Project title	Wind turbines under harsh operation conditions
Project number	TG0-21
Organisation	Chalmers University of Technology,
Project leader	Ola Carlson
Other participants	See table below
Report for	2016-09-01 – 2018-09-30
Participating companies	See table below

Academic partners

Division	Person	Title
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Fluid Dynamics	Hamid Abedi	Doctor
Dynamics	Viktor Berbyuk	Professor
Dynamics	Håkan Johansson	Associate Professor
Dynamics	Thomas Abrahamsson	Professor
Dynamics	Majid Khorsand	Doctor
SWPTC	Sara Fogelström	Coordinator
Structural Engineering	Alexandre Mathern	PhD student
Electric Power Engineering	Ola Carlson	Associate Professor
Automatic control, Automation and Mechatronics	Sebastian Gross	Associate Professor

Industry partners

Röbergsfjällets vind AB	Tord Östlund
Rabbalshede kraft AB	Björn Johansson
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Project description, summary

This project focuses on the harsh operational conditions that sometimes lead to gearbox and bearing failures before their expected lifespan has been reached. Individual wind turbines that are subjected to extreme wind conditions and otherwise severe operational conditions has been identified in close cooperation with wind turbine operators. Methods for determining the operational severity from data acquired during operation have been developed to obtain relevant operational severity indices. Raw measured data has been processed and compared to the assumed data that was used in the wind turbine design process. Feedback from maintenance reports have been used to strengthen the relevance of these indices. A multiphysics model have been incorporated for simulation of the wind turbine dynamical behaviour under the conditions given by measured wind and grid dynamics. The project has used the synergy of the competences developed within all different competences of SWPTC's.

The assessment has been made using 17 wind turbines of same design but with different operational conditions. Comparisons have been made between data from these turbines, and comparison has also been made using simulated data for complex and flat terrain. The results show that the complex terrain increases the fatigue on the gearbox shaft and the fluctuation of wind direction in the complex terrain is much higher than for the flat terrain, resulting in more destructive fatigue loads. Simulation also shows that de-rating of the turbine has a significant impact on the loads in the drive train but no significant impact on the fatigue loads on the nacelle.

Results

The results are described per work package in the project, see below.

WP1: Project organisation
A detailed work plan has been established, monthly planning meetings have been carried out, workshop for gearbox examination has been organised and work meetings regarding simulation of the wind turbine have been carried out regularly.

WP2: Case studies
The wind turbines operators and owners have informed about their wind turbine fleets and clarified which wind turbines that are available for the study, altogether 75 wind turbines from four manufactures.
There are different systems running for capturing operational data during operation. The “Breeze data” is available for the whole fleet of wind turbines. However the data resolution is poor. Normally Breeze stores only one measurement data point at each 20 seconds, i.e. 0.05 Hz. Then it is difficult to observe any details related to loads based on turbulence or other environment or technical conditions.
For that reason, the project has managed to get higher resolution measurement data for specific turbines in the available fleets. The data comes from Vestas which provide some general data with 1 Hz. For this reason, in combination with the failure rates and model parameters availability, the project has concluded that Vestas V-90 turbines is the type of turbine that should be studied.

WP3: Fluid dynamics
The complex topography of Röbergsfjället wind farm was extracted from LASer data (LAS file), obtained from SLU (www.slu.se), using a commercial software called Global Mapper; and it was imported into STAR-CCM+ to generate the computational grid for the numerical simulations. The on-site meteorology mast data, provided by project partners, were used to determine the dominant mean wind speed/direction and turbulence intensity. These data were also used to validate the numerical modelling.
The numerical simulations were done over the complex and flat terrains. For this purpose, a high-fidelity approach, Large-Eddy Simulation (LES) was employed over a computational domain of size L=10 km x W=10 km x H=2 km, to simulate the atmospheric turbulence and time-varying wind profile for a period of 10 minutes. The surrounding area of Röbergsfjället wind farm is covered partly by farmlands and partly by dense forest. However, in the numerical simulation, it was assumed that the complex and flat terrains are covered by a horizontally homogeneous forest with a height of 20 m.
The results show that the time-averaged stream wise velocity over the complex terrain is higher than over the flat terrain. This can be explained as the well-known phenomenon - the so-called speed-up - which occurs over hills/mountains. Contrary to the flat terrain, the mean flow passing over the complex terrain is deflected laterally and vertically while the lateral deviation is greater than the vertical one. Therefore, all turbines located in the complex terrains are continuously exposed to a more violent yawed and inclined flows compared to the flat terrains. As a consequence, wind farms located in complex terrains suffer from large fluctuating forces acting on rotor blades resulting in higher fatigue loads, higher maintenance costs and shorter lifetime.

WP4: Nacelle and drive train
The very dominating load, affecting the internal parts of the gearbox, is the drive torque on the shaft. This torque is related to the power output of the turbine. By reducing the power at the same rotor speed, the loads acting inside the gearbox is reduced with the same portion. This high number of load/stress cycles should be below the theoretical “Cut-off limit” in design standards, where 1E+8 load cycles are defined as a limit for infinite life. But the absolute difference for infinite life is small. Wear and tear, loads close to the cut off limit, are likely to cause a small slope also above 1E+8 load cycles. This high cycle slope might be crucial for the life of the gearbox component.
In combination with nacelle bending moment, which might cause displacements in the gearbox housing, leading to non-uniform internal loadings, the harsh conditions create a load situation which is above the design requirements of the gearbox. Relatively small constraints in maximum power output might be the difference between limited and infinite life.

WP5: Mechanical loads and aging of towers and foundations
A common approach for the design of foundation is that the turbine and foundation are usually analysed separately and the loads used to design the foundation are calculated assuming a rigid foundation. This way of designing has its limitations and will influence the design loads crucially for stability/durability, especially for larger wind turbines and poorer soil conditions. The effect of soil-structure interaction (SSI)

on the design of gravity foundations for wind turbines was studied by implementing SSI in the open source aero-servo-elastic simulation tool FAST. A parametric study was conducted to investigate the influence of SSI for different soil conditions. The study showed the potential impact on the fatigue loads and the natural frequencies of the system. The stability of a foundation is conventionally checked with empirically developed formulas. A comparison was conducted by computing a three-dimensional yield surface for a shallow foundation under combined loading (horizontal and vertical forces and moments). It was shown that this method lead to less conservative results.

There are numerous reports from Sweden and abroad of cracked concrete foundations of wind turbines but there is lack of details on their causes and consequences. Observations and recommendations of measures for preventing low quality foundations have been summarized in a paper.

WP6: Electric drives and grid disturbance

Transient models of grid, converter and generator during grid disturbance has been developed in previous projects and have been used in this project. Typical voltage dips in the grid were the inputs for the simulations. The results showed that there is a significant torque peak from the generator when there is a large voltage dip in the grid. The peak can be as high as the rated torque doubled and the duration is around 50 ms. The peak occurs when the voltage comes back after the dip. But the torque peak is very short, and the softness in the generator rotor, the shaft and the mechanical coupling to the gearbox will absorb the force and there will be a minimal extra torque on the gearbox shaft.

WP7: Control to reduce the load

The actual V90 control system is unknown to the project participants. But from analyses of the measurement data, the control system can be predicted. It is noted that the V90 turbine operate at constant rated rotor speed above a certain power which is below rated power. As a starting point, an open source controller (NREL 5 MW) has been evaluated. By parameter substitution and tuning, a very good agreement has been obtained when comparing the measured 1 Hz data with the simulation output when using the adapted generic controller.

It has also been shown that the constant rotor speed at various power output can be achieved by using a PI-controller for the torque setting in medium winds Source code and parameter settings are part of the project results. However, what are a bit tricky is the transition criteria between different regions. Therefore, the robust NREL controller has been used for the load calculations. The differences in loads are insignificant.

The major control action to reduce the loads is the power output. From comparisons of different power settings the following conclusions are stated:
The fatigue loads are far from equal for wind class II conditions rated 1.8 MW compared to wind class III conditions rated 2.0 MW.
De-rating of the turbine has significant impact on the loads in the drive train but no significant impact on the fatigue loads on the nacelle.

WP8: Simulation of the wind turbine

This work package has summarised the steps needed to generate a new wind turbine blade model for aero elastic simulation purposes. This is also to provide knowledge and hints for other research activities, where new generic turbines are requested and required. Besides the new V90 blades, a whole generic V90 turbine has been created for the simulations in the project. This input parameters have been used to simulate V90 using both FAST and VIDYN aero elastic simulation codes. A system simulation model in FAST or VIDYN can reasonably well predict the hub forces and nacelle motions of a Vestas V90 turbine under different kind of wind load in operation.

WP9: Multidisciplinary questions

Based on the various subsystems dealt with in WP 2-8, issues arising from the various subsystems has be studied, such as how the turbulent wind creates forces on the shaft and gearbox and can grid disturbance create a damage on the generator and also damage the gearbox? Can turbulent and gusty winds create additional stress on the foundation? Just to name a few issues. Some answers has been created such as fast generator torque fluctuations in not transferred to the gearbox shaft. But it is clearly shown that complex terrain create more turbulence and there by more loads.

WP10: Measurements and measurement system
In collaboration with the wind turbine owner the project managed to receive measurements from the sensors of wind speed, wind direction, yaw position, pitch angle, rotor speed and generator power with the sampling rate of 1 second. The measurements with the sampling frequency of 1 Hz were collected for 16 wind turbines from June 2017-October 2018. Similar measurements from a V90 in flat terrain from a previous project has also been used for comparison. A number of measurements were collected and correlated with data of gearbox repair.

An additional measurement campaign, contributed by QUALISYS, that is based on optical measurement of gearbox motion, was evaluated for one turbine. This study revealed the possibility to evaluate turbine performance based on motion tracking of gearbox.

Fulfilment of SWPTC's goals

The main goal of the SWPTC is to develop knowledge of the full wind turbine system through deep understanding of the system components and their interaction. This project is in line with that aim since it targets the complete wind turbine structure with analysis based on a synergy of theory, modelling and collected operational data from sensors.

Wind turbines always operate within the Atmospheric Boundary Layer (ABL) and are therefore subjected to atmospheric turbulence. Therefore, prediction of flow field is extremely important for design, development and optimization purposes. In the project, advanced computational methods for more accurate prediction of atmospheric boundary layer over complex terrains are developed. This will lead to:

- Assessing the economic feasibility of a wind turbine farm project
- Increased lifetime of wind turbines
- Reduced operating and maintenance costs

Deviations from project plan

The main goals of the project has been fulfilled.

Publications

No publications so far, a large technical report is done and a scientific journal paper is planned.

External activities

Presentations on wind power conferences are planned during the coming year.