fatigue load of wind turbines located in a wind farm without compromising their reliability (i.e. without the need of additional sensors) by using available standard SCADA signals. A need which has previously been investigated using neural networks to estimate load indicators [1], [2], [3], [4] and which is further extended giving special attention to the wind farm effects in offshore locations.

The approach presented in this study is part of a PhD project and includes the comparison of previous researches [1], [2], [3], [4] to define the baseline methodology for the project. The approach includes the use of measurement data to validate an aeroelastic model, which itself facilitates training the neural network for less probable events, which are not recorded during the measurement campaign. The data used to train and test the neural networks comes from the research project “Control of offshore wind farms by local wind power prediction as well as by power and load monitoring” (Baltic I), which is funded by the German Environmental Ministry. The EnBW Baltic 1 wind farm includes 21 Siemens 2.3-93 wind turbines located 13 km north of the Darß peninsula in Germany.

The results encompass the definition of a methodology that uses several statistics from SCADA signals and a trained neural network to estimate fatigue loads on a wind turbine located in a wind farm, as well as the definition of further improvements needed for its generalization, which are classified in those that represent the physical phenomena and are used to feed the neural network, those referred to the neural network topology itself, and finally, those that represent the output data based on its potential use.

REFERENCES

[1] Cosack, N., “Fatigue load monitoring with standard wind turbine signals”, PhD thesis, University of Stuttgart, 2010
[2] Smolka, U., et al, “Fatigue load monitoring for a tripod support structure based on standard wind turbine signals”, EWEA Offshore Conference, 29 Nov – 01 Dec 2011, Amsterdam, The Netherlands
[3] Obdam, T.S., et al, “Flight leader concept for wind farm load counting”, ECN-E-09-068, Energy Research Centre of the Netherlands, 2009
[4] Hofemann, C., et al, “Analysis of wind turbine data with view towards load monitoring”, 5th PhD Seminar on Wind Energy in Europe 2009, 30 Set – 01 Oct 2009, Durham, United Kingdom

TURBULENCE, ABL & MEASUREMENTS

Qualyfying an on-shore met-mast for measuring off-shore wind

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Full-scale wing measurements have been accomplished on an island (Frøya) off the coast of Trøndlag in Norway. Time series of wind speed and temperature are obtained for two and a half years using ultrasonic anemometers in a 100 meters high met-mast at the wind measuring station Skipheia (Station A) located on Frøya. A secondary met-mast (Station B) is located on the Sletringen islet, and is occupied by a single 3-d ultrasonic anemometer at 45 meters height. Sampling rates of the anemometers at Station A and B are 1 Hz. On those time series some minor gaps occurred due to power cut.

In the course of time, two LIDARs were engaged at sites A, B and C for relatively shorter yet adequate periods, for validation of off-shore wind and spatial analysis purposes (see Fig 1).

Figure 1: Location of the measurement stations.

1. Comparison of the LIDAR and met-mast measurements

A STATISTICAL DESCRIPTION OF THE MEANDERING OF A WIND TURBINE WAKE IN HOMOGENEOUS TURBULENCE

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ABSTRACT

The meandering motion of a wind turbine wake is an important input to aeroelastic simulations of a wind turbine operating in the wake of another wind turbine. The current state of the art method for simulating this meandering motion, without resorting to LES simulations, models the wake as a passive tracer emitted in a frozen turbulence field, see e.g. Larsen et al. [1]. The approach presented here replaces the afore-mentioned frozen turbulence assumption and models instead the wake meandering motion by a process that could be described as a wavelength dependent random walk.

An important input is the downstream correlation of a rotor averaged wind speed. This information can either be measured in the field, using at least two for the purpose instrumented met masts, be extracted from LES or DNS simulations or be extracted from the correlation in both time and space, $R_{ij}(\boldsymbol{r},\Delta t) = \langle u_i(\boldsymbol{x},t) \cdot u_j(\boldsymbol{x}+\boldsymbol{r},t+\Delta t)\rangle$, provided that these statistics are known for the incoming wind field, see Ott and Mann [2] and Hunt et al. [3]. The output is statistics of the meandering motion at any downstream position, from which realistic time series of the meandering motion readily can be generated.

REFERENCES

[1] G. C. Larsen, H. A. Madsen, K. Thomsen, and T. J. Larsen, “Wake meandering: a pragmatic approach”, Wind Energy, vol. 11 (2008), no. 4, pp. 377–395.
[2] S. Ott and J. Mann, “An experimental test of Corrsin’s conjecture and some related ideas”, New Journal of Physics, vol. 7 (2005), p. 142.
[3] J. C. R. Hunt, J. C. Buell, and A. A. Wray, “Big whorls carry little whorls”, in Studying Turbulence Using Numerical Simulation Databases (1987), pp. 77–94.

NEAR-SHORE WIND MEASUREMENTS WITH THE SPHERE ANEMOMETER AND STANDARD SENSORS IN WIND ENERGY

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ABSTRACT

The Sphere Anemometer is a new approach to drag-based wind speed and direction measurements which makes use of the flow-induced forces acting on a flexible tube with a sphere on top. The velocity-dependent deflection of the sphere-tube combination is detected by means of the highly resolving light pointer principle. This allows for the simultaneous measurement of both horizontal wind components with a time resolution better than 30Hz [1]. The Sphere Anemometer exhibits neither over-speeding like known from cup anemometers [2], nor flow disturbances due to support structures as occurring for most ultrasonic anemometers designs [3].

In our contribution we will introduce the measuring principle and characteristics of the Sphere Anemometer. Additionally, we will compare measurements with Sphere Anemometer, a 3D ultrasonic anemometer and a state-of-the art cup anemometer obtained from measurement campaigns at two near-shore sites. Although both sites are located in the German Wadden Sea the anemometers a facing quite different conditions, as one site is a research platform exposed to a rather undisturbed wind field while the second site is the nacelle of a multi-megawatt wind turbine.

Figure 1: Sphere anemometer and cup anemometer installed on the nacelle of a near-shore wind turbine in the German Wadden Sea.

REFERENCES

[1] H. Heißelmann, J. Peinke, M. Hölling, "The Sphere Anemometer: Characteristics and Restults from Field Test", Proceedings of the German Wind Energy Conference DEWEK (2012)

[2] A. Albers, D. Klug, D. Westermann, "Cup Anemometry in Wind Enginieering, Struggle for Improvement", DEWI Magazin, vol.18 (2001) pp. 17-28.

[3] A. Wiesner, F. Fiedler, U. Corsmeier, "The Influence of the Sensor Design on Wind Measurements with Sonic Anemometer Systems", Journal of Atmospheric and Oceanic Technology, vol.18 (2001) pp. 1585-1608.

Digital Holographic Particle Image Velocimetry for 3D Flow Measurements

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ABSTRACT

To answer current questions in fluid dynamics and turbulence research three dimensional fluid flow measurements with high temporal resolution are demanded. A technique which does without large measurement equipment within the flow in order to minimize effects on the flow behavior is particle image velocimetry (PIV). Small particles are induced into the flow and a sheet within the flow is illuminated with laser pulses. The light scattered by the particles is recorded by a camera. From the particle movement between these images, the flow behavior is extracted indirectly. A technique expanding this spatially two dimensional technique to the third dimension is tomographic PIV. Usually, at least four cameras are adjusted precisely to each another. Then, conclusions can be drawn about the behavior of the flow from the recorded scattering light. The work presented here deals with a different approach, which uses only a single camera for three dimensional measurements by employing not only the scattered light intensity but also its phase information. In digital holographic PIV the tracer particles are illuminated with coherent, collimated light and the light scattered by the particles, the so-called object beam, is superposed with unscattered light, which serves as the reference beam . The superposition on a camera chip generates a digital hologram. Subsequently, the original light fields in time are reconstructed by simulating a reconstruction with a plane wave numerically and the particle positions have to be detected. The hologram reconstruction is highly amenable to parallelization. Hence, we employ calculations on a graphics processing unit. Besides the financial benefits of using only a single camera, it also simplifies measurements of flows with only few possibilities for optical accesses, as in-line holography requires only two accesses. These are needed for the illuminating collimated beam and for the object beam. Furthermore, a continuous wave laser is employed and hence, the temporal resolution of the system is only limited by the frame rate of the camera and not by pulse repetition rates of lasers.

Apart from theses advantages, digital holography applied to fluid flow measurements possesses need for further development before it can be used as a customary technique similarly to two dimensional PIV. The poor resolution of digital sensors in comparison to formerly used photographic plates yields a small numerical aperture and hence a large depth of focus in the reconstructed particle images. The precision of the particle reconstruction influences the success of subsequent particle tracking. Hence, algorithms have to be found that deliver a sufficient spatial resolution in three dimensions. Furthermore, the reconstructed particle images contain speckle, which can be generated by random constructive interference of light scattered by several particles within the volume. So an algorithm should also be capable of distinguishing between reconstructed particles and speckle. Here, using the access to the phase information in addition to the intensity information in digital holography offers a promising approach. Though the numerical reconstruction yields intensity as well as phase information of the original light field, most known algorithms use the intensity information only. In spite of this, our measurements reveal more distinct phase structures in comparison to the intensity profiles. So an algorithm is implemented that excludes random constructive interferences without defined phase structures from scattering particles while the total information of intensity and phase is used in order to gain a higher precision of particle localization. This algorithm is applied to holograms recorded of polystyrene particles moving in a water flow and the reconstructed particle positions are tracked in time. The application of this technique in water flows offers the possibility to investigate flows with higher Reynolds numbers than would be reached in air flows, which facilitates further research of turbulent fluid dynamics.

Far shore atmospheric conditions in scope of wind turbine design

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ABSTRACT

In this research it is aimed to quantify far shore atmospheric conditions in scope of wind turbine design. The research has an interdisciplinary orientation, and both in depth meteorological research is carried out alongside applied wind turbine design analyses. Key topics are the description of wind shear and turbulence statistics and the impact of atmospheric stability on both atmospheric conditions as well as on wind turbine design. A crucial outcome of the research is a framework that describes how to determine wind turbine design parameters for a far shore site, also in absence of local observation data, and how to prescribe atmospheric conditions for far shore wind turbine design.

Research carried out so far shows that Monin-Obukhov [1] similarity theory can be applied in the lowest 100m of the far shore atmospheric boundary layer. This has led to a choise of accurate stability corrected wind profiles, turbulence spectra and wind variance profiles for a far shore site. These formulations have been used to initialize fatigue load analyses with the design software Bladed for the NREL 5MW reference wind turbine. A reference simulation was also initialized where atmospheric conditions where prescribed as stated by the IEC guidelines.

It is found that atmospheric stability causes a coupling between wind shear and turbulence. This coupling is not included in the IEC guidelines, which causes an overestimation of fatigue loads by approximately 10% (fig 1.). Besides, it is recognised that the relative amount of shear and turbulence in the atmosphere depends strongly on atmospheric stability. Most likely this does not only influence wind turbine fatigue loads, but in fact any process that depends on both wind shear and turbulence.

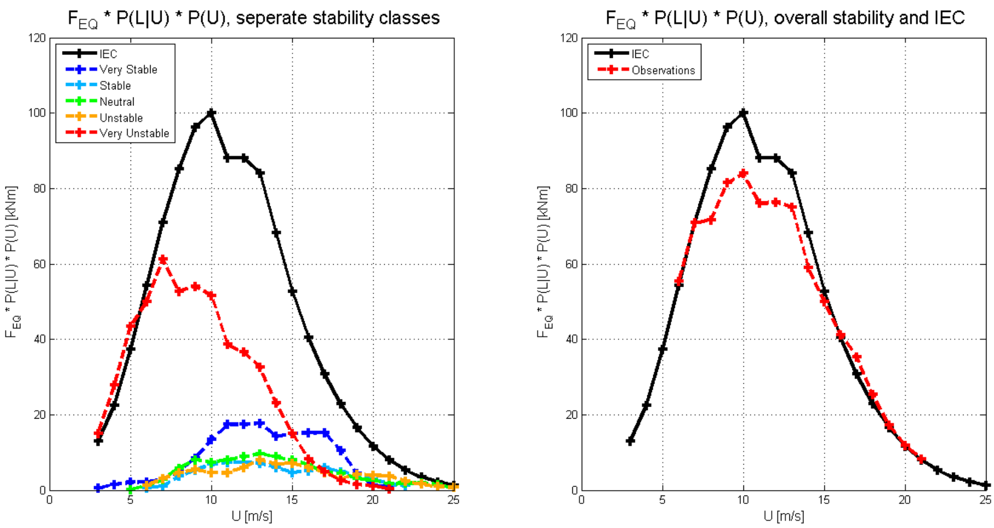

Figure 1: equivalent loads as a function of stability (left) and cumulative loads (right).

REFERENCES

[1] Monin, A. S. and Obukhov, A. M. (1954): *Basic laws of turbulent mixing in the ground layer of the atmosphere.* Tr. Akad. Nauk., SSSR Geophiz. Inst., 24 (151)

Force dynamics of airfoil segments with active flow control under turbulent in-flow conditions generated with an active grid

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ABSTRACT

Wind turbines work within the atmospheric boundary layer (ABL), which is dominated by turbulence. A proper analysis of such turbulent flows shows that they are highly intermittent, i.e. they feature gusty structures. These gusty structures have a big impact on the wind energy conversion process, e.g. mechanical load fluctuations, wich are considered to increase wind turbine failure rates [1][2]. Active flow control (AFC) elements on rotor blades are desired, to reduce changing forces caused by the turbulent in-flow conditions.

The aim of the present project is the development of a new testing approach for wind tunnel experiments, that allows an investigation of the force fluctuations on airfoil segments with and without AFC elements under realistic and reproducible conditions. Therefor, the turbulent in-flow is generated by an active grid which is mounted at the wind-tunnel nozzle in a closed test section (fig.1). It has been shown, that the reproduction of in-flow conditions comparable to those in the ABL is possible with this setup [1]. Aerodynamic quantities of interest e.g. lift and drag forces and pitch and roll moments will be measured using a six-component force balance.

To achieve a quantitative analysis of the performance of AFC units, it its intended to develop a stochastic method, which enables to differentiate between deterministic and noisy dynamics of the response (control) system. We expect that such kind of quantification of the performance of AFC systems will be useful for further academic and industrial investigations.

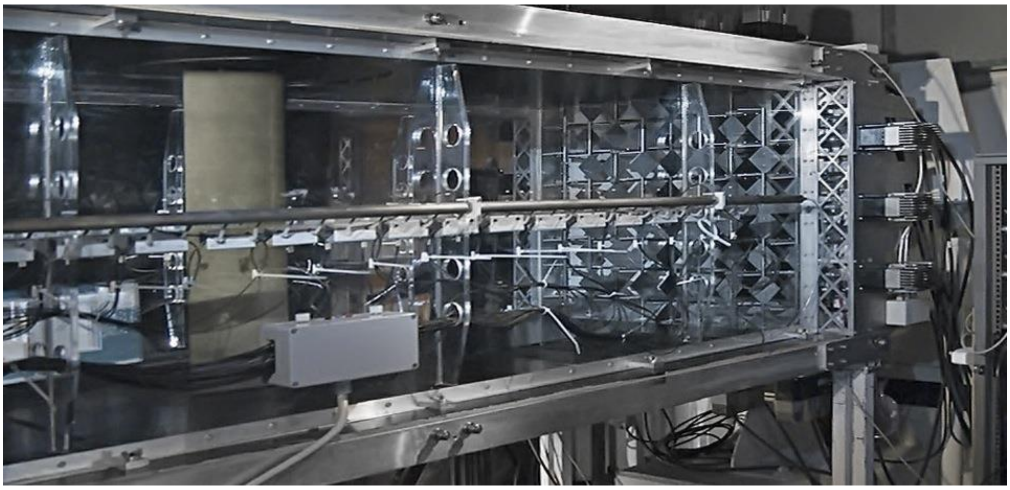

Figure 1: Closed test section with active grid and 2D airfoil segment.

REFERENCES

[1] M. Wächter, H. Heißelmann, M. Hölling, A. Morales, P.Milan, T. Mücke, J. Peinke, N. Reinke, P. Rinn, "The turbulent nature of the atmospheric boundary layer and its impact on the wind energy conversion process", Journal of Turbulence, 2012, 13, N26

[2] P. Tavner, Y. Qiu, A. Korogiannos, Y. Feng, "The correlation between wind turbine turbulence and pitch failure", EWEA 2011, p.149

CTRW 3D wind field and its influence on fatique

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ABSTRACT

The Wind Energy standards[1] specifies different wind field models to simulate the turbulent inflow conditions for wind turbines. These models are generating purely Gaussian statistics for the wind fluctuations, which is in contrast to experimental data. The main idea of this work is the simulation of stochastic 3-dimensional wind fields considering advanced characterization of turbulence on scales ranging from a few meters to some hundred meters. For simulation Continuous Time Random Walk (CTRW) theory is used. The model enables to adapt parameters in order to accurately reproduce time dependent statistical features of wind turbulence. These statistical futures and its influence on wind turbine fatigue are investigated.

REFERENCES

[1] [1] IEC 61 400-12-1, 1st Ed. 2005-12

RECONSTRUCTING TURBULENCE COHERENT STRUCTURE AS SIMULATION INTITIAL CONDITION USING LARGE-EDDY SIMULATION VIRTUAL-FLIGHT-MEASUREMENT

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ABSTRACT

In order to build any type of wind energy facility a proper statistic evaluation of the wind behavior and its power potential at the construction region are among the most dominant design and manufacturing parameters. Wind turbulence random nature and its extreme nonlinearities coming from convections and dissipations has been proved to require approximated models capable to describe it varying on accuracy and the scale of interest. Apparent evidences for this are researches for decades and enormous efforts has been made in academic and industrial areas to develop models which match experiments the best. Adding this all to the fact an applicable simulation requires a realistic initial conditions the measurement comes to play the feeder role in all procedures in the field.

The turbulence study of the atmospheric boundary layer is one of the most relevant to the wind energy production field. Due to involvement of high altitudes in which measurements are taking place flights are one of possibilities to obtain the sample properties. In Environmental physics chair of Center for Applied Geoscience at Universität Tübingen Unmanned Aerial Vehicle (UAV) flights are the main approach to accomplish this goal.

Furthermore constructing the turbulence field in a fine time and space resolution from the coarse measurements source is an elaborate task. This can be observed both in the cost and limits of the remote measurement. During this work a code-package in C and C++ languages is going to be developed which is going to implement the complementary technique [1] by using both the Proper Orthogonal Decomposition (POD) [2] and the Linear Stochastic Estimation (LSE) [3] to extract the most out of the limited amount of the information for reconstructing the turbulent field. Beside that, in-house use of Linear Algebra Package (LAPACK) [6] libraries has made many of large scale numerical efforts more convenient.

Using PALM [4] open-source simulation software, spatial and temporal properties of the flow resulted from simulation are in hand. A small portion of the result data-set will be selected to mimic the real parallel-swarm-flight measurement data. The combined properties are then going to be used as input for the DLR-TAU Software [5] for further Detached-Eddy Simulations. This is possible by extracting coherent structures of the turbulence and combine them by the statistic synthetic turbulence properties. As an enhancement the effect of the added coherent structure to DLR-TAU input will be studied.

Finally the ultimate outcome of this work series is going to use the real measurement data obtained by UAV parallel-swarm-flights as input for study of the turbulence and the current work is the first attempt to practice that procedure.

REFERENCES

[1] J. P. Bonnet, F. Coiffet, J. Delville, E. Lamballais, J. F. Largeau and L. Perret, “Generation of Three-Dimensional Turbulent Inlet Condition for Large-Eddy Simulation”
[2] G. Berkooz, P. Holmes, J. L. Lumley, “The Proper Orthogonal Decomposition in the Analysis of Turbulent Flow”
[3] R. J. Adrian, “Stochastic Estimation of Conditional Structure: a Review”
[4] PALM, http://palm.muk.uni-hannover.de/
[5] TAU, http://tau.dlr.de/
[6] LAPACK, http://www.netlib.org/lapack/

A BAYESIAN MODEL OF WIND DIRECTION

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ABSTRACT

In many wind energy studies, wind velocity and wind direction constitute the basis of the research. Our current interest lies in statistical modeling of wind direction as a powerful wind direction model ultimately leads to a viable short term wind power forecast model. On that account, it has been crucial to model wind direction as a circular component. We consider a circular time series modeling for wind direction to take the account of their dynamic structure over time. We propose a novel wrapped autoregressive wind direction model along with a Bayesian methodology for statistical inference. We analyze the wind direction data recorded hourly in a northwestern wind farm in Turkey between 1 january 2012-31 january 2012 and apply our method to model the hourly shift in wind direction. Proposed model is also compared against the standard wrapped autoregressive time series based on an information criterion. The proposed wind direction model is expected to improve the short term wind power forecast.

Wind Prediction Enhancement by Environmental Parameters

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ABSTRACT

We currently consider a linear prediction approach to wind speed prediction based on temporal and spatial data. In this approach, the wind speed and direction are modelled by the magnitude and phase of a complex valued time series [1,2]. For temporal prediction only, in the past multivariate techniques have been applied, such as quaternions where the 4 parameters comprise of the 3-dimensional wind velocity and temperature [3,4]. The aim of this project is to explore such multivariate prediction methods, and to see whether an advantage in terms of short term prediction of wind speed can be extracted.

The purpose of this project is twofold. Firstly, multivariate signal processing methods will be reviewed, with a particular attention to whether vector-valued arithmetic or representation by compact forms such as as complex numbers or quaternions offer advantages in terms of processing and/or performance [5]. Secondly, the major aspect of the project will be to apply such methods to multivariate FINO offshore platform research data [6]. For this, the inspection of the data and identification of "good" intervals — i.e. no or little missing data, checking for anomalies such as outliers, etc — will be vital. The method can be benchmarked against persistence and existing prediction implementations that use 2-dimensional wind velocity only [2].

REFERENCES

[1] J. Dowell, S. Weiss, D. Hill, and D. Infield. A complex-valued multichannel filter approach to short term directional wind forecasting. Wind Energy, 2013. (submitted).

[2] J. Dowell, S. Weiss, D. Hill, and D. Infield. A cyclo-stationary complex multichannel Wiener filter for the prediction of wind speed and direction. In 21st European Signal Processing Conference, Marrakech, Morocco, September 2013. (submitted).

[3] C. Jahanchahi, C. Took, and D. Mandic. On HR calculus, quaternion valued stochastic gradient, and adaptive three dimensional wind forecasting. In International Joint Conference on Neural Networks, pages 1–5, Barcelona, Spain, July 2010.

[4] C. Took and D. Mandic. The quaternion LMS algorithm for adaptive filtering of hypercomplex processes. IEEE Transactions on Signal Processing, 57(4):1316–1327, April 2009.

[5] C. Took, D. Mandic, and J. Benesty. Study of the quaternion LMS and four-channel LMS algorithms. In IEEE International Conference on Acoustics, Speech and Signal Processing, pages 3109–3112, 2009.

[6] http://www.fino-offshore.de

Turbulence and Wake measurements at wind turbines using several unmanned aerial vehicles at one time

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ABSTRACT

The aim of this project, started in March 2013, is to obtain measurements of the airstream velocity near wind turbines at several fixed points at a high frequency rate (above 1 kHz).
There are already some ongoing projects regarding airborne flow measurements near wind turbines at other universities. A good overview is given in [1].
The difference to these projects is that we want to achieve a simultaneous measurement of flow data at several discrete points in space. With a suitable spatial and temporal resolution a better validation and comparison of CFD simulations to the field environment will be given.

In the context of this project an appropriate aircraft configuration shall be evaluated or, if necessary, developed here at the university. It is a precondition that the aircraft must have a takeoff weight below 5 kg. This will be an immense advantage for official flight permissions according to the regulations in most European countries.

Another important part of the project is the choice of measurement equipment, its integration at the aircraft and the calibration of probes in the wind tunnel.

REFERENCES

[1] G. Giebel (ed.), U.Schmidt Paulsen, J. Bange, A. la Cour-Harbo, J. Reuder, S. Mayer, A. van der Kroonenberg, J. Mølgaard, Autonomous Aerial Sensors for Wind Power Meteorology - A Pre-Project, Risø-R-1798(EN) January 2012

Experimental Stereo Vision Studies of Flow and Structural Effects on Wind Turbines

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ABSTRACT

Modern vision technologies show great potential in wind energy research. In this project they will be used and developed to study dynamical movements of turbines and also certain flow properties. Through this project, stereometric techniques are going to be used to measure deflections and characterize the dynamics of a small, floating, model-scale offshore wind turbine with a vertical axis of rotation. This knowledge will be coupled to dynamical models of the turbine. In the other part of the project, the cameras will be used to measure the tip vortex of an operating wind turbine using Background Oriented Schlieren method (BOS), actually this method uses the refractive index distribution in a density gradient field to find the flow patteran around the target object.Finally the results will be compared to current models of the vortex. BOS method has been successful in studying different types of flow such as tip vortices around the helicopter blades [1].

This method has been used for measurements in wind turbines at Risø Campus of DTU. U.S. Paulsen and et al. in their recent studies on wind turbines have indicated that Full-field optical techniques, particularly stereo photogrammetry and videogrammetry systems, have some intrinsic features and capability that are extremely advantageous for the present challenge of measuring the operational deflection shapes of huge rotating objects [2,3].

So far, the image acquisition system has been set up that takes synchronous images by two cameras and store them on the hard disk. In addition, software to control frame rate and exposure time has been produced. Furthermore, some preliminary investgstions on BOS were done by carrying out a small test to identify the plume around the candle. Another small test was arranged to detect the motion of a pendulum which was traveling on a semi circular path as a practice for the stereo vision experiments.

Now, we are trying to configure the BOS test for a 35 m tall horizontal axis wind turbine, so the positions of the cameras, lens characteristics and the pattern position, located behind the tip vortices, are being set up and the tests will be done soon. Also I would have a presentation in stereometric techniques at the Wind Turbine Measurement Technique course in DTU.

REFERENCES

[1] Paulsen, U. S., schmidt, T, & Erne, O. (2010). Developments in Large Wind Turbine Modal Analysis Using Point Tracking Videogrammetry. Proceedings of the 28th IMAC, Conference on Structural Dynamics.

[2] Yang, Z., Sarkar, P., & Hu, H. (2012). Visualization of the tip vortices in a wind turbine wake. The Visualization Society of Japan, 15, 39–44.

[3] Richard, H., Raffel, M. (2001). Principle and applications of the background oriented schlieren (BOS) method. Journal of Measurement Science and Technology, 12, 1576–1585.

NEW APPROACH FOR HIGHLY RESOLVED MEASUREMENTS IN ATMOSPHERIC FLOWS

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ABSTRACT

Investigations of turbulent flows within the atmospheric boundary layer are of great interest for the wind power sector. Particularly, there is a demand for better understanding small-scale turbulent structures, which presumably have an impact on airfoil dynamics of wind turbines. Standard anemometers like ultrasonic or cup anemometers do not yield the necessary spatial and temporal resolution in order to address this lack of knowledge. For that reason we present a new kind of anemometer, the so-called 2d-Atmospheric Laser Cantilever Anemometer (2d-ALCA, figure 1), which can operate in rough atmospheric environments and is capable of performing measurements with a spatial resolution of about 1mm and a temporal resolution greater than 1kHz. The sensing element is a tiny cantilever, which experiences some drag forces when exposed to the flow. Its deformation is gathered by means of the laser pointer principle, similar to the measuring technique used in atomic force microscopes. For a straight inflow the cantilever bends like a free-hanging and loaded beam structure, whereas oblique flows cause additional twisting. Thus two velocity components can be measured simultaneously.

Figure 1: Design of the 2d-Atmospheric Laser Cantilever Anemometer with detailed view of the Cantilever.

The cantilever is made of stainless steel and is coated with gold for protection against corrosion due to humidity and salty air. First measurements with the prototype were taken at a nearshore test site in Northern Germany and on the FINO3 met mast. The data sets of the 2d-ALCA match very well with measurements obtained from a standard cup anemometer for low frequency regions, i.e. frequencies, which are resolved by both sensor types. For higher frequencies up to the resonance frequency of the cantilever, the 2d-ALCA gives an insight into the small scale structures of the turbulent flow. Increment statistics were computed up to time steps of 10ms. On scales below 10s intermittent behaviour is prominently present.

REFERENCES

[1] S. Barth et al., Laser-Cantilever-Anemometer - A new high resolution sensor for air and liquid flows, Rev. Sci. Instrum. 76, 075110 (2005)

TURBINE MODELING AND CONTROL

The Influence of Tip Speed Ratio Variations on the Wake behind Two Model Wind Turbines

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ABSTRACT

Already in the design phase of a wind farm the aerodynamic interactions between the wakes of single turbines are of great importance. In a wind farm arrangement the wake behind the upwind turbines will inevitably affect inflow conditions and thus also the energy potential of the downwind turbines. Besides a significant deficit in wind velocity the downstream turbines are objected to increased turbulence intensity levels. The additional turbulence can cause intense material fatigue through flow-induced vibrations at the downstream rotor.

By the means of hot wire measurements the local velocity deficit and the turbulence intensity in the wake behind an array of two model wind turbines are assessed in the wind tunnel laboratory at NTNU Trondheim. The effect of limited or increased tip speed ratio of both turbines on the flow field in the wake behind the array of two turbines is investigated. At a fixed separation distance of three rotor diameters between the two turbines the wake profiles are recorded for different tip speed ratio combinations at another three rotor diameters downstream of the second turbine.

It can be observed that an operation of the first turbine at the optimum power point causes the highest velocity deficits for constant second turbine tip speed ratios. In this case, the maximum possible kinetic energy is extracted by the first turbine. However, the minimum velocity deficit in the wake behind the two turbines is also very dependent on the tip speed ratio of the second turbine. The highest velocity deficit is found for a high second turbine rotational speed. Conversely, a low second turbine tip speed ratio yields comparatively low velocity deficits.

Evaluating the dimensions of the wake profiles it is primarily the first turbine tip speed ratio, which defines the width of the wake. Furthermore, a significant influence of second turbine's rotational speed on the symmetry of the wake could be found. High second turbine tip speed ratios result in an almost symmetrical wake profile. The obvious asymmetries at low rotational speeds of the second turbine are assumed to originate from a strong rotation in the rotor wake interacting with the turbine tower. But also increased first turbine rotational speeds intensify the turbulent mixing process and result in a more symmetric wake profile. The maximum turbulence intensities in the wake are predominantly influenced by the second turbine rotational speed. The highest turbulence intensities can be found for a high tip speed ratio of the second turbine.

REFERENCES

[1] L.J. Vermeer, J.N. Sørensen, A. Crespo. “Wind turbine wake aerodynamics”. Prog Aerospace Sci 2003;39:467e510.
[2] B. Sanderse. “Aerodynamics of wind turbine wakes: literature review”. ECN 2009. Report ECN-E-09e016.
[3] M.S. Adaramola, P.Å. Krogstad. “Experimental investigation of wake effects on wind turbine performance”. Renewable Energy 36 (2011) 2078e2086.
[4] R. Gómez-Elvira, A. Crespo, E. Migoya, F. Manuel, J. Hernández. “Anisotropy of turbulence in wind turbine wakes”. J Wind Eng Ind Aerodyn 93 (2005) p. 797-814.
[5] S. Barber, N. Chokani, R.S. Abhari. “Wind Turbine Performance and Aerodynamics in Wakes within Wind Farms”. Proc EWEA 2011.

ELECTROMECHANICAL DRIVETRAIN SIMULATION

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ABSTRACT

Wind turbines are complex structures that are subject to different dynamic loads from fluctuating wind resource and the dynamic behaviour of the grid. The DTU developed Horizontal Axis Wind turbine simulation Code (HAWC2) is one of the leading simulation software used by industry and academic research to study the time domain response of wind turbines [1]. The models used by the software are structures based on multi-body system (MBS) dynamics theory and the aerodynamic part is based on the blade momentum theory [1]. One area that needs further investigation is dynamics of the drive train. For example, the gearbox and generator system in aerolastic studies are often treated as ideal or first order systems. In [2] the gearbox is considered ideal, therefore the drive train model is implemented by referring the generator rotor inertia to the low-speed shaft. Hence, there is no formulation that contains several degrees of freedom (DOF) that could describe the behaviour of the gearbox and its interaction with the rest of the turbine. The fundamental motivation for working on more detailed models of the wind turbine components is that it is possible to create a framework for reliability, by investigating the internal loads in the drive train, and how those loads have interacted with the rest of the wind turbine. Incidentally, the gearbox is the most expensive subsystem in the wind turbine to maintain [3] and the one that presents the most failure.

In [2], an integrated dynamic analysis platform using HAWC2 and Matlab/Simulink was developed and used to study the impact of grid faults on wind turbine structural loads. In this framework, HAWC2 is used to simulate the blades, shaft and tower of the wind turbine, while MATLAB and Simulink is used to simulate the electrical generator, the controllers and the power system.

Existent work within the theory of gear transmissions have focused in modelling techniques of gear contacts [4] and the internal dynamics of a planetary stage gearbox [5] using MBS. The objective is to create detailed drive train models with increasing complexity, such as [6], in order to obtain more detailed information of the drive train loads in a wind turbine. The first stage in this work begins with a MBS formulation of the drive train to study the influence of additional DOFs and flexibilities into the structural loads of the wind turbine.

REFERENCES

[1] T.J. Larsen and A. M. Hansen, "How 2 HAWC2, the user's manual," tech. rep., DTU Wind Energy 2012.
[2] B. Barahonam, A. D. Hansen, N. A. Cutululis, and P. Sørensen, "Coupling of HAWC2 and Matalab: Towards an integrated simulation platform," in EWEC 2010, 20-23 April 2010, Warsaw, Poland, 2010.
[3] P. Veers, "Databases for use in wind plant reliability improvement," in Wind Turbine Condition Monitoring Workshop, October, 2009, Broomfield, CO, 2009.
[4] S. Ebrahimi and P. Eberhard, "Rigid-elastic modeling of meshing gear wheels in multibody systems," Multibody System Dynamics, 2006.
[5] J. Lin and R. G. Parker, "Analytical characterization of the unique properties of planetary gear free vibration," Journal of Vibrations and Acoustics, 1999.
[6] F. Oyague, "Progressive dynamical drive train modeling as part of NREL gearbox reliability collaborative preprint," in WINDPOWER 2008 Conference and Exhibition, Houston. Texas, 2008.

Data-Driven Wind Farm Control

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ABSTRACT

Wind turbines in a wind farm influence each other's power production and loads through wakes that form downstream of each turbine rotor. The amount of wake interaction depends on time-varying atmospheric conditions (wind speed, turbulence, atmospheric stability, wind direction). We can control each turbine by adjusting the generator torque, pitching the blades, or turning the rotor in and out of the wind (yawing). Currently, each turbine is controlled individually, not taking into account the wake interaction.

The goal of this project is to develop distributed, data-driven control algorithms to deal with the non-linear, time-varying wake interaction effect in wind farms and optimize power production and loads. These data-driven control algorithms can either be based on a model-free approach, such as the gradient-based optimization algorithm presented in [1], or be model-predictive control algorithms based on simplified models that are updated online using measured data, see Figure 1.

An example of such a model-predictive wind farm control algorithm is a scheme where we update the parameters of an extended Park/Jensen model [2] predicting the velocities in the wind field in a wind farm based on measured data, and subsequently optimize the yaw angles and/or the axial induction factors of each turbine using the model. The optimized axial induction factors can then be mapped back to the control settings of each turbine. We are developing such a control scheme using data generated by NREL's Simulator for Offshore Wind Farm Applications (SOWFA) [3], a high-fidelity simulator of the interacting dynamics of the wind flow and the wind turbines in a wind farm.

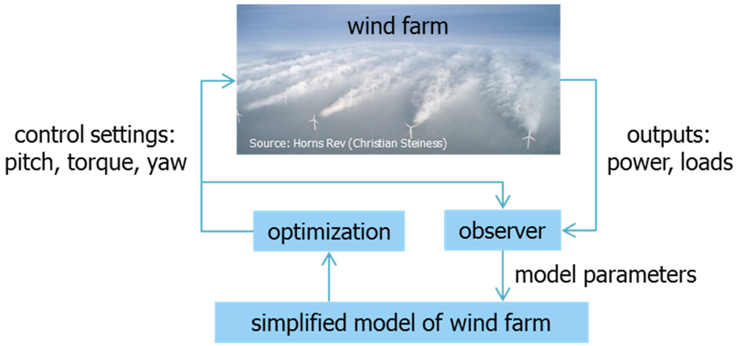

Figure 1: A data-driven model-predictive control scheme for wind farm control.

REFERENCES

[1] P.M.O. Gebraad, F.C. van Dam, J.W. van Wingerden. "A Maximum Power-Point Tracking Approach to Wind Farm Control", Proc. of The Science of Making Torque from Wind, 2012.

[2] I. Katic, J. Højstrup, N.O. Jensen. "A Simple Model for Cluster Efficiency", Proc. of EWEA 1986.

[3] P. Fleming, S. Lee, M. Churchfield, A. Scholbrock, J. Michalakes, K. Johnson, P. Moriarty, P. Gebraad, J.W. van Wingerden. "The SOWFA Super-Controller: A High-Fidelity Tool for Evaluating Wind Plant Control Approaches", Proc. of EWEA 2013.

Advanced LIDAR-assisted Control of Wind Turbines

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ABSTRACT

During the last years, advanced control strategies for wind turbines have drawn more and more interest not only within the research community but also in the wind industry. A reason for this increasing interest is the need for alternative ways of mitigating the loads of beyond state-of-the-art sized wind turbines in addition to structural enhancements, which will not be able to cope with the continuing growth in wind turbine's sizes in the future.

A promising approach of these advanced control strategies at the moment is the incorporation of preview wind information measured by a LIDAR (LIght Detection And Ranging) device in order to implement a feed-forward controller. The LIDAR technology measures wind speed remotely by taking advantage of the optical Doppler-effect. By installing a LIDAR device on top of a wind turbine's nacelle or inside its spinner, it provides a measurement of the wind speed from a certain distance ahead of the turbine.

Many contributions from the research community have shown the potential of LIDAR-assisted feed-forward control in theory and, lately, SWE together with NREL delivered the first proof-of-concept of a LIDAR-assisted feed-forward controller with field test results [1,2]. At the same time, commercial LIDAR systems for nacelle-based applications, recently, entered the market progressively, promoting their use beyond research. And finally, wind turbine manufacturers have shown an increasing interest in LIDAR-assisted control, too.

Although there are already many suggestions for the utilization of LIDAR measurements for load mitigating as well as power enhancing control strategies, there are still open questions to be solved before these concepts are ready to be applied comprehensively. Especially, the reconstruction of the significant wind speed and its preprocessing turns out to be crucial and immense important for a successful application. Futhermore, the experiences from the first field tests show that it is possible to adapt the feed-forward controller to the changing quality and validity of the LIDAR measurements in real time [3].

The aim of my PhD project is to investigate the suggested LIDAR-assisted control strategies more deeply and further develop them with regard to the challenges mentioned above. A special focus lays on the question how the inflowing wind field needs to be measured in order to reconstruct the significant quantities like the rotor effective wind speed or the wind shears in an optimal and robust way. Thereby, I will look into inhomogeneous inflow conditions like in complex terrain or in wake situations. Furthermore, I will pursue the question how the LIDAR measurements need to be preprocessed adaptively and online in order to achieve optimal control action.

The paper comprises an overview of current contributions to the field of LIDAR-assisted control and outlines the remaining challenges as well as ideas and possible scopes of my PhD project.

REFERENCES

[1] D. Schlipf, P. Fleming, F. Haizmann, A. K. Scholbrock, M. Hofsäß, A. Wright, P. W. Cheng, *Field Testing of Feedforward Collective Pitch Control on the CART2 Using a Nacelle-Based Lidar Scanner*, The Science of Making Torque from Wind, Oldenburg, Oldenburg, October 2012.

[2] A. K. Scholbrock, P. Fleming, L. Fingersh, A. Wright, D. Schlipf, F. Haizmann, F. Belen, *Field Testing LIDAR-Based Feed-Forward Controls on the NREL Controls Advanced Research Turbine*, 51th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Grapevine, Texas, January 2013.

[3] F. Haizmann, P. Fleming, D. Schlipf, A. Scholbrock, M. Hofsäß, A. Wright, P. W. Cheng, Implementation of an Online Correlation Analysis for an Adaptive LiDAR based Feed-Forward Controller for Wind Turbines, EWEA Annual Event 2013, Vienna, February 2013.

Applying Coordinated Control to Wind Turbines in Bladed

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ABSTRACT

As turbine size increases the tasks assigned to the controller expand and the design becomes more demanding. One additional task often given to the central controller is to reduce tower loads. A traditional method of doing this is to introduce a tower feedback loop. This loop works by augmenting the pitch demand by an additive adjustment in response to a measurement of the tower head velocity or acceleration.

The aim of the present project is to advance a different approach, Coordinated Control, which reduces the tower loads and alleviates the problem of right half plane zeroes caused by the tower dynamics in above rated operation of a wind turbine. This builds upon the thesis of Aristeidis – Panagiotis Chatzopoulos[1] converting the Simulink models for two turbines, the Supergen 5MW and the Supergen 2MW exemplar turbines, to a form suitable for Bladed.

The coordinated controller utilizes a parallel path structure as shown in the figure below, using a notch filter to reduce the pitch demand at the tower frequency. An inverse of this filter is introduced into the torque demand path ensuring that the rotor speed is still effectively controlled. A modification of this method, controlling power and torque (and generator speed indirectly) is then implemented to reduce fluctuations in the power output.

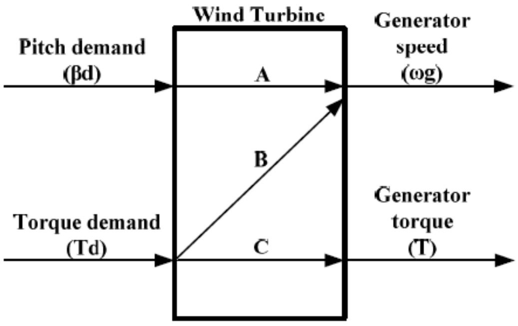

Figure 1: Parallel path structure

Comparisons between tower loads and power outputs with and without the Coordinated Control will be made with a view to comparing the effectiveness of this controller with changing turbine size.

REFERENCES

[1] A. P. Chatzopoulos, (Thesis) Full Envelope Wind Turbine Controller Design for Power Regulation and Tower Load Reduction

Adaptive Dynamic Control of a Wind Generator

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ABSTRACT

The aim of the present project is to obtain a better understanding of the dynamic control of a wind turbine. To accomplish this a wind generator model will be developed and the adaptive dynamic control will be applied.

The non-linear systems are difficult to model and to control. New modern control techniques allow controlling these systems without having the system model, reducing the complexity. Among these techniques, it is the adaptive dynamic control that estimates the parameters of the dynamic system on-line and adapts their control to the new conditions without spreading the error throughout a feedback network. Thanks to this relevant feature a neural network controller can be directly adapted.

So as to demonstrate the effectiveness of the technique in question, Matlab/Simulink simulation tests will be carried out.

Key words: Adaptive dynamic control, Neural network, Matlab/Simulink.

REFERENCES

[1] G. Saikalis, F. Lin, "Adaptive Neural Network Control by Adaptive Interaction ", IEEE control society, 2001 American Control Conference, vol.2 (2001) pp. 1247-1252.
[2] F. Wang, H. Zhang, D. Liu, "Adaptive Dynamic Programming: An Introduction", IEEE Computational Intelligence Magazine, May 2009.
[3] Y. Tang, H. He, Z. Ni, J. Wen, X. Sui, "Reactive Power Control of Grid-Connected Wind Farm Based on Adaptive Dynamic Programming", Elsevier Publications, March 2013, pp. 1-8.

Control of a Variable Pitch Vertical Axis Wind Turbine

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ABSTRACT

Compared to the widespread horizontal axis wind turbines (HAWT), vertical axis wind turbines (VAWT) are less efficient but have to advantage of being more robust in its construction than HAWT. Blade design is less complex, since they don't have to be selfsupportive, because they are supported by two arms connected to the main shaft, which also reduces structural loads of the blades. The major advantage of VAWT is the independence of wind direction, which makes VAWT very attractive for turbulent regions, e.g. cities or forests, and avoids installing a yaw system to track the wind direction [1].

This paper yields to overcome another effect characteristic for VAWT: the pulsation of the output power, due to cyclic torque pulsation with the 3p-frequency (see Figure 1). This is to be done by designing an appropriate controller using pitch and generator torque control. It was shown in [2], that using generator torque control only does not lead to a convenient reduction of the output power pulsation. Therefore the main control objective is smoothing the output power, while reducing the torque pulsation to reduce structural loads at the shaft and maximizing output power.

A simplified model of a VAWT, installed at RWTH Aachen University by the Aerodynamic Institute (see Figure 1), with 20kW rated power and 35m hub height is developed for the purpose of rapid control protoyping. The model considers the main shaft and the tower as flexible and also incorporates pitch actuator and generator dynamics to achieve a satisfying controller design. The controller is tested with a more detailed and complex model developed by the Aerodynamic Institute [3].

Figure 1: VAWT research turbine at RWTH Aachen University

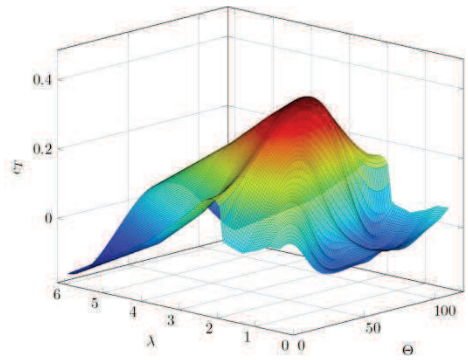

Figure 2: Dependency of the torque coefficient c_T from tip speed ratio λ and the angular position θ of the rotor

Power Adjusting Controller for a 2MW Wind Turbine

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ABSTRACT

The aim of the present project is to obtain a better understanding of how the Power Adjusting Controller (PAC) works for a 2MW wind turbine. The PAC has initially been developed and modelled on the 5MW Supergen Exemplar wind turbine. The PAC is able to adjust the power output of the wind turbine by a given change ΔP. This allows far more flexible control of the wind turbine.

The PAC operates as a separate controller, operating as a “jacket” around the central controller, as can be seen in “fig. 1”. To accomplish this an in depth understanding of wind turbine dynamics is needed.

Once the PAC has been developed for the 2MW machine, investigations into the difference in performance between using the PAC with the 5MW machine and using the PAC with the 2MW machine can be made and the potential for improved/decreased PAC performance with increasing turbine size can be evaluated.

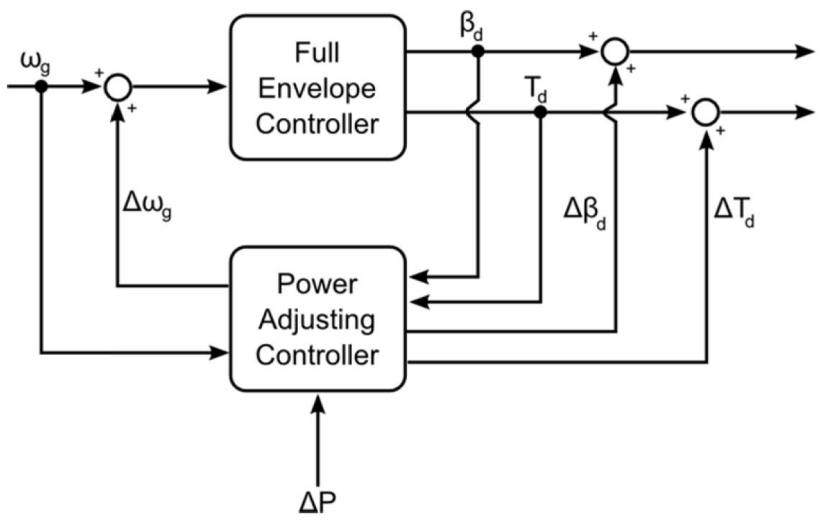

Figure 1: Power Adjusting Controller illustration.

Efficient modelling of floating wind turbines

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ABSTRACT

As offshore wind turbines are installed in deeper water, interest is growing in floating wind turbines because, among other reasons, they may become cheaper than fixed-bottom turbines at greater depths [1]. Efficiency in simulation codes is always desirable, and is particularly important for floating wind turbines: capturing the lowest natural frequencies of the floating platform requires very long time-domain simulations.

We propose a frequency-domain method for predicting the steady-state response of floating wind turbines. Compared to time-domain methods (e.g. [2]), this type of method has the advantages of improved speed and direct calculation of response statistics. The main challenge to this approach is that it requires a linearised model of the turbine structure and loading. There are many sources of non-linearity in a floating turbine, such as rotor dynamics, hydrodynamic loads, aerodynamic loads, and control system actions, which we will address in turn.

First the dynamic behaviour of a flexible rotor on a moving platform is considered: although this is a non-linear system, it is shown that, under reasonable conditions, the response of the blades to platform motion is in fact linear and presents no obstacle to frequency-domain analysis. Linearised analysis of the hydrodynamic wave and current loads on the floating platform follows well established methods through which the mean and slow-drift forces can be included [3]. Non-linear viscous drag forces are accounted for through stochastic linearisation.

The results of the frequency-domain model are spectra and statistics of the platform motions, tower and blade deflections. These have been compared with published results for the OC3-Hywind turbine [4]; for example a good agreement in the surge and pitch spectra can be seen in Fig. 1.

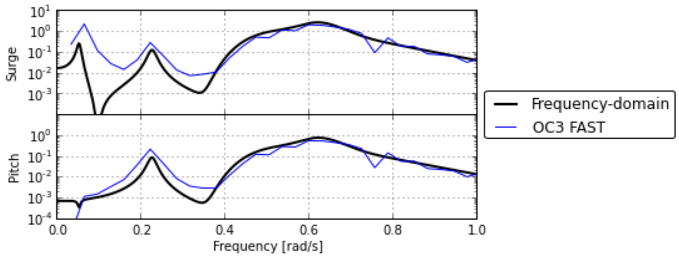

Figure 1: Example results from frequency-domain model compared with time-domain results [4].

REFERENCES

[1] A.R. Henderson & D. Witcher. “Floating Offshore Wind Energy—A Review of the Current Status and an Assessment of the Prospects.” Wind Engineering 34, 1–16 (2010).
[2] J. Jonkman. “Dynamics of Offshore Floating Wind Turbines—Model Development and Verification.” Wind Energy 12, 459–492 (2009).
[3] O.M. Faltinsen. “Sea loads on ships and offshore structures” (1990).
[4] J. Jonkman et al. “Offshore Code Comparison Collaboration within IEA Wind Task 23 : Phase IV Results Regarding Floating Wind Turbine Modelling.” European Wind Energy Conference (2010).

Iterative Learning Control for Individual Blade Pitch

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ABSTRACT

Active control for wind turbines, besides achieving power control, also offers the potential for reducing dynamic lifetime loads, facilitating more cost-effective design. Individual blade pitch control has been shown capable of reducing the periodic loads imposed on the wind turbine. Conventionally, the controller is designed as a set of SISO PI-controllers, after linearising the periodic system via the 'Coleman' transform. Each frequency peak in the load spectrum, requires a new linearisation, and this successive controller design reduces optimality. Further, it has been seen that ignoring the multi-input-multi-output (MIMO) nature of the plant can adversely affect the potential for load reduction.

Iterative learning control (ILC) is a control methodology designed for asymptotic rejection of periodic disturbances, which makes it uniquely suitable for exploiting the periodicity in the loading [1]. It consists of synthesising a periodic control input as a linear combination of basis functions, which is adaptively updated, online, in a data-driven manner. As such, the pitch excursions can be precisely controlled in terms of frequency content, and physical constraints can be accounted for, achieving optimality in a global sense. ILC was implemented for pitch control for a direct-drive wind turbine in the simulation software GH BLADED™. Fig. 1 compares the blade root out-of-plane load spectrum for one specific realisation of a wind field, for the cases with and without ILC. It can be observed that ILC reduces almost all energy at the dominant 1P peak, while the other parts of the spectrum are virtually unaffected. This also implies that the energy in the control input is concentrated in a very narrow band.

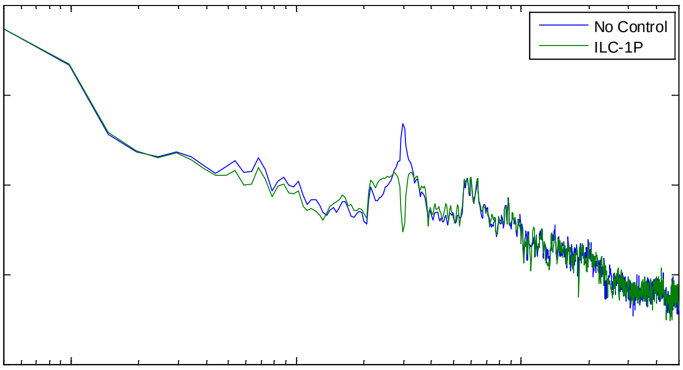

Figure 1: OoP Load Reduction – wind speed 18 m/s, T. I. 14% [Axes omitted for confidentiality reasons]

Future work in this field will be aimed at implementing this technique on a wind turbine prototype of 2m diameter, that will be tested in a wind tunnel. Further, the project aims at investigating the actuator configuration for maximising wind load control potential using advanced control methodologies.

REFERENCES

[1] J.-W. vanWingerden, A. W. Hulskamp, T. Barlas, I. Houtzager, H. E. N. Bersee, G. A. M. van Kuik and M. Verhaegen, "Two-Degree-of-Freedom Active Vibration Control of a Prototyped "Smart" Rotor", IEEE Transactions on Control Systems Technology, vol. 19 (2011) pp. 284-296.

AEROSERVOELASTIC MODELLING AND ACTIVE CONTROL OF VERY LARGE WIND TURBINE BLADES FOR GUST LOAD ALLEVIATION

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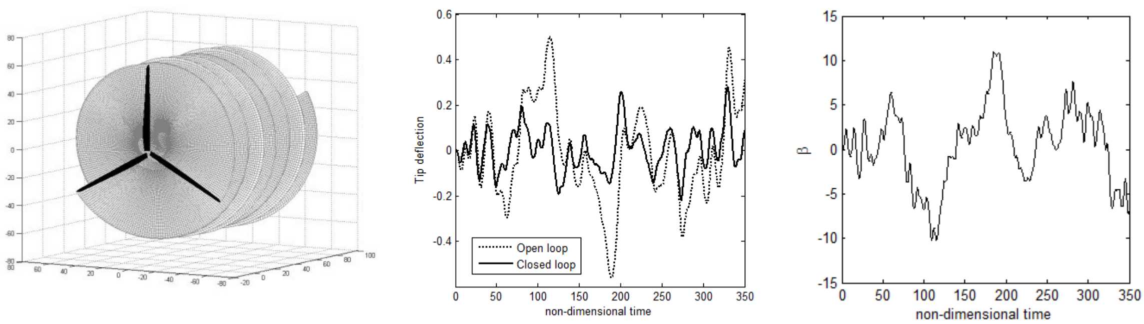
ABSTRACT

The increased flexibility of wind turbine blades necessitates accurate predictions of the aeroelastic effects and requires localised active control techniques to overcome unnecessary loadings and oscillations. In this paper an aeroservoelastic model capturing the structural response and the unsteady aerodynamics, will be used to demonstrate the potential of load alleviation using active control surfaces. The structural model is a geometrically-nonlinear composite beam, which is linearised around equilibrium rotating conditions and coupled with a linearised 3D Unsteady Vortex Lattice Method (UVLM) with prescribed helicoidal wake, as shown in Fig. 1a. Most existing works relying on Blade Element Momentum theory with various corrections, hence the use of UVLM in this paper seeks to complement and provide a direct higher fidelity solution of the unsteady rotor dynamics assuming attached flow conditions. The resulting aeroelastic model is in a state-space formulation suitable for control synthesis [1].

Modelling the NREL 5-MW referene wind turbine with active flap control, the paper will demonstrate that root-bending moments (RBM) and tip deflections can be reduced by more than 30% using LQG controllers with RBM as measurement feedback. The time series for the tip deflection and flap deflection angle are shown in Fig. 1b and 1c. Also, comparisons between using LQG and PD controllers show that PD requires up to twice the amount of energy required by LQG controllers to achieve the same level of performance. The use of multiple flaps will also be demonstrated. With the order of the aeroelastic system relying closely on the spatial discretisation of the UVLM, a novel method of controller synthesis using coarse spatial discretisation will be used to obtain lower-order closed-loop models with performances comparable to higher-order models [2].



(a) (b) (c)

Figure 1: (a) UVLM model with prescribed helicoidal wake. (b) Time series of tip deflection. (c) Time series of flap deflection angle β

REFERENCES

[1] B.F. Ng, H. Hesse, R. Palacios, J. M. R. Graham, E. C. Kerrigan, Aeroservoelastic modelling and load alleviation of very large wind turbine blades, AWEA 2013, Chicago, IL.

[2] B.F. Ng, R. Palacios, J. M. R. Graham, E. C. Kerrigan, Robust control synthesis for gust load alleviation from large aeroelastic models with relaxation of spatial discretisation, EWEA 2012, Copenhagen, Denmark.

Investigation of Possible Applications for the Power Adjusting Controller

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ABSTRACT

A Power Adjusting Controller (PAC) has been developed that will allow wind farm operators far more flexible control of their assets. The controller allows a wind farm operator to change the power output of wind turbines in a farm accurately by an amount ΔP, set by the operator. This value can be negative (a reduction in power) which can then be held indefinitely, or a positive value, which can be held for a limited time before being "paid back". There are many possible applications of this new controller such as aiding grid support and reducing turbine loads.

Two possible applications of the PAC are synthetic inertia and droop control. Whilst there is currently no requirement for wind farms to provide grid support, as the number of wind farms attached to the grid increases the likelihood of some kind of requirement being introduced increases. This requirement could be introduced for all wind farms, not just new farms. In such a scenario, a controller such as the PAC, that allows an alteration to the power output of a wind farm without affecting the central controller, becomes highly desirable.

This paper details how the PAC can be used for these applications and evaluates the effectiveness of these techniques via simulations. The possible impact upon the turbine loads and how the effectiveness of these techniques varies with the turbine size is also discussed.

REFERENCES

Providing Grid Frequency Support Using Variable Speed Wind Turbines with Augmented Control, Adam Stock, W.E. Leithead, Scientific Proceedings of the European Wind Energy Association Conference 2012, pp152-156

Active Stall Control of HAWT – Blade Planform Optimization Including Stall Actuation

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ABSTRACT

Increasing sizes of Horizontal Axis Wind Turbines (HAWT) and the trend of installing them further offshore drives the search for robust designs. Modern HAWTs deployed offshore are variable speed and pitch controlled. But if the Pitch System (PS) is eliminated the maintenance costs decrease and the availability will increase, which may lead to a lower Cost Of Energy (COE). This research investigates active stall control for HAWT power regulation as an alternative for pitch control, where active stall control in this context means applying add-ons that actively provoke stall.

The National Renewable Energy Laboratory (NREL) 5MW machine [1] is used as a benchmark and three different actuation technologies are considered for active stall control: Boundary Layer Transpiration (BLT), Trailing Edge Jets (TEJ), and Dielectric Barrier Discharge Plasma Actuators (DBD). A Blade Element Momentum (BEM) code is used to simulate the HAWT aerodynamics. Previous research showed HAWT active stall control is feasible only if the blade is initially designed to incorporate active stall control [2].

To perform an integrated design a blade planform optimizer is developed. The code minimizes the COE subjected to constraints on twist and chord, namely upper and lower bounds and maximum radial variation of the planform variables.

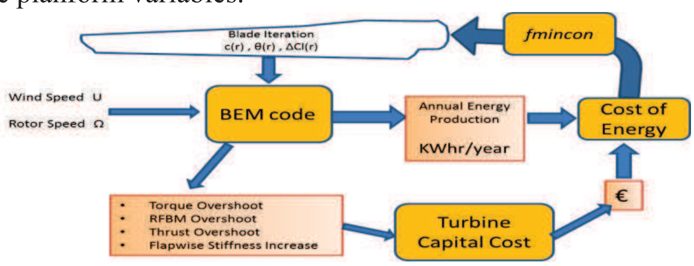

Fig 1: Planform Optimizer Diagram

In each iteration the BEM code runs over the wind speed range of operation determining the Annual Energy Production (AEP). The overshoot in the loading, compared to the reference pitch regulated case, is used to assess the effect on mass and cost of each HAWT component according to [3]. The relative reduction in pitch systems cost and its related maintenance are expressed by the P_Factor. Table 1 shows the COE obtained with the optimizer, relative to the reference case, when different values of maximum torque overshoot (T_Max) are allowed. If the PS costs are halved and a 30% torque overshoot is allowed, the COE is already smaller than for the reference case.

T_Max \ P_Factor	1	0.5	0
1.15	1.062	1.034	1.006
1.3	1.015	0.988	0.961

Tab 2: :Relative COE with Torque Overshoot & Pitch Factor

Actuators using different technologies considered are at present incorporated in the optimizer, describing actuator authority and cost, both capital (€) and operational (power consumption, required air flux, etc). The applicability of each actuator type to replace/mitigate the pitch mechanism is assessed by evaluating the whole system in terms of the final COE.

Hydrodynamic and Aerodynamic Loads Alleviation of an Offshore Wind Turbine by Adaptive Control

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ABSTRACT

Offshore wind is becoming an important contributor to the European electricity supply. It has been estimated that between 20 GW and 40 GW of offshore wind energy capacity will be operating in the EU zone by the year 2020. Furthermore, trends show that offshore wind farms are increasingly built further from the coast, in deeper waters and the market moves towards multi-megawatt turbines with rated power above 5 MW, characterized by larger rotor diameters.

To develop a new concept of larger, more reliable and efficient wind turbines, loads on several critical components are to be correctly estimated and mitigated by specific and effective control strategies. Several studies [1], [2] have already devised opportune control methods to reduce the action of those aerodynamic and hydrodynamic fatigue loads an offshore wind turbine encounters throughout its lifetime. Examples include regulation concepts such as the individual pitch control [4], generator torque control, gust and storm estimators [3], as well as either active or passive regulation of the tower vibrations [2], [5], [6]. By means of suitable combinations of the above regulations, aerodynamic and hydrodynamic excitations can be flattened. The recent EU-funded project "UpWind" [2], has been highlighting the capability of particularly tailored control procedures accounting for loads reduction.

The hereafter outlined investigation may be intepreted as the *trait d'union* between the current technology and the upcoming generation of larger wind turbines, in terms of loads reduction, control and structure-design optimization; it will be undertaken as part of a PhD project, comprises four main sub-tasks and will be carried out within the recently commenced "OWEA Loads" project, funded by the German Environmental Ministry; the analysis is conducted for the "Alpha Ventus" test site, characterized by a 28 m water depth and deployed 60 km from the German shore. The research project involves, among others, a co-operation with the University of Stuttgart and the 5MW-class turbine manufacturer AREVA Wind GmbH.

The objectives of the proposed research include: development and implemention of a methodology for an adaptive control to mitigate critical aerodynamic and hydrodynamic loads of an offshore wind turbine, by establishing an effective objective function for the controller; to validate the effectiveness of the proposed control strategies by applying them on an existing real wind turbine model, located at a specific wind farm with *in-situ* tests; to generalize and transfer the proposed methods to other site and loading conditions, wind turbine and/or support structure models.

REFERENCES

[1] E. Bossanyi (2009), UpWind: Controller for 5MW reference turbine.
[2] T. Fischer (2013), Mitigation of Aerodynamic and Hydrodynamic Induced Loads of Offshore Wind Turbines
[3] S. Kanev, T. van Enegelen (2008), Wind Turbine Extreme Gust Control, ECN-E-08-069.
[4] S. Kanev, T. van Enegelen (2009), Exploring the Limits in Individual Pitch Control, ECN-M-09-053.
[5] W. Leithead (2010), Control strategies for blade and tower load reduction, Supergen Wind Assembly 2010.
[6] A. Wright, L. Fingersh (2008), Advanced Control Design for Wind Turbines, NREL/TP-500-42437.

Design and Evaluation of a Wind Speed Estimator for Hub Height and Shear Components

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ABSTRACT

Wind turbine control systems often rely on linear models of the turbine that vary with wind speed [1]. Additionally, there has been recent interest in preview-based control strategies that utilize the correlation between the preview wind measurements and the actual wind disturbance at the turbine [2,3]. Therefore, it is important to be able to estimate the wind speeds that the turbine experiences. Numerous techniques have been explored for estimating the effective wind speed encountered by a turbine rotor [1], primarily relying on generator speed measurements. The wind speed estimator in this work is based on a proposed Kalman filter-based estimator [1,4], and extended to include estimation of the effective time-varying horizontal and vertical shear components in addition to the effective hub height wind speed. With the addition of shear component estimates, this wind speed estimator can be used as part of an individual blade pitch feedforward control system to provide the correlation between the hub height and shear wind preview measurements and the wind experienced by the turbine [2].

Measurements of generator speed, tower top acceleration, and blade root bending moment are used to estimate the three wind components. The Kalman filter utilizes linear state-space models of the turbine that vary with mean wind speed containing generator, first tower fore-aft, and first blade flapwise degrees of freedom. As suggested in [4], the state-space model is augmented with simple first-order wind speed dynamics driven by white Gaussian noise, thus fitting the required structure for state estimation using Kalman filtering.

The performance of the linear wind speed estimator is investigated using nonlinear aeroelastic simulations of the NREL 5MW turbine model with realistic turbulent wind fields. Although the turbulence experienced by the turbine does not adhere to the simple wind speed dynamics model used in the estimator, the more complicated turbulence can still be estimated using sensor measurements. The impact of different levels of measurement noise on estimator performance is also examined. Furthermore, because the wind speed estimator uses the variance of both the measurement noise and the noise that drives the wind dynamics as Kalman filtering parameters, the impact of uncertainty in the variance estimates on estimator performance is explored as well.

The results from this research show that with realistic levels of measurement noise, hub-height and shear components can be estimated accurately up to roughly 1 Hz for the NREL 5MW turbine. However, the accuracy of the hub height component estimate is slightly higher than the accuracy of the estimates of the shear terms. Due to measurement noise and un-modeled turbine dynamics, the Kalman filter cannot accurately determine high frequency components of wind speed. However, the bandwidth of the wind speed estimator is sufficient for most blade pitch control applications.

REFERENCES

[1] M. Soltani et al., "Estimation of rotor effective wind speed: A comparison", to appear in IEEE Transactions on Control Systems Technology (2013).

[2] E. Simley, L. Y. Pao, "Reducing LIDAR wind speed measurement error with optimal filtering", Proc. American Control Conference, Washington, D.C., 2013.

[3] A. Scholbrock et al., "Field testing LIDAR-based feed-forward controls on the NREL controls advanced research turbine", Proc. AIAA Aerospace Sciences Meeting, Dallas, TX, 2013.

[4] T. Knudsen, T. Bak, M. Soltani, "Prediction models for wind speed at turbine locations in a wind farm", Wind Energy, vol.14 (2011) pp. 877-894.

Nonlinear power conversion in a wind farm

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Abstract

In the near future, a large number of turbines in very large wind farms will feed their power directly into the electrical grid. The temporal fluctuations in power due to wind turbulence can destabilize the grid and possibly increase the risk of blackouts.

In this PhD project, we aim at understanding the atmospheric interactions within the wind farm and to allow for a sufficient prediction matching the available data. These should usually include the position, wind direction, velocity and power output of each turbine.

For a description of the grid dynamics, nonlinear dynamical systems theory can be applied.

While investigating the power output series of two turbines, similarities between them become obvious; despite some necessary shrinking and stretching of the respective time series. On the other hand the problem of prediction consists of identifying events when an atmospheric front reaches at the first, and then another turbine, or when one is located in the wake of another. The straightforward application of Dynamic Time Warping (DTW) yields an initial, but not satisfactory solution for this identification problem. Due to the fact that DTW is based on a minimization problem, the use of appropriate constraints might give better results.

For this purpose the application of an atmospheric model considering the data situation is planned to determine these constraints approximately. Supposed that the DTW does the rest, the identification problem would be solved.

As a consequence, an appropriate, improved control strategy of the turbines' power output could lead to states in the grid which provide beneficial properties, such as enhanced stability.

Individual pitch control for two-bladed wind turbines

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ABSTRACT

In the past decades, researchers and manufacturers focused for a large extent on the design and optimization of three-bladed wind turbines. Currently, however, the focus gradually shifts from onshore turbines to offshore turbines, which also renews the interest for two-bladed wind turbines. Moreover, as wind turbine rotors become larger and more flexible, the control system becomes more and more important. For the aforementioned reasons, it is apparent that therefore also the control system for two-bladed wind turbines should be investigated.

In literature a lot of information is found on controlling the individual pitch angle of each blade. A large part of this literature only focuses on three-bladed rotors, e.g., [1]. Although many papers mention that the controller structure used to reduce the blade loads can easily be generalized to any number of blades, our research shows that Individual Pitch Control (IPC) for two-bladed wind turbines can be done in a simpler and more efficient approach. In the 'traditional' approach, the measured blade loads are transformed from a rotating frame of reference to a non-rotating frame of reference. As a result of this transformation, two control loops are required in the non-rotating reference frame to reduce the blade loads. In our approach, again a (simple) transformation is performed on the blade load signals. However, this new approach only requires a single control loop to reduce the blade loads. Furthermore, the new approach can easily be extended to also reduce higher order periodical blade loads.

We show by means of a comparison that our new approach for IPC of two-bladed turbines performs equally well compared to the traditional IPC approach (see fig. 1). However, the new approach only requires a single control loop compared to two control loops required by the traditional approach. Finally, the new control structure allows to reduce all periodical blade loads by using only two control loops.

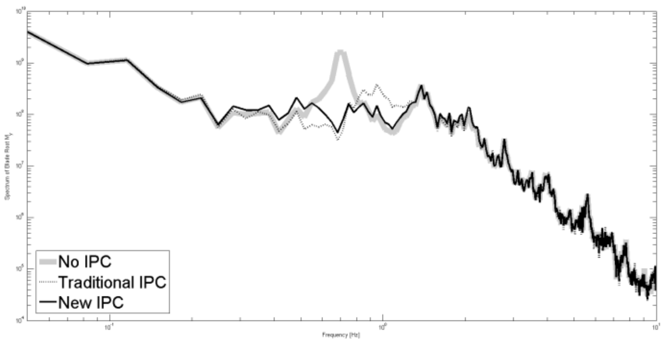

Figure 1: Spectra of the blade root moment of a two-bladed turbine for no IPC, traditional IPC and the new IPC.

REFERENCES

[1] E.A. Bossanyi, "Individual Blade Pitch Control for Load Reduction", Wind Energy, vol. 6 (2003) pp. 119-128.

TURBINE OPERATION, PERFORMANCE AND MAINTENANCE

A case study of surface roughness effect in boundary layer flows

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ABSTRACT

Wind turbine blades are subject to different environmental conditions that affect the surface of the blades. These environmental effects may change the wind turbine blade surface from its considerably smoother condition to various degrees of rough surface conditions. These effects pronounce themselves more with the ice accretion related roughness in cold and arctic weather conditions along with the overall change of the blade profile shape due to the accreted ice layers.

Surface roughness is an important parameter that needs to be taken into account because it directly determines the boundary layer flow characteristics. The importance of surface roughness parameter can easily be understood by considering that in a similar flow situation (i.e., same Reynolds number flow), skin friction and related drag force definitions of the surfaces [1] are dependent on the boundary layer flow characteristics, while these flow characteristics are determined by roughness characteristics of the surface especially in the turbulent boundary layer flow situation [2].

Turbulent boundary layer flows have no exact numerical solutions in contrast to laminar boundary layer flows; an approximation to turbulent boundary layer solutions can be to utilize integral boundary layer methods [3].

This work aims to present the effects of surface roughness with a case study in boundary layer flows, which concentrates on the current methodologies utilized in the ice accretion simulation program: TURBICE.

REFERENCES

[1] H. Saarinen, Processing of the wet growth in the Turbine Blade Icing Model, *MSc thesis*, Helsinki University of Technology, 2000

[2] F. M. White, *Viscous Fluid Flow*, 2nd Ed., McGraw-Hill, 1991.

[3] W. M. Kays, M. E. Crawford, *Convective Heat and Mass Transfer*, 3rd Ed., McGraw-Hill, 1993.

SELECTING THE MOST USEFUL SENSORS TO INCREASE THE AVAILABILITY OF OFFSHORE WIND FARMS

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ABSTRACT

The specific conditions of an offshore wind farm (higher loads, lower accessibility, harsh environment, etc.) reduce the availability and increase the operation and maintenance costs, compared with those of an onshore wind farm. The aim of the present project is to tackle these issue and thus change the cost of energy for the better. Condition monitoring (CM) improvement and more precisely a better use of the sensor network is one way to achieve this.

On a WT, hundreds of sensors are found at different location and can be used for condition-based maintenance. Unfortunately, a high number of sensors leads to more complexity in the analysis and relationships and redundancies between sensors are difficult to find as well. Finding the most important sensors needed for CM reduces this complexity and can improve the accuracy of failure detection and prediction.

Moreover, through a high number of sensors, a WT may be subject to more and more frequent short stops that are not always necessary (false alarms). If less sensors are required for CM, the number false alarms can be then reduced.

A model of a WT is designed for the purpose of this project. The ‘healthy’ behavior of the WT is discretized in working states, since the WT behavior varies with respect to the environmental and operational conditions. These states are group in six main categories ('stopped', 'starting', 'running', 'transition around rated power', 'shutdown' and 'idling'). The current state of the WT can be identified with only six sensors, as shown in a previous work [1].

The second step is to build a model-based reasoner. This reasoner should be able to detect minor failures and abnormal modes [2]. Comparing the modeled behavior and the ‘measured’ behavior, the reasoned is able to detect them [3]. It uses (physical) relationships between sensors, redundancies in the sensor network (at a WT level and at a wind farm level), knowledge of the previous state, expected signals from the current state, possible following state, etc. Among others, the reasoner makes use of qualitative physics tools, which are suitable for measurement and sensor interpretation [4], [5] because of the uncertainty of measurement and the lack of information encountered, especially while trying to minimize the number of sensors.

REFERENCES

[1] C. G. F. Boussion and G. J. W. van Bussel, “Optimization of the information needed for wind turbine health monitoring,” in *International Workshop on Structure Health Monitoring, Stanford CA, 2013, to be published*.

[2] E. Echavarría, T. Tomiyama, H. W. Huberts, and G. J. W. van Bussel, “Fault diagnosis system for an offshore wind turbine using qualitative physics,” in *EWEC*, 2008.

[3] A. Darwiche, “Model-based diagnosis under real-world constraints,” *AI magazine*, vol. 2, pp. 57–73, 2000.

[4] K. D. Forbus and J. de Kleer, “Implementing qualitative process theory,” in *Building Problem Solvers*, 1993, pp. 347–424.

[5] B. J. Kuipers, *Qualitative Reasoning - Modeling and Simulation with Incomplete Knowledge*. 1994.

Drivetrain availability and O&M costs in offshore wind turbines

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ABSTRACT

With a wide and rich array of candidate wind turbine drivetrains it is difficult to judge which is the best for offshore applications [1]. In order to evaluate which drivetrain and generator type will lead to the lowest cost of energy for offshore wind, one needs to answer the following questions for offshore wind turbines:

- How does availability change when different (a) gearboxes types and (b) generator types are chosen?
- How do O&M costs change when different (a) gearboxes types and (b) generator types are chosen?

From onshore to offshore:
There is some comparative data for older turbines which focuses on direct-drive versus geared wind turbines and synchronous generators versus induction generators. Onshore data is cited, as the offshore wind turbine data is limited or not published [2].
There may be some mileage in assuming failure rates are constant from onshore to offshore wind turbines, but that downtimes are increased due to more difficult access. Work by others in the Strathclyde University Wind Energy DTC [3],[4] will be used to 'adjust' the required data.
This data will be interpreted to identify changes in downtime (and O&M cost) for different drivetrain and generator types: e.g. permanent magnet vs synchronous generators, medium speed gearbox vs direct drive. The influence on cost of energy will be estimated.

REFERENCES

[1] CDT in Wind Energy Systems Cohort 2012, "Drivetrain Reports", May 2013, University of Strathclyde.
[2] Spinato F. *et al.*, "Reliability of wind turbine subassemblies", IET Renew Power Gen, 2009, vol. 3, issue 4.
[3] Feuchtwang J.B. and Infield D.G., "The Offshore Access Problem and Turbine Availability – Probabilistic Modelling of Expected Delays to Repairs", European Offshore Wind Conference 2009, Stockholm
[4] Dinwoodie I. and McMillan D., "Sensitivity of Offshore Wind Turbine Operation & Maintenance Costs to Operational Parameters", 42nd ESReDA Seminar, May 2012, Glasgow, UK
[5] Faulstich S. *et al.*, "Component reliability ranking with respect to WT concept and external environmental conditions", UpWind Report, Deliverable WP7.3.3, WP7 Condition Monitoring.

Estimation of the Power Electronics Lifetime for a Wind Turbine

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ABSTRACT

The aim of this project is to have an estimation of the lifetime of power electronics devices in the wind turbines. The lifetime of power electronic devices is related to the thermal cycling of the devices, and this cycling is caused by variations in the losses of the devices caused by turbine power variations and the alternating current conducted by them.

A steady-state model has been used to simulate a year of operation with 10-minute averaged wind data, and combine the lifetime consumption from this simulation with that of the dynamic simulation and find the estimated lifetime.

The main task of this paper is to investigate the effect of the wind speed variations in the lifetime consumption from the different frequency components in the loss spectrum of the power electronic devices.

Permanent Magnet Synchronous Generator Fault Identification Using Stator Current Analysis

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ABSTRACT

During recent years the permanent magnet synchronous generator (PMSG) are being used more and more in high power wind turbine applications. In order to enable variable speed operation with this type of generator power electronic converters are needed. A common converter topology in wind power application is the so called back-to-back converter. In addition to enabling variable speed, it also makes the electrical connection between the generator and the electrical grid indirect. This indirect connection provides the possibility to control the generator regardless of the grid condition, simplifying the grid code compliance. This wind turbine configuration (a PMSG and a power electronic converter) does not require a gearbox, which is one of the most common components to fail in wind turbine applications. To repair or exchange a gearbox is often a costly and time consuming which also leads to a long down-time.

However, just choosing a direct-drive over an indirect-drive does not completely solve the problem, as statistics have shown that the number of generator failures for direct-drive generators is significantly higher than for indirect-drive ones. This motivates the need for good generator condition monitoring and fault detection mechanisms. There are papers which suggest different methods based on a variety of different signals to be monitor and process to identify faults. However, some of the methods presented in papers require that additional signals are monitored and processed, which leads to more expensive and complex monitoring system.

The proposed method in this paper only requires the stator currents and the rotor position. The rotor position is commonly measured in wind turbine (otherwise it can also be estimated from the stator currents) and the stator current is measured within the power electronic converter. As windings are the most common part in a generator to fail, this method is focused on detecting interwinding faults. The generator is modeled analytically as a three phase permanent magnet synchronous machine, but with an additional fourth winding. The fourth winding is in parallel with one of the three other phases and short-circuited and is modeled as a fraction of a healthy phase. This fourth winding is magnetically coupled with the other three phases, where the induced fault current in the fourth winding will impact the currents in the three healthy windings. The interaction of the fault current will be observable in the other currents in the same manner as if the generator was electrically unsymmetrical. In the rotating reference frame (where AC currents become DC currents) there will be an super imposed oscillation on the currents at twice the electrical rotating frequency due to the fault, see the figure below. In the final paper, the results from the analytical model will be verified with finite element analysis.

This method was developed at the Swedish Wind Power Technology Centre, which focus on developing knowledge of the design of wind turbines and of optimizing maintenance and production costs.

Design of thick wind turbine airfoils

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ABSTRACT

With increasing power requirements, wind turbines are getting larger and there is interest to develop thick airfoils that would satisfy increasing structural demands as well as minimize the airfoil noise. There are several airfoil families dedicated to wind turbines and they have been used on modern turbines [1], [2]. However, increasing demands on efficiency show that airfoils need to be optimized to be less sensitive to roughness caused by accumulated dirt and bugs on the blade surfaces. As wind turbines are installed in populated areas trailing edge noise should also be addressed.

In this paper thick airfoil design based on direct method [3] is discussed. Airfoils are aimed to be used on pitch-regulated variable speed multimegawatt turbines. Numerical multidisciplinary optimization is applied which allows imposing multiple constraints and design objectives from both aerodynamical and structural point of view. Optimization algorithm is coupled with a visco/inviscid flow solver and response parameters are used directly as design objectives (lift/drag ratio and transition point location) or they are bounded in constraint function. Design variables are coefficients of a shape function describing the airfoil geometry. Airfoil noise is minimized through constrained boundary layer thickness. Roughness sensitivity is expressed via weighted function employed on free and forced transition aerodynamic parameters. Satisfying the imposed constraints yields a high performance and low noise thick airfoil family.

REFERENCES

[1] W. A. Timmer, R. P. J. O. M. Van Rooij, Summary of the Delft University wind turbine dedicated airfoils, Journal of Solar Energy Engineering , 125 (2003), 488.

[2] F. Bertagnolio, N.N. Sørensen, N. Niels , J. Johansen, P. Fuglsang, Wind turbine airfoil catalogue, 2001. 151 p. (Risø-R-1280(EN)).

[3] X.D. Wang, W.Z. Shen, J. Chen, W.J. Zhu, J.N. Sørensen, J.T. Cheng (2010),"Airfoils and method for designing airfoils", International patent No.PCT/EP2010/056810

Power Curve Measurements of Locally Manufactured Small Wind Turbines Part II

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ABSTRACT

This project is a direct continuation of work presented at the 8th PhD Seminar on Wind Energy in Europe [1], which introduced the first set of results from a long-term study designed to measure the performance of a series of small wind turbines designed, built and installed on the Scottish peninsula, Scoraig [2]. Over the last year, measurements have been obtained from four separate machines using the international standards for power performance testing of small wind turbines [3] as a guide, and the monitoring of three further turbines is planned over the coming months. This data set provides valuable insight into the performance of a range of machines from 1.8m to 4.2m in diameter and facilitates further understanding of the influence of the many variables inherent in machines constructed by hand. For example, the performance of the furling mechanism that protects the turbine from overspeeding in high winds has been found to be extremely different between machines, as shown in fig.1b). Over-furling can lead to decreased energy yield, whilst under-furling can leave the machine vulnerable to failure in high winds. To determine the cause/s of this variation, measurements of physical variables, such as tail moment arm and tail bearing torque are planned on each machine.

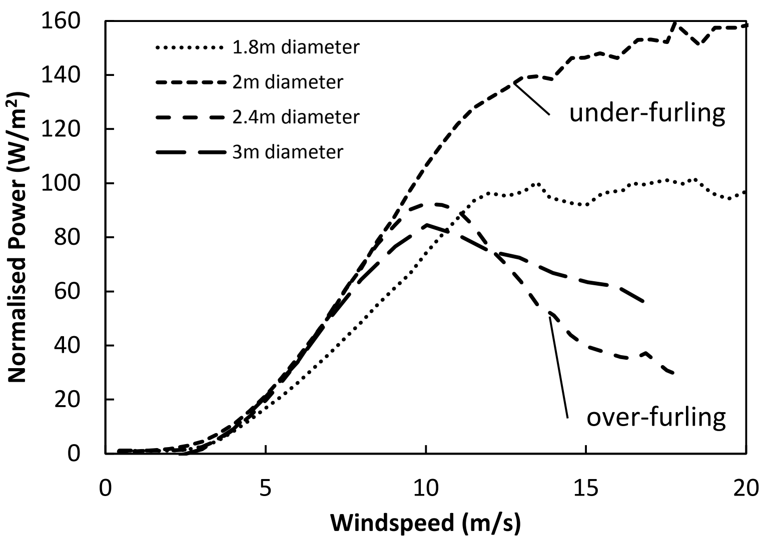

Fig.1: Analysis of furling system performance by a) measurement of tail moment arm and b) power performance logging

REFERENCES

[1] J. Leary, H. Piggott, R. Howell & A. While, "Power Curve Measurements of Locally Manufactured Small Wind Turbines", 8th PhD Seminar on Wind Energy in Europe, ETH Zurich, Switzerland, September 12-14 2012.
[2] H. Piggott. A Wind Turbine Recipe Book. Scoraig Wind Electric. 2009
[3] IEC Wind Turbines, Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines. 2005

DEVELOPMENT AND APPLICATION OF A DESIGN AND SIMULATION TOOL FOR VERTICAL AND HORIZONTAL AXIS WIND TURBINES

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ABSTRACT

The software QBlade is being developed since 2010 [1] as an integral open source framework for horizontal (HAWT) and vertical (VAWT) axis wind turbine rotor design and simulation. QBlade covers all necessary steps for aerodynamic wind turbine design by combining airfoil analysis with blade design and blade element momentum method based simulation algorithms.

The popular airfoil design code XFOIL [2] is integrated within the graphical user interface of QBlade to enable the design of custom airfoil shapes and the computation of airfoil lift- and drag coefficients that are needed for a simulation. An additional module extrapolates airfoil lift and drag data to angles of attack beyond the stall point. The module for blade design allows the intuitive design of VAWT or HAWT rotor geometries (fig.1) employing the internal airfoil database and 3D visualization. From these rotor geometries a detailed wind turbine setup, including pitch or rotational speed controllers and generator efficiency can be defined and simulated. The evaluation of conducted simulations in the internal post-processor allows displaying more than 60 simulation variables in dynamic graphs. This combined functionality results in a comprehensive and user friendly tool for wind turbine research and development.

QBlade is constantly being maintained, validated and advanced with new functionality. In the near future the software will be extended with a coupling to the NREL design tools [3] WT_Perf, Aerodyn and FAST. Furthermore, a module for a simplified structural blade definition is currently under development. This paper will present in brief the theory of QBlade, demonstrate its functionality in a case study and also highlight the current and planned new developments.

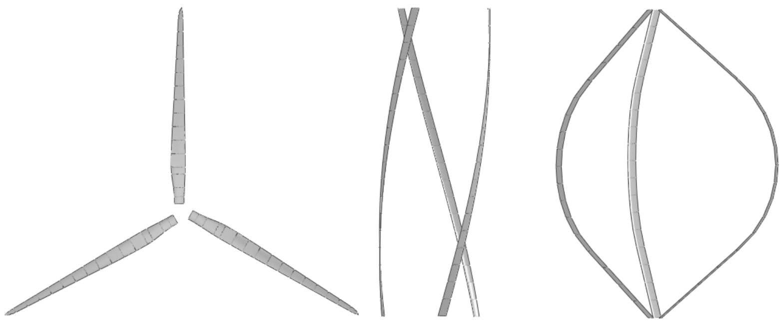

Figure 1: Various rotor blade geometries designed and simulated in QBlade

REFERENCES

[1] Marten, D., Pechlivanoglou, G., 2010, "Integration of a WT blade design tool in XFOIL/XFLR5", Proceedings of the DEWEK 2010
[2] Drela, M., Giles, M., 1989, "Viscous-Inviscid Analysis of Transonic and Low Reynolds Number Airfoils", AIAA Journal Vol.25, No.10
[3] NWTC Computer-Aided Engineering Tools, FAST by Jason Jonkman, WT_Perf by Andrew Platt, Aerodyn by David J. Laino, *http://wind.nrel.gov/designcodes/simulators/*, accessed 30-April-2013.

A study of current maintenance challenges in a large offshore wind farm – a case study

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ABSTRACT

The aim of the present research project is to obtain a better understanding of the operations and maintenance (O&M) processes that are performed in the offshore wind energy sector. So far, the focus on O&M of offshore wind parks has been very limited and is currently in its early phases [1]. A comparative study of the existing life cycle analysis of offshore wind parks found that the majority of these analyses do not include an O&M aspect in their calculations [2]. This fact clearly indicates a lack of focus on O&M in the offshore wind energy sector. Existing literature on maintenance and service within the wind energy sector is scattered within various subjects like development of sensors for oscillation [3] decision theory [4], or mathematical models for planning of maintenance [5][6]. In the present study the current O&M processes of a large offshore wind park is investigated. The wind park is operating in one of the most harsh and stochastic environments in the North Sea. The wind park is operated by one of Europe's largest energy companies and the study gives an insight and a deeper understanding of the challenges of operating and maintaining a large offshore wind farm under very rough sea conditions. The main methos used in this study is the case study method [7][8][9]. We have followed a team of service-technians for a longer period of time to investigate their work tasks. Furthermore, we have followed the company's surveillance center that monitors all their wind turbines. This has given an insight in how maintenance jobs are generated from reciving the first alarm from a wind turbine, to diagnosis, considerations, planning, excecution and evaluation of the maintenance task carried out.

REFERENCES

[1] I.B Utne, "Maintenance strategies for deep-sea offshore wind turbines", Journal of Quality in Maintenance Engineering, vol.16(4)(2010) pp. 367-381.
[2] M. Hofmann, "A Review of Decision Support Models for Offshore Wind Farms with an Emphasis on Operation and Maintenance Strategies", Wind Engineering, vol.35(1)(2011) pp. 1-16
[3] P. Caselitz, J. Giebhardt, "Rotor condition monitoring for improved operational safety of offshore wind energy converters", Journal of Solar Energy Engineering, vol.127(2)(2005) pp. 253-261
[4] J. Dalsgaard Sørensen, "Framework for Risk-based Planning og Operation and Maintenance for Offshore Wind Turbines", Wind Energy, vol.12(5)(2009) pp. 493-506
[5] F. Besnard, M. Patriksson, A.B. Strömberg, A. Wojciechowski, L. Bertling, "An Optimization Framework for Opportunistic Maintenance of Offshore Wind Power Systems" IEEE Power Tech (2009) pp. 1-7
[6] F. Besnard, M. Patriksson, A.B. Strömberg, A. Wojciechowski, K. Fischer, L. Bertling, "A Stochastic Model for Opportunistic Maintenance Planning of Offshore Wind Farms" IEEE Trondheim Power Tech Conference (2011) pp. 1-8
[7] R. K. Yin, "Case Study Research", SAGE Publications, 5th edition (2009)
[8] K. M. Eisenhardt, "Building Theories from Case Study Research", Academy of Management Journal, vol. 14(4)(1989) pp. 532 - 550.
[9] K. M Eisenhardt, M. E. Graebner, "Theory building from cases: Opportunities and challenges", Academy of Management Journal, vol. 50(1)(2007) pp. 25-32.

OFFSHORE WINDFARM SHIPPING AND LOGISTICS – THE DANISH ANHOLT OFFSHORE WINDFARM AS A CASE STUDY

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ABSTRACT

During the life-cycle of a windfarm, shipping and logistics efforts play a vital role. Due to the silo-based/myopic view on costs from most organizational wind supply chain constituencies and the lack of platform leadership (Cusumano *et al*, 2002) developed in the relatively immature wind industry, it is almost impossible to obtain a balanced view of the full cost breakdown for an end-to-end, cradle-to-grave life-cycle of a windfarm.

A large part of the windfarm cost break-down can be attributed to the "visible" parts of the windfarm such as the wind turbines and sub-stations. However, no clear answer is available when it comes to determining the shipping, logistics, and supply chain management (SCM) portion of the total windfarm life-cycle costs.

Using the Danish Anholt offshore windfarm as a case study, this paper analyzes the different phases of the wind farm life-cycle from a shipping/logistics/SCM cost perspective. Based on an extensive exploratory study performed by the first author from 2010 to present, discussions during meetings, conferences, and as part of site visits (Brinkmann & Kvale, 2009) with more than 250 interviewees from different levels of the organizations (Nonaka & Takeuchi, 1995) have formed the basis of the creation of a shipping/logistics cost forecasting tool for one of the life-cycle phases of the offshore windfarm.

From the Anholt case, shipping/logistics costs during the installation & commissioning phase are forecasted (Kotzab *et al*, 2007) and opportunities to save costs within shipping/logistics/SCM related tasks (Christopher, 2010) are discussed with an aim towards reducing the overall levelized cost of energy (LCoE).

The paper concludes that further research to create a forecast for the shipping/logistics cost part of the entire life cycle of all projected offshore windfarms estimated to be constructed up to 2050 is needed in order to be able to provide relevant supply chain constituencies with shipping/logistics/SCM cost forecasts for the entire windfarm life-cycle.

REFERENCES

[1] Brinkmann, S. & Kvale, S. (2009): *Interviews. Learning the Craft of Qualitative Research Interviewing*, Second Edition, Sage

[2] BTM Consult a part of Navigant (2012): *International Wind Energy Development. Offshore Report 2013*

[3] BVG Associates (2011): *A guide to an offshore wind farm. Published on behalf of the Crown Estate*

[4] Christopher, M. (2010): *Logistics and Supply Chain Management, Creating Value-Adding Networks*, Fourth Edition, Prentice Hall

[5] Cusumano, M.A. & Gawer, A. (2002): *Platform Leadership. How Intel, Microsoft, and Cisco Drive Industry Innovation*, Harvard Business School Press

[6] Kotzab, H., Mikkola, J.H., Schary, P.B., Skjøtt-Larsen, T. (2007): *Managing the Global Supply Chain*, Third Edition, Liber/Copenhagen Business School Press

[7] Nonaka I. & Takeuchi, H.: *The Knowledge Creating Company. How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, 1995

USING LEARNABLE MULTI-AGENT-SYSTEMS FOR OPTIMAL O&M DECISION MAKING SUPPORT OF WIND TURBINES

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ABSTRACT

Traditional maintenance costs (i.e., labor and material, logistic) in the wind energy sector have perceptibly escalated at a tremendous rate over the past decades [1]. Although modern onshore wind turbine (WT) attain high technical availability of up to 98 %, the evaluation of maintenance work in previous projects ([1], [2]) shows, that high WT availability requires additional maintenance work and costs. The dominant reason for the ineffective management is the lack of factual data that quantify the actual need for repair or maintenance of WT and equipment. The consideration of several conditions e.g. weather/power forecasts, stock keeping etc. are also essential for optimal maintenance decisions.

Multi-Agent-System (MAS) also known as Agent-Based-Modeling and Simulation (ABMS) can model the competitive aspects in such a way that the (intelligent) Agents negotiate quasi among themselves, which interests to be considered in decision-making [3]. Wind farm Operators (WFOs)/service companies are missing tools and necessary information (e.g. failure statistics, weather forecasts, staff disposition, etc.) needed for their maintenance decisions. For the support of a foresighted maintenance strategy a MAS based on Belief-Desire-Intention (BDI) architecture is to be developed, which uses reliability characteristics and cost information, and weighs the competitive interests of the different aspects for the studied case. It suggests therefore favored maintenance measures for the decision-maker. A BDI Agent is able to continuously reason about beliefs (states), goals (desires), and intentions (plans) and act accordingly. In this work we investigate the case of Q-learning with ϱ-greedy exploration; one of the most studied Reinforcement Learning algorithms.

Fig. 1. shows the different Agents managing the different competitive tasks. Some of them have the task to analyse the failure rates and remaining useful life, while others regard weather and power forecasting, and the third category deals with temporal development of the fluctuating electricity tariff.

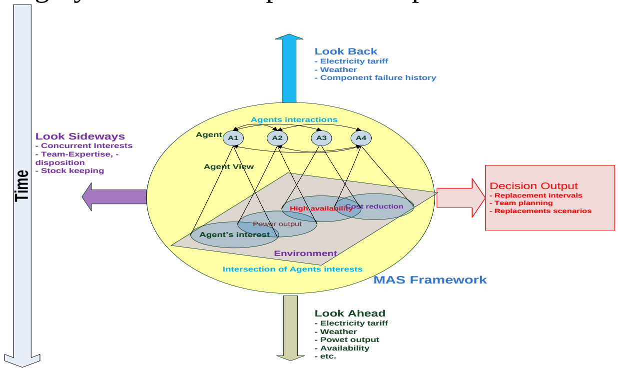

Figure 1: Use of MAS for improving the maintenance decisions

Within this contribution an approach based on MAS and using BDI architecture will be described. Furthermore Q-Learning will be applied for the Agents to make them more explorative. The contribution will show results on the ability to improve operating maintenance scheduling.

REFERENCES

[1] http://www.evw-wind.de/
[2] http:// www.offshore-wmep.de/
[3] Michel North, Charles M. Macal, Managing Business Complexity, Press, USA; 1st edition, 2007

EXTENSION OF THE PROPORTIONALITY METHOD APPROACH FOR STRUCTURAL HEALTH MONITORING OF WIND TURBINE ROTOR BLADES

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ABSTRACT

The rotor blades of a wind turbine form a vital part of the overall structure and their continuous monitoring is therefore of great significance. Structural health monitoring contributes to early damage detection and to the improvement of competitiveness by preventing high maintenance and repair costs. The proportionality method, the extension and improvement of which is the objective of this work, ranks between the numerous approaches that aim at the detection of damage at an early stage. According to this method, which is based on Gasch's proportionality method [1], under harmonic excitation close to the first eigenfrequency, the maximum oscillation velocity is proportional to the maximum dynamic stress by a factor referred to as the proportionality factor. The proportionality factor describes the dynamic behavior of the structure and its variation can be used as damage indication [2]. The extensions pursued in the current work concern the applicability of the proportionality method for non-harmonic excitation, which approximates the stochastic excitation applied to a rotor blade during the operation of a wind turbine, and the modification of the method for application to other quantities than velocity, i.e. acceleration.

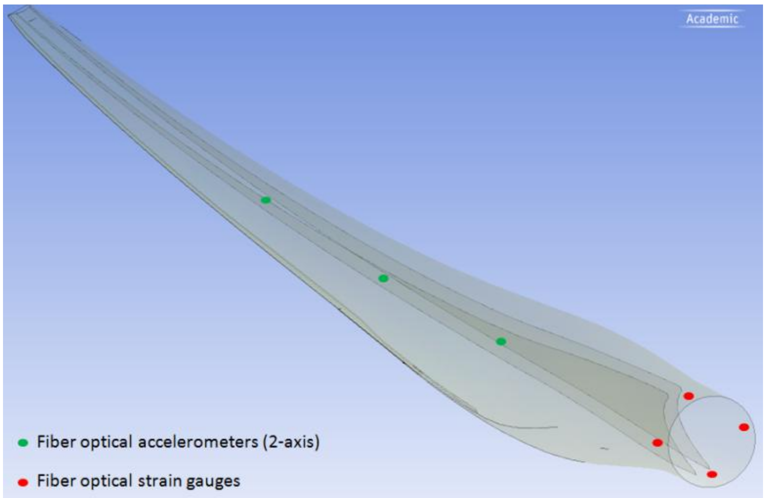

Figure 1: Sensor concept for the application of the proportionality method during a fatigue test.

REFERENCES

[1] Gasch, R., 1968, *Eignung der Schwingungsmessung zur Ermittlung der dynamischen Beanspruchung in Bauteilen*, PhD Dissertation, Technische Universität Berlin, Faculty of Mechanical Engineering, Berichte aus der Bauforschung Nr. 58

[2] Zerbst, S., 2011, *Global approach for early damage detection on rotor blades of wind energy,* PhD Dissertation, Leibniz Universität Hannover, Faculty of Civil Engineering, Institute of Structural Analysis, ISSN 1862-4650

OPTIMIZATION OF ROTOR BLADES USING ADJOINT METHODS IN OpenFOAM

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ABSTRACT

The wind field is unsteady and turbulent, therefore wind turbines are exposed to alternating loads, which lead to stress and fatigue. There are several methods to reduce the effects of these loads, one of them is passive flow control based on bend-twist-coupling. The bend-twist-coupling method leads to a specific, determined deformation of the blade which causes an optimized angle of attack and therefore a reduction of forces acting on the blade under certain load conditions. The aim of this project is to develop a Computational Fluid Dynamics (CFD) based optimization tool for blades using bend-twist-coupling. In order to reduce the load cycles introduced by a turbulent wind field and wind gust, the complete rotor blade has to be taken in count, as wind velocities and forces vary along the length of the blade. The proposed passive flow control is faster and more effective compared to pitch control systems, therefore even high frequent turbulences can be counterbalanced.

One way of optimization is the usage of CFD, but as the computation time may be very high, the processes of optimization shall be improved. We propose to use adjoint methods in order to minimize the effort of CFD. There are three steps necessary for adjoint methods: First, the Navier-Stokes Equations (NSE) should be solved. Then adjoint variables are defined, in a way that the NSE have to be solved just once for all optimizations that shall be conducted. As a third step, the adjoint variables become optimized on the base of the solved NSE of step one. Thus the adjoint methods offer the optimization of several variables by solving the linear equation system (NSE) just once.

To investigate and develop such a blade, adjoint methods for rotating grids in the open-source simulation package OpenFOAM®[1] shall be implemented. Othmer et al. [2] already use adjoint methods for inlet flows and fixed meshes (*adjointShapeOptimizationFoam*). The solver used for this project shall combine adjoint methods with external aerodynamics, moving meshes and rotating grids. In order to use adjoint methods, target functions, that will contain the adjoint variables, must be defined (second step as described above). This will be done using the load conditions defined in IEC-61400-1 [3]. By this, favorable bending for different inflow conditions shall be found.

The simulations are computed using the computing resources of the FLOW cluster [4] of the University of Oldenburg. This PhD project is part of the smart blade project.

REFERENCES

[1] Open-source CFD toolbox OpenFOAM: http://www.openfoam.com/
[2] Othmer et al., "Implementation of a continous adjoint for topology optimization of ducted flows", 18th AIAA CFD Conference, June 2007, AIAA 2007-3947
[3] IEC-61400-1 http://www.iec.ch/index.htm
[4] Facility for Large-scale Computations in Wind Energy Research (FLOW): http://www.uni-oldenburg.de/fk5/scientific-computing/hpc-facilities/flow/

MICROSCALE, MESOSCALE AND ENERGY

TERRAIN FITTED TURBULENT FLOW SOLUTIONS COUPLED WITH A MESOSCALE WEATHER PREDICTION MODEL

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ABSTRACT

Atmospheric turbulent flows are computed using a in-house Navier-Stokes solver (HYPE3D) coupled with a mesoscale meteorological weather prediction software (WRF). The Navier-Stokes solutions are obtained in parallel on terrain fitted high resolution, unstructured hybrid grids, which are partitioned by using Metis. The terrain topology of interest, which may be obtained in various resolution levels, is accurately modeled using unstructured grids in the CFD solution domain. The coupling between the CFD and the WRF domains is depicted in Figure 1. The widely used meteorological weather prediction software WRF is used to provide unsteady boundary conditions for the CFD solution domain. Due to difference in grid structures and resolutions (Figure 2), the interpolation of flow variables from WRF domain onto CFD domain requires certain approximations. In this study, several coupling approaches are investigated by using modified boundary conditions to match the ground surfaces of both low resolution WRF data and HYPE3D flowfield . Unsteady boundary conditions are currently implemented in serial solutions. The main objective of this study is to obtain parallel solutions losely coupled to the WRF solutions and asses the performance of the modified Spalart-Allmaras turbulence models for the solution of atmospheric lows.

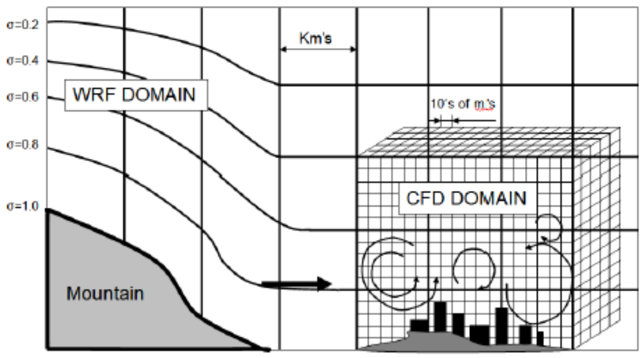

Figure 1:WRF and HYPE3D domains.

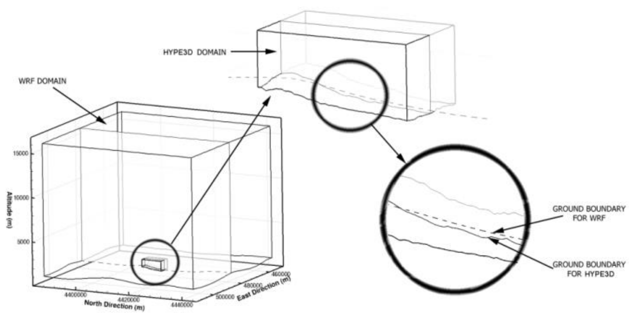

Figure 2: Undefined regions due to difference of coordinate systems

Improving WRF-based Mesoscale Predictions for Site Assessment

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ABSTRACT

Relevance
Mesoscale predictions of wind resources are employed in conjunction with field measurements for the assessment of the feasibility and for the optimal design of wind farms. One of the most widely employed mesoscale models is the Weather Research and Forecasting (WRF) model. The uncertainties in the predictions from WRF are largely dependent on the setup of the simulation and the input parameters, and on how the predictions are subsequently used to predict the energy of wind farms. This study focuses on benchmarking the uncertainty and error in different strategies of using the WRF model. The predictions are compared with long-term measurement data from 15 tall met-mast towers and 20 wind-farms located across Germany.

Approach
In the first part of the study, the impacts of the following are assessed: (1) the planetary boundary layer parameterisation of Mellor–Yamada–Janjic (MYJ) compared to the default parameterization of Yonsei University; (2) the use of Corine land-cover data to model surface roughness instead of the default US Geological Service data; and (3) boundary conditions based on the European Centre for Medium-Range Weather Forecasts (ECWMF) global climate model data compared to the default US National Centre for Environmental Prediction data. In second part of the study, the predictions of annual energy yield are assessed. First, the use of vertical profiles of wind speed across the rotor plane obtained from WRF is compared to the empirically extrapolated vertical shear profiles as are commonly used in energy yield prediction methods. Further, using geographically indexed, high-resolution land-cover and digital elevation models, the errors in wind speed profiles due to spatial averaging over the terrain in the mesoscale simulations are assessed.

Results
The improvements in the predictions of wind resource are follows when compared to the long-term measurement data. The reduction in the relative error of 10-minute averaged wind speed is: (1) 8% by use of the MYJ planetary boundary layer scheme; (2) 11% by use of the Corine land-cover data; and (3) 3% by use of ECWMF-based boundary conditions. It is also shown that energy yield predictions are improved by 27% when WRF-derived wind speed profiles are used instead of vertical shear profiles

Conclusions
This study assesses and benchmarks various simulation strategies of using the WRF mesoscale model for the assessment of sites of potential wind energy projects. It is shown that errors in the prediction of the wind resource and the energy yield are sensitive to the setup of the simulation and the input parameters and the subsequent use of predicted wind resource. The use of MYJ planetary boundary layer scheme and Corine land-cover data (as compared to default WRF datasets) provides a significant improvement in the accuracy of the predicted wind speed, and hence the predictions of energy yield.

EVALUATION OF A MESO-MICROSCALE APPLICATION OVER COMPLEX TERRAIN FOR WIND FARM SITTING

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ABSTRACT

Current study focuses on the analysis of the performance of both mesoscale meteorological models and downscaling procedures performed as a post-process to the mesoscale prediction with the use of microscale model. The influence of atmospheric stability is also investigated by the employment of meteorological parameters based on mast instrumentation and the equivalent stemming from the output of numerical weather prediction models. The applied methodologies are evaluated in areas with heterogeneous terrain characteristics (fig.1) with flow conditions highly influenced by thermal stratification.
Two state of the art numerical weather prediction models are applied and one linear microscale model is addressed for the estimation of the speed up driven by the topography. In particular, SKIRON forecasting system [1], a mesoscale non-hydrostatic model based on Eta/NCEP concept and SKIRON-WRF combination[2], a merger of SKIRON and WRF prediction model are employed. Furthermore, utilization of WAsP as a linear microscale model for the estimation of the influence that a flow is facing from the interaction with the terrain, allows the calculation of the forecasted wind speed within the sub-grid domain of the atmospheric model in a fast dynamical process. For the examination of atmospheric stability, the several classes are obtained by the application of Richardson and Fraude number [3].

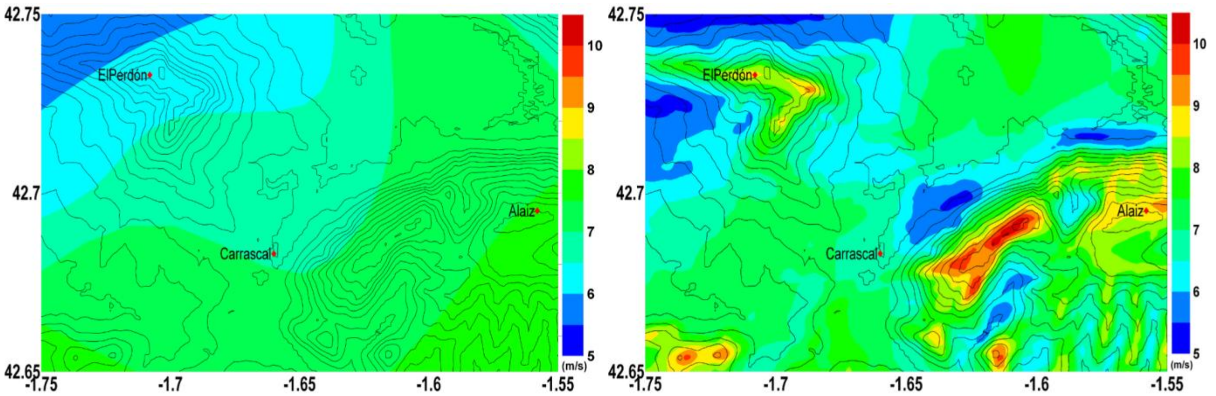

Figure.1: Average wind speed for one year over an area of 40km x10km of North Spain for (a).SKIRON mesoscale model (left) (b). SKIRON/WAsP meso-microscale combination (right).

REFERENCES

[1] Kallos G., 1997: The Regional weather forecasting system SKIRON. Proceedings, Symposium on Regional Weather Prediction on Parallel Computer Environments, 15-17 October 1997, Athens, Greece, 9 pp.
[2] Correia P., Lozano S., Loureiro Y., Cantero E.,: Characterization of wind at the Alaiz experimental wind farm using high resolution simulations with mesiscale models. EWEA Proceedings, 4-7 February 2013, Vienna, Austria.
[3] Sanz Rodrigo J., Borbón F., Gómez P., Courtney M.S., Wagner R., Dupont E., Multi-site testing and evaluation of remote sensing instruments for wind energy.Rewneable Energy,Volume 53, May 2013.

Engineering and Energy Yield: The Missing Dimension of Wind Turbine Assessment

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ABSTRACT

Questions of energy yield and engineering are notably absent from the growing literature on planning for wind developments. Planning consent for onshore wind farms has become a contentious issue in the UK as the push for renewable resources of energy comes up against intense community resistance on grounds of visual impact and potential impacts of noise, and on health and safety (1). The goal of optimising the energy yield of decentralised energy investment sits uneasily with the politics of planning for wind turbines. In countries such as the UK, land-use planning consent regime is not concerned with the energy yield potential of wind developments, as this is a matter for the developer rather than the state. Where this might become an issue is where regulators have to balance the impact of siting arrangements on energy yield.

This research highlights the importance of the energy yield issue in the planning consent for wind farms. Our argument is that this dimension is somewhat marginalised in planning decision-making. Whilst the logic of the yield gap can be understood, it nevertheless runs counter to the ideal of maximising investment in energy decarbonisation. Our concerns are grounded in the specific context of the UK, but are more broadly applicable because the energy yield gap is a broader reflection of fault lines in state carbon regulation across planning systems. We have drawn on experience from Denmark to show how energy yield might be better integrated and we have highlighted some of the benefits that might result.

REFERENCES

1. Barclay C. Consents for Wind Farms - Onshore [Internet]. 2012 p. 1–9. Available from: http://www.parliament.uk/briefing-papers/SN04370

TURBINE STRUCTURE & MATERIAL

FSI on wind turbine blades using OpenFOAM

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ABSTRACT

The keep its role as one of the most important renewable energy sources of the future, the main task of the wind industry in this decade is to reduce the costs of energy. Caused by this requirement, wind turbines and their blades are designed larger and larger. To enable the development of a new generation of large wind turbine blades with blade lengths of more than 60 m, a precise calculation of the aerodynamic forces acting on the blade coupled with a detailed analysis of the structural behavior of the blade is fundamental. Until today, the analytic Blade Element Method (BEM) is mainly used to predict the loads acting on wind turbine blades within the industry. The calculated loads are then fed into FEM simulation softwares like ABAQUS [1] to investigate the structural behavior of the blade. Due to advances in both available computational power and software, it makes sense to couple Computational Fluid Dynamics (CFD), used for the accurate prediction of aerodynamic loads, with numerical structural solvers. These methods, denoted as Fluid-Structure Interaction (FSI) methods, enable the detailed simulation of the permanent interaction between the aerodynamics of the blade and the blade structure itself.

The main aim of this PhD project is to optimize the existing FSI solver included in the open source CFD package OpenFOAM [2] in respect to the simulation of wind turbine blades. To restrict the computational effort for transient FSI simulations to a minimum, a beam model will be implemented in the first step of this work.

After the implementation of this more suitable structural model, the extended solver will be tested and validated. At the end of this project, a series of FSI simulations will be conducted to investigate the interaction of the aerodynamics and the structural behavior of two different sets of wind turbine blades. The simulations will be computed using the computing resources of the FLOW cluster of the University of Oldenburg [3].

REFERENCES

[1] Dassault systems, ABAQUS: http://www.3ds.com/products/simulia/portfolio/abaqus
[2] OpenFOAM project webpages: http:/www.openfoam.com
[3] Facility for Large-scale Computations in Wind Energy Research (FLOW): http://www.uni-oldenburg.de/fk5/scientific-computing/hpc-facilities/flow

NURBS-based parametric modelling of wind turbine blades

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ABSTRACT

Offshore wind turbines need to be designed such that they need a minimum amount of maintenance because the maintenance costs of offshore wind turbines are significantly larger than their onshore counterparts. The pitch system significantly contributes to the maintenance costs. It is therefore desirable to remove this component or at the very least minimize its operation. An alternative approach to regulate the power is to use the stall control, where the stall characteristics of the wind turbine blade together with the rotational speed are used for power regulation. Structural bend-twist coupling has great potential to design passive stall controlled wind turbines with optimal energy capture capability. A multidisciplinary optimization formulation is needed to design twist coupled blades that can be used on variable speed stall regulated wind turbines. The structural modelling methods currently used to design wind turbines are not suited to explore the entire design space that controls the twist coupling due to their limited capability to vary the geometrical shape of the blades.

A new approach based on NURBS is proposed for modelling wind turbine blades capable of varying the shape and material properties of the blades. NURBS are non-uniform rational B-splines[1] used in computer aided design. With this method of modelling wind turbine blades, shape and sizing optimization can be performed with increased freedom to investigate the whole design space that affects the twist coupling. The wind turbine blade is parameterized in terms of its beam axis, initial twist, and weighted airfoil shape at a control point. The beam axis controls the geometrical shape of the blade such as sweep, curvature, and so on. Weighted airfoil shapes are airfoil shapes multiplied by the chord at a control point. In this way a great freedom in cross sectional shape can be achieved with limited airfoil data. Finally, the initial twist controls the structural twist of the blade.

A Matlab tool based on this method is created. It is capable of generating beam and shell models of a generic wind turbine blade. A shell model of a turbine blade with 2 spars including structural twist, sweep and curvature is shown in figure (1), demonstrating the capability of the method to model generic wind turbine blades. This tool can easily be coupled to a finite element analysis tool and optimization software for multidisciplinary optimization.

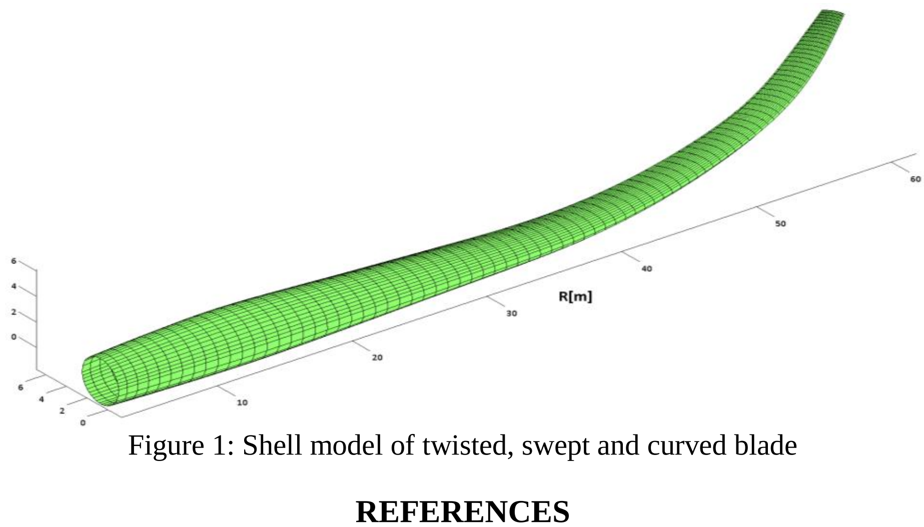

Figure 1: Shell model of twisted, swept and curved blade

REFERENCES

[1] Piegl les A., Tiller W., “The NURBS Book”, Springer, 1997

Ultimate strength of wind turbine blade structures under multi axial loading

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ABSTRACT

Wind turbines must endure a variety of weather conditions including uncontrollable, extreme winds without developing damage and fracture during a lifetime of minimum 20 years. The variety of loading leads to multi axial loading resulting in complex states of stress. The prediction of the effects of the complex states of stress with existing failure criteria can be uncertain and damages and failures often occur earlier than expected. In order to increase reliably and robustly operating wind turbine systems it is of great importance to predict damage initiation and growth accurately. Therefore a profound understanding of the mechanical behaviour of composite materials and structures for wind turbine blades is necessary.

The purpose of this PhD project is to investigate how multi axial loading effects influence the ultimate strength of typical composite structures in wind turbine blades and to develop methods to perform reliable prediction of failure. The complex loading of wind turbine blade structures subjected to different realistic load case will be investigated in order to determine most critical multi axial loading spots in the structure. Damage detection, modelling and prediction of damage evolution under multi axial loading will be carried out based on accurate physics-based failure criteria that have been developed and are preferred to curve-fitting-based criteria. The main limitation associated with latter criteria is that their applicability is restricted to load combinations corresponding to those from which the fitted curves originate. The ability of different criteria to predict failure under multi axial loading conditions will be investigated and methods to account for imperfections will be developed.

PROBABILISTIC DESIGN OF EXTREME LOADS ACTING ON THE FOUNDATION PILES OF A JACKET DURING AN 1-YEAR STORM

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ABSTRACT

Up-to-day, the design of offshore wind-energy converters (OWECs) is based on guidelines and standards, which are mostly based on the semi-probabilistic concept, using partial safety factors. Using probabilistic methods, a more advanced structural design of OWECs shall be found in order to improve safety and reduce costs. This is the aim of the project "Probabilistic Safety Assessment of Offshore Wind Turbines" [1] where the authors participate.
In this paper, an OWEC consisting of the OC4 jacket structure and the NREL 5MW wind-energy converter is loaded by an 1-year storm. The resulting axial force acting on the foundation piles is compared to the pile resistance for tension loading. Also the scattering of the wave induced loads as well as of the pile resistance due to the soil have to be considered.

Instead of applying just one characteristic value for the wind speed, a range of wind speeds is used to determine the resulting extreme load for each of the wind speeds which are covered by the extreme value distribution of the 1-year wind speed. Also, a extreme value distribution of the axial pile force can be found for each wind speed as well, as shown in fig.1 for a wind speed of 36 m/s. In addition, the probability distribution function of wind speed and wind induced axial pile force is shown in fig. 1.

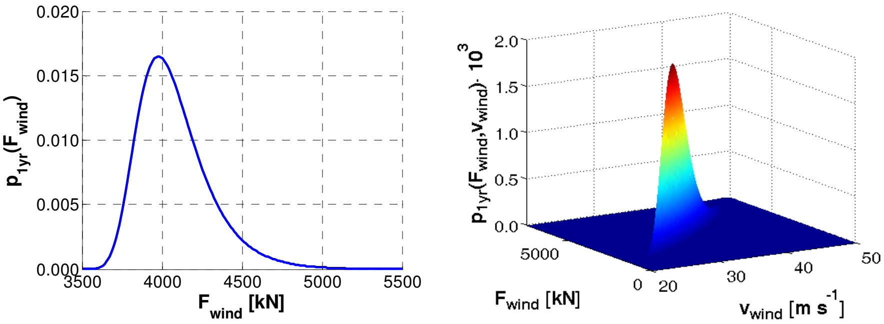

Figure 1:Extrem value distribution for a wind speed of 36 m/s (left), probability distribution function of wind speed and wind induced extrem load (right).

To find the extreme value distribution for one wind speed, many one-hour time series have to be generated for evaluation. Instead of finding the distribution for each wind speed considered, an approach was developed: only the extreme value distribution for one wind speed has to be determined, the others can be found on basis of the general statistic properties of the corresponding time series and the already known extreme value distribution.

To determine the probability of failure, several methods can be applied. One possible method is to compare the probabilities of acting loads and of pile resistance, as stated in Eurocode 0, Annex C [1].

REFERENCES

[1] "Probabilistic Safety Assessment of Offshore Wind Turbines", Annual Reports (2010-2012), Leibniz University Hannover. www.psb.uni-hannover.de
[2] European Standard 1990, "Basic of structural design", European Committee for Standardization (2002), Brussels, Belgium.

Conceptual Design of Floating Wind Turbines

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ABSTRACT

After the first fixed bottom offshore wind parks have been installed and grid connected their cost is in the grasp of market standards. In order to promote the harvesting of offshore wind worldwide foundations need to become more economical, more adaptable to different sites and reliable in terms of resistance and maintenance. Fixed bottom foundations need to withstand excessive wave loads and large amounts of steel are needed for these types of foundations, which are limited to a sea depth of about 50m.

Floating foundations are a new approach to the offshore wind sector. They offer the prospect of being flexible to the site and facilitating the installation. But primarily their shape offers numerous degrees of freedom for design. With the use of concrete as base material it is possible to design economical floating support platforms that allow a stable behavior. However, the aim is to also mitigate extreme and operational loads through the hydrodynamic characteristics of the platform. Various numerical modeling methods exist already, mostly from oil & gas industry. Most common is the application of linear hydrodynamics, whereas also semi-empirical formulations like the Morison Equation exist. Both approaches are very different and allow a detailed understanding and answering of questions, like e.g., for which dimensionless properties is diffraction important, for which other is viscous damping important, how can wave excitation be reduced? Figure 1 shows the platform pitch angle and the tower base moment for two simulations of a reduced model, described in [1], of a spar mounted floating wind turbine. Although both experience turbulent wind only one receives the impact from irregular waves. It can be seen that the pitch angle is almost equal but tower base loads are mostly influenced by the waves. This shows that it is possible to allow large platform displacements, e.g., to mitigate loads from extreme gusts but that it is necessary to limit structural impacts from incident waves.

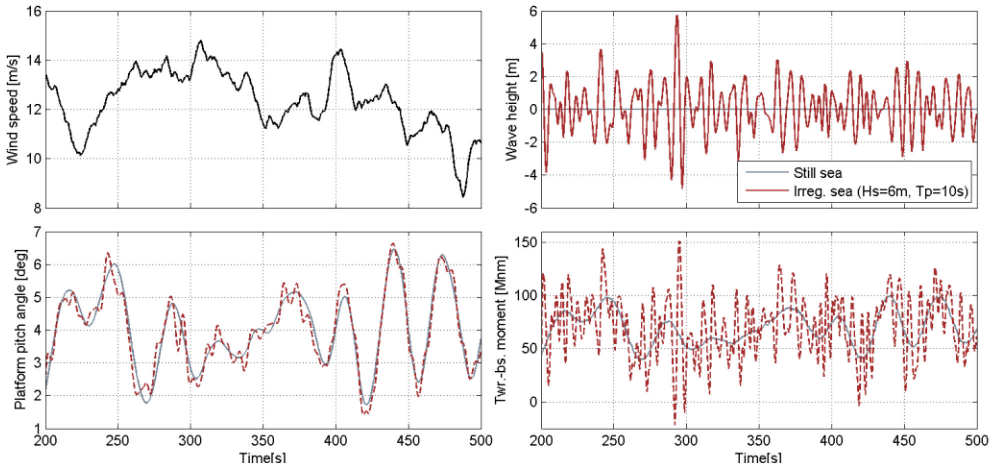

Figure 1 - Comparison of platform pitch angle and tower base moment under wave loads and in still sea.

REFERENCES

[1] F. Sandner, D. Schlipf, D. Matha, R. Seifried, and P. W. Cheng, “Reduced Nonlinear Model of a Spar-Mounted Floating Wind Turbine,” in Proceedings of *DEWEK*, Bremen/Germany 2012.

POWER SYSTEMS

Loss-Of-Mains protection immune to fast system dynamics

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ABSTRACT

With the integration of renewable energy sources such as wind into the UK power system, the system inertia will be significantly reduced; as a result, expected rates of change of system frequency are predicted to increase.

Islanding, or Loss-Of-Mains (LOM), is where distributed generators continue to provide power even when a fault has occurred in the power system. This is undesirable as it poses risks such as health risks to utility workers [1]; consequently, distributed generators are designed to be able to detect islanding and stop producing power in such an event (LOM protection).

Currently, the preferred method of LOM protection is based on the comparison of the measured df/dt against a fixed threshold; this method is known as ROCOF. With the high rates of change of frequency on the rise with the reduced system inertia, the challenge of stability of distributed generation connection goes up and also the possibility of a total blackout through spurious operation of LOM protection on large numbers of generators. A different approach to islanding detection, which is not as sensitive as the ROCOF method, is thus desirable.

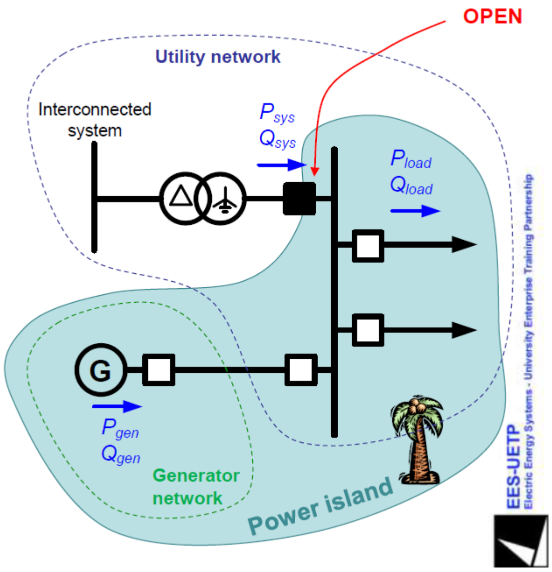

Figure 1. Illustration of islanding [1]

REFERENCES

[1] C. Booth, Proection of Future Networks with Distributed Generation: Loss-Of-Mains Protection, 2011

Possible Power of Offshore Wind Power Plants (PossPOW)

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ABSTRACT

In recent years, the very large offshore wind farms were designed as wind power plants, including possibilities to contribute to the stability of the grid by offering grid services (also called ancillary services). One of those services is reserve power, which is achieved by down-regulating the wind farm from its maximum possible power. There exist reliable methodologies to determine the possible power that can be achieved during the downregulation periods of individual turbine. However, the sum of the possible powers of the individual wind turbines in a wind farm is more than the available regulating power. This is due to the fact that a turbine in the wake of a down-regulated turbine sees more wind than would be available without the down-regulation, due to decreased wake effect.

In order to be able to offer reserve power in the market, the System Operators need to be able to trust the level of reserves. However, currently Energinet.dk, UK National Grid and other Transmission System Operators (TSOs) have no real way to determine exactly the possible power of a whole wind farm which is down-regulated. Therefore, the aim of the present project is to develop a verified and internationally accepted way to determine the possible power of a down-regulated offshore wind farm which requires multi-disciplinary approach which includes wake modeling of large offshore wind farms, aerodynamic models for wind turbines, stochastic model estimation and computer simulations.

The project starts with the calculation of rotor wind speeds of the turbines in the down-regulated wind farm using the power, pitch angle and rotational speed measurements as inputs which also requires the power curve information. Since the calculation is to be performed for downregulation periods, the power curve provided for optimum operational conditions is no longer valid and the power coefficient needs to be updated for changing pitch angle values which is the key aerodynamic parameter for down-regulation. Also considering the generic structure of the project, an algebraic relation proposed by Anderson et al. [1] between the power coefficient, tip speed ratio and pitch angle was used and the wind speed was calculated for each turbine iteratively using second-wise data obtained from Horns Rev I wind farm and a good agreement with the nacelle wind speed measurements is achived. Also, those intermediate results of the first period of the project was further investigated using power spectrum analysis to observe large and small scales which are dispersed over the entire wind farm or associated with individual turbines, respectively in terms of wind speed for certain time intervals.

To take into account the changing wake effects for normal and downregulated operations, two different approaches are considered. The first one is to use the rotor wind speed values of upstream turbines as inputs to the wake model and apply it directly to estimate the velocity deficit and calculate the possible power output of the wind farm. The second approach includes inverse usage of wake modeling as well as the direct one and for the first part, the wake flow will be inputted together with the down-regulated axial force information to the model to create the atmospheric wind field as there are no turbines. For the second part, that ambient flow is used together with the thrust which is updated and valid for normal operation conditions to predict the available power. After performing a comprehensive analysis for those two approaches, one that is found to be more useful to meet the requirements of this project will be applied.

Electromechanical Integration and Optimization of Direct Drive Generators for 10-20MW Wind Turbines

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ABSTRACT

At present, wind turbines are going to 10MW and higher. New wind turbine generators are being designed to meet the very high power production. Conventional direct drive generators excited by permanent magnets become rather big in size and mass due to very low rotational speed and subsequent very high torque. One of the challenges of such generators lay on the integration and optimization of the electromechanical system which must solve the large amount of mechanical and electrical loading and result in a cost-effective design.

This work aims at design optimization methods of integrated electromechanical systems. Firstly, review of typical electrical and mechanical designs of conventional direct drive generators is presented. Secondly the optimization of generator design[1, 2] is introduced taking the mechanical integration [3] into account. Then the optimized design is used in a wind turbine model to calculate the electrical and mechanical performance and a comparison with other topologies of wind turbine generators is conducted [4]. Last, direct drive superconducting generators as a potential replacement of permanent magnet generators [5] are briefly introduced in both electrical and mechanical aspects. This is to give a vision of the generator evolution for large wind turbines.

The research shows that direct drive generators are encountering problems on considerable size, mass and cost at 10-20MW if conventional field excition by permanent magnets is still used. Optimized design of electromachanical integration is able to give a relatively economical solution. Besides, future topologies such as superconducting generators are potentially qualified candidates to reduce size and mass but their cost-effectiveness remains questionable.

REFERENCES

[1] H. Polinder, J. G. Slootweg, "Design optimization of a synchronous generator for a direct-drive wind turbine", European Wind Energy Conference 2001, Copenhagen.
[2] Hui Li, Zhe Chen, "Design optimization and comparison of large direct-drive permanent magnet wind generator systems", International Conference on Electrical Machines and Systems 2007, Seoul, pp. 685-690.
[3] A. Zavvos, A. S. McDonald, M. Mueller, "Electromagnetic and mechanical optimization of direct-drive generators for large wind turbines", 5th IET International Conference on Power Electronics, Machines and Drives (PEMD 2010), Brighton, pp. 1-6.
[4] H. Polinder, F. A. van der Pijl, G. –J. de Vilder, P. Tavner, "Comparison of direct-drive and geared generator concepts for wind turbines", IEEE Transaction on Energy Conversion, vol. 21, no. 3, pp. 725-733, 2006.
[5] A. B. Abrahamsen, N. Mijatovic, E. Seiler, M. P. Sorensen, "Design study of 10 kW superconducting generator for wind turbine applications", IEEE Transactions on Applied Superconductivity, vol. 19, no. 3, pp. 1678-1682, 2009.

Self-Organized Synchronization and Voltage Stability in Networks of Synchronous Machines

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ABSTRACT

In our research project we are going to investigate voltage and rotor angle stability/synchronization in power networks from a nonlinear dynamics point of view focussing on the impacts of fluctuating feed-in and grid decentralization.

In this approach the power grid is represented by a network of synchronous machines. We point out the relationship between power system stability and synchronization phenomena in nonlinear sciences as the so-called classical network representation is shown to correspond to a modification of the prominent Kuramoto model (KM). The KM describes populations of coupled oscillators displaying a phase transition from incoherence to partially synchronized states at a critical coupling coefficient [1,2]. The classical Kuramoto-like network representation has been the means of choice for power system stability analysis of the nonlinear dynamics community so far (see e. g. [3,4,5,6]), in spite of some substantial shortages like neglecting voltage dynamics. We present the extension of the classical network model to a higher dimensional model incorporating voltage dynamics and voltage angle stability interplay [7,8]. This extended model is more realistic, because it takes into account the machines' electrodynamic nature to a greater extent, although it still highly reduced. The investigation of small systems subjected to disturbances uncovers significant differences in the system behaviour between the classical and the extended model.

We discuss the implications for the stability analysis of complex power networks and the potentialities of the extended model with respect to modern power grids characterized by a high percentage of renewable energy plants and we present some first results.

REFERENCES

[1] S.H. Strogatz, "From Kuramoto to Crawford: exploring the onset of synchronization in populations of globally coupled oscillators", Physica D, vol.143 (2000) pp. 1-20.
[2] A. Pikovsky, J.K.M. Rosenblum, J. Kurths, "Synchronization: A universal concept in nonlinear sciences", Cambridge University Press (2003).
[3] G. Filatrella, A.H. Nielsen, N.F. Pedersen, "Analysis of a power grid using a Kuramoto-like model", The European Physical Journal B, vol.61 (2008) pp.485-491.
[4] F. Dörfler, F. Bullo, "Synchronization and transient stability in networks of non-uniform Kuramoto oscillators", American Control Conference (2010), pp. 930-937.
[5] Y. Susuki, I. Mezic, T. Hikihara, "Global swing instability of multimachine power systems", 47th IEEE Conference on Decision and Control (2008), pp. 2487-2492.
[6] M. Rohden, A. Sorge, M. Timme, D. Witthaut, "Self-Organized Synchronization in Decentralized Power Grids", Phys. Rev. Letters , vol.109 (2012), pp. 064101.
[7] J. Machowski, J. Bialek, D.J. Bumby, "Power System Dynamics: Stability and Control", John Wiley & Sons (2008).
[8] P. Kundur, N.J. Balu, M.G. Lauby, "Power System Stability and Control", McGraw-Hill (1994).

OTHER

Optimal Design of Wind-Solar Autonomous Systems with Storage

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ABSTRACT

The aim of this project is to investigate the optimal design of autonomous systems to minimize cost subject to energy balance equations. To accomplish this a mathematical description of the scenario will be formed and the most appropriate optimization technique will be applied.

There are many buildings, enterprises and communities which are not connected to the electrical grid. Such systems are typically small and located in remote areas where a network connection is not economically viable. This scenario highlights the migration from centralized to decentralized energy supply systems. This shift brings new challenges for the planning and operation of energy supply systems. In particular, the optimal operation and cost optimization for an autonomous system consisting of wind power, solar power and energy storage. The optimization is focused on minimizing the cost function based on demand and potential system constraints.

REFERENCES

[1] R. Luna-Rubio, M. Trejo-Perea, D. Vargas-Vázquez and G.J. Ríos-Moreno, "Optimal sizing of renewable hybrids energy systems: A review of methodologies", in *Solar Energy, Volume 86, Issue 4, April 2012, Pages 1077–1088*.

[2] A. Gupta, R.P. Saini and M.P. Sharma, **"**Modelling of hybrid energy system-Part I: Problem formulation and model development", in *Renewable Energy, Volume 36, Issue 2, February 2011, Pages 459–465*.

[3] A. Gupta, R.P. Saini and M.P. Sharma, "Modelling of hybrid energy system-Part II: Combined dispatch strategies and solution algorithm", in *Renewable Energy, Volume 36, Issue 2, February 2011, Pages 466–473*.

[4] A. Gupta, R.P. Saini and M.P. Sharma, "Modelling of hybrid energy system-Part III: Case study with simulation results", in *Renewable Energy, Volume 36, Issue 2, February 2011, Pages 474–481*.

[5] J.L. Bernal-Agustín, R. Dufo-López, "Simulation and optimization of stand-alone hybrid renewable energy systems", in *Renewable and Sustainable Energy Reviews, Volume 13, Issue 8, October 2009, Pages 2111–2118*.

[6] R. Bãnos, F. Manzano-Agugliaro, F.G. Montoya, C. Gil, A. Alcayde and J. Gomez, "Optimization methods applied to renewable and sustainable energy: A review", in *Renewable and Sustainable Energy Reviews, Volume 15, Issue 4, May 2011, Pages 1753–1766*.

[7] L. Ferrer-Martí, R. Pastor · G. M. Capó and E. Velo "Optimizing microwind rural electrification projects", in *Journal of Global Optimization, Volume 50, Issue 1, May 2011, Pages 127-143.*

WINDBENCH: Benchmarking of wind farm flow models

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ABSTRACT

The aim of the project is to provide an environment for supporting joint research in the Wind Energy community. The task is being addressed by building a research community around a web portal WINDBENCH.

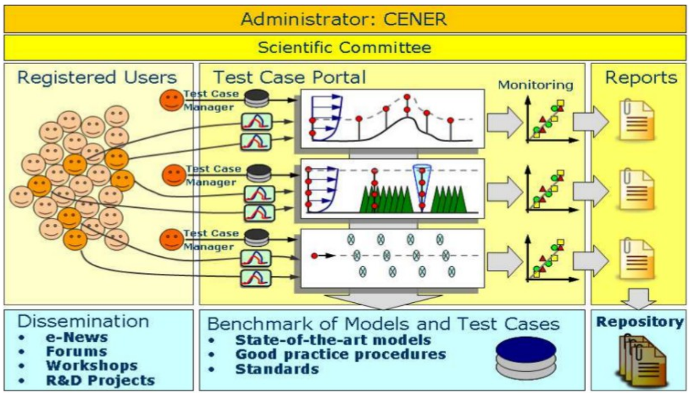

Figure 1: Structure of Windbench.

Windbench allows secure storage of the measurements data and benchmarking results, where owner of the data has a full control over their access. It maintains quality of the data by enforcing templates and reviewing procedures, provides a database of available test cases and wind flow models, and gives possibility of contacting owners of the data. Finally it is to provide tools to communicate (forums, mailing lists) and to compare benchmark results.

The future work will focus on improving the benchmarking procedures based on the feedback of the community and providing useful tools that will encourage the use of the portal. While Windbench project is currently specialized in wind farm models, efforts are being made to expand the portal's functionality and validation procedures to address all the aspects of wind resource assessment. With this approach it is hoped to join different branches of community and allow the improved communication and exchange of data.

Damping of Wind Turbine Tower Vibrations

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ABSTRACT

Offshore wind turbines supported on monopiles are sensitive to waves acting at an angle relative to the wind direction because of the small aerodynamic damping in the side-to-side mode [1]. A way to extend the feasibility of the monopile support to deeper waters and larger turbines is to reduce the dynamic response by means of external damping. Tuned liquid dampers or pendulum type dampers are already installed on some offshore wind turbines today [1, 2]. These dampers should be placed at or around the top of the tower, where the absolute motion amplitude of the targeted vibration mode is largest. Efficient damping by means of a pendulum type damper, though, is associated with large damper motion and damper mass, which is undesirable at the top of the slender wind turbine. Furthermore, the pendulum requires several periods to get synchronized with the motion of the primary structure, thus making it less efficient with respect to instantaneous impulse loading from a large wave. Instead the present Ph.D. project considers the possibility of installing dampers inside the wind turbine tower using bracing systems, whereby the dampers act on the relative motion of the tower. Maximization of the attainable damping and the damper stroke is of primary concern for the effective implementation of the present damper systems inside the wind turbine tower. The relative motion of the tower is expected to be small, which means that an effective damper system requires some form of motion amplification devices, e.g. toggle braces, in order to amplify damper stroke. On the other hand attainable damping is associated with the ability of the damper to lock the structure motion in a modified mode shape, which is slightly different due to the presence of the damper system itself. As demonstrated optimal damper design and installation requires consideration of both damper stroke and attainable damping.

REFERENCES

[1] N. Tarp-Johansen, L. Andersen, E. Christensen, C. Mørch, S. Frandsen, and B. Kallesøe, “Comparing Sources of Damping of Cross-Wind Motion ”, in Proceedings of the European Wind Energy Conference & Exhibition 2009, Stockholm.

[2] K. Argyriadis & N. Hille, “Determination of Fatigue Loading on a Wind Turbine with Oil Damping Device ”, in Proceedings of the European Wind Energy Conference & Exhibition 2004, London.

Vertical Axis Wind Turbine Drivetrain Options

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ABSTRACT

The aim of this project is to answer the questions "What does a large scale vertical axis wind turbine drivetrain look like and what are the drivetrain options?"

Projects and companies such as NOVA [1] and VertAx [2] are currently looking at Vertical Axis Wind Turbines for offshore deployment. Previous drivetrain studies and designs have been conducted for low power units [3],[4] with limited work at larger scales [5]. As with Horizontal Axis Wind Turbines there are a number of options for the drivetrain including:

- Type and use of gearboxes (3 stage, single stage, direct drive)
- Location of generators (in HAWT: upwind, on top, downwind of tower)
- Number and integration of bearings

VAWTs give a number of challenges and opportunities for the drivetrain:

- Slow rotational speed, high torque input to drivetrain
- Large diameter generators (if located around tower [2])
- Multiple and distributed generators (around tower circumference)
- Possibly two point power takeoff (axially offset) [2]
- Gearboxes and generators can be mounted at sea level [1], so can make use of heavier generators and aid access for maintenance
- Vertical axis loading on drivetrain components, mountings and bearings

To answer these questions, potential drivetrain options will be considered with particular attention directed towards the integration into the turbine. A number of the most attractive candidate options will be modeled and the cost/benefits of each assessed.

REFERENCES

[1] http://www.nova-project.co.uk/
[2] http://vertaxwind.com/technology.php#electrical
[3] Chan, T.F.; Lai, L.L., "An Axial-Flux Permanent-Magnet Synchronous Generator for a Direct-Coupled Wind-Turbine System," Energy Conversion, IEEE Transactions on , vol.22, no.1, 2007
[4] Eriksson, S., "Direct Driven Generators for Vertical Axis Wind Turbines", Uppsala University, 2008
[5] Michon, M., "Permanent Magnet Machines for Vertical Axis Wind Turbines", UK Magnetics Society Meeting *"Permanent Magnets - Cradle to Grave"*, Stoke on Trent, February 2012

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