Annual Report

period 9
2019-01-09 – 2019-12-31

SWPTC

SWEDISH WIND POWER TECHNOLOGY CENTRE

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Project title	Swedish Wind Power Technology Centre
Project number	Swedish Energy Agency; P-no: 32591-2, Dnr:2014-002371
Project duration	2019-01-09 – 2022-12-31
Organisation	Chalmers University of Technology, Dept. of Energy and Environment
Report for	2019-01-09-2019-12-31
Project leader	Ola Carlson
Project coordinator	Sara Fogelström
Board members	
Chairman of the board	Matthias Rapp
Academic partners	Luleå University of Technology, RISE, RISE Sicomp, Lund University, Chalmers University of Technology
Industrial partners	EnBW Sverige, Greenbyte, Modvion, NCC Sverige, Rabbalshede Kraft, Stena Renewable, TensionCam System

Project description

The two goals of the Swedish Wind Power Technology Centre, SWPTC, are to enhance knowledge of the components and systems, throughout the entire wind turbine and associated systems, to facilitate top-class research with the aim of producing optimum wind turbines and subsystems and of reducing operating and maintenance costs, as well as Swedish development and production of components and subsystems.

In the first stage of SWPTC, knowledge was built up about wind turbines among the participating academic partners, from expert knowledge in their respective fields to their application to wind power. This could then be further developed in stage two, where more in-depth research was carried out and links were also established between the areas of expertise. This development is intended to continue in the third stage when several cross-disciplinary projects are planned, and some has started.

The focus of activity in SWPTC is on knowledge for technology development and the efficient operation of wind turbines, since this is very important for cost-effective electricity generation, which needs to be adapted to the natural sites in Sweden. The adaptation of the power electronics of wind turbines to the Swedish electrical system is also important for a stable power grid. A further important characteristic of a competence centre is its critical mass and this is particularly applicable to wind power technology which encompasses several technical areas of expertise.

The research carried out at SWPTC is mainly aimed at the individual wind turbine, since it is essential to first understand how its individual parts work together to ensure the optimum conversion of wind energy to electrical energy. Today's view that a group of wind turbines can be equated to a power plant shows the importance of having good knowledge of the interaction between wind turbines in a wind farm and the best way to control and link these together to maximise electricity generation and obtain the best service life. The research will focus on large wind turbines and wind farms to be sited in forest, mountain and offshore environments.

SWPTC has identified six research areas that stage 3 will focus on. These are Supporting Structure, Electric Drive Train and DC grids, Lifetime and maintenance, Deicing and ice detection, Forest/Complex terrain and control as well as Grid service from wind turbines.

In order to develop the research areas and address various problems, in-depth knowledge of different areas of expertise is required. The different areas of expertise which form the basis for wind power technology are described in the next chapter. These areas are Electric Power Engineering, Fluid Dynamics, Automatic control, Dynamics, Structural Engineering, Materials Technology and Numerical Analysis and Optimisation

The projects in SWPTC are carried out in close collaboration with industrial partners to facilitate the utilisation of the research findings. The role of industry in a project may include many different elements, everything from proposing and writing project applications, taking an active part in calculations and the analysis of results, delivery of measurement data, component and operational data, description of a plan for a service contract, to participating in a doctoral student's reference group.

At Chalmers there are five divisions active in SWPTC; Electric Power Engineering, Dynamics, Fluid Dynamics, Structural Engineering and Mathematics. The units Renewable Energy from the Ocean and Wind, Building and infrastructure and Transport safety at RISE, also work within the Centre. The Centre is unique in the way that many divisions, from several areas of research, cooperate in one Centre.

Results

All projects from stage 2 ended with that stage. Therefore, two new projects have started during 2019. The projects within stage 3 should be broader than previous stages and include at least two areas of expertise. One project includes the continuation of a PhD project from stage 2 as well as senior researchers. The other project is a senior researcher project. The project portfolio covers three of six research areas of the programme description so far.

At the end of the reporting period, the Centre projects employ one PhD-students and three senior researchers. Around five permanent employees at Chalmers have been engaged as supervisors or project leaders, on a part time basis, mainly at professor or associate professor levels. Around 25 people from the industry partners also work with SWPTC projects. During this period the Centre has generated about three full-time equivalent of work.

A summary of carried out work in the two ongoing projects will be found below.

Methods and material for sustainable and cost effective structural supporting systems for wind power plants

One part of the project is to investigate cost-effective processes and solutions of onshore supporting structures in the design, construction and management. The work has started with implementation of set-based design process of the foundation. Another work package in the project convers development of an innovative wood tower. The progress in this WP includes a principle proposal of anchoring of tower base to the foundation. The last WP in the projects investigates methods for supervision of bolt pretension. With better understanding and control of the pretension, a bolt joint design can be optimised with downsizing of both the bolt itself as well as the surrounding components. The WP has defined a test scheme and schedule for systematic workshop loading tests with relevant number and size of bolt connections. Furthermore, the WP has executed theoretical calculations and FE-models of the bolt connection and nut to provide theoretical input to use in the test validation program. Workshops tests and FEM-modelling have resulted in important findings and improvements regarding mechanical design of the cavity, cavity position and pattern on the measurement object (bolt, nut or washer).

Site-Adaptive Analysis Methods to Predict and Enhance Lifetime of Wind Turbines

A generic gearbox, relevant to a 2MW machine has been defined to be used for comparative studies of wind turbine operation. This includes arrangement and specification of gears and bearings, as well as CAD model. The mean flow and the turbulent kinetic energy profiles for all turbines at the project site have been extracted for a period of 100 minutes. The results show that the mean wind and turbulence intensity profiles depend on the turbines' location due to the impact of the complex terrain. Furthermore, the work with developing a new preventive maintenance model into an algorithm has continued. An optimisation model was proposed whose solution suggest wind turbine owners which components, and when, should undergo the next preventive maintenance (PM). The algorithm suggests how the wind turbine owners can apply the optimization model, how they can reschedule the maintenance. When applying already published data, it showed the cost has been reduced around 35% compare to pure corrective maintenance by a better planning methodology.

Finances

At the end of the report period, the Centre has received 4 790 000 SEK in cash, whereof 84 % comes from the Swedish Energy Agency, 15 % comes from industry partners and 2 % from the academic partners. The total cash budget for whole duration of stage 3 of SWPTC is 24 million SEK.

During this period, the Advisory Board recommended funding for two projects that together with the management cost of the Centre, cover 74% of the total budget of the Centre. Chalmers rector followed the recommendations and decided to fund the two projects.

During this period, the industrial companies have carried out 40 % of their total share of in-kind, and the academic partners have carried out 1 % of their total share of in-kind. During the whole of stage 3, 24 million SEK of in-kind work will be carried out.

For more details about the finances of the Centre's, see the attached financial report.

Other internal activities
During this period SWPTC has had three Advisory Board meetings.

Deviations from project plan
The two started projects are slightly behind schedule, but this will not affect the goals of the projects.

Publications during this period
No publications have been made during this period.

External activities
SWPTC organised a wind power seminar at the conference Vind2019 in October 2019 together with the other wind related research programmes in Sweden.

During this period SWPTC has participated at two board meetings within European Academy of Wind Energy (EAWE) in Cork, Ireland in June and in Nantes, France in October 2019. SWPTC has also participated in two board meetings within European Energy Research Alliance (EERA) in Bilbao, Spain in April and in Amsterdam, the Netherlands in September 2019, as well as in the EERA JP Wind & SETWind Annual Event 2019.

Projects

The Centre has two on-going projects.

Project title	Methods and material for sustainable and cost effective structural supporting systems for wind power plants
Organisation	RISE, Chalmers University of Technology
Project leader	Anders Wickström, RISE
Other participants	Hamidreza Abedi, Chalmers, Rasmus Rempling, Chalmers, Jesus Armesto Barros, NCC, Nilla Olsson, NCC, Alexandre Mathern, NCC, Tobias Larsson, NCC, Erik Dölerud, Modvion, Carl-Johan Åkerström, Modvion, Jonas Nilsagård, TensionCam
Report for	2016-10-01 – 2017-09-30
Participating companies	NCC, Modvion, TensionCam Systems, Rabbalshede Kraft, Stena Renewable

Project description

The overall purpose of this project is to increase the knowledge of tomorrow's supporting structures and to aid business development in Swedish wind power and construction sectors. With this project, the sectors will come closer to delivering solutions that are more cost-effective, with a less impact on the environment and minimal maintenance. The results will extend the life of wind turbine towers and foundations by better load predictions and load control.

It will also propose specific solution aspects where wood is the base material in turbine towers. Towers built in laminated wood has a potential to reduce manufacturing costs to 40% lower cost than the corresponding tower in steel and minimizes environmental impact. This project will provide clarifications on potential risks, by validations from the new Chalmers pilot research turbine at Björkö and by additional analyses and laboratory tests. Further a reliable connection to the (concrete) foundation will to be invented, tested and evaluated for an optimal full-scale 150 meters wood tower.

Methods for measurement of pretension in bolts do exist but are for various reasons not used on a general basis. With better and cheaper control of pretension, a bolt joint design can be optimised with downsizing of both the bolt itself as well as the surrounding components. This project will provide a documented and validated methodology to control and supervise pretension in tower bolt connections.

Results

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

WP2: Numerical simulations of complex terrain
No results, as the work package starts 2020

WP3: Product and Processes
The aim is to investigate cost-effective processes and solutions of onshore supporting structures in the design, construction and management. The work has started with implementation of set-based design process of the foundation.

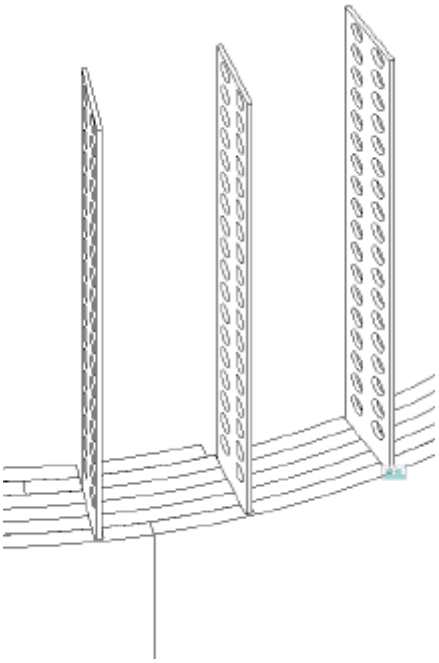
WP4: Intelligent supporting structure
The aim is to investigate monitoring systems inside the foundations that can act as an intelligent agent for stakeholders. Achievements during period include established connection with stakeholders and started investigating different systems. Furthermore, the installation of sensors at Chalmers test research turbine has been supported.

WP5: Innovative wood tower
This part of the project started: 2019-10-01, hence three months of work only. But it will follow up the ongoing activities with the tower for the Chalmers research turbine at Björkö, which is to be equipped with a 30 meters wooden tower. This project will use this tower for measurements and validations.

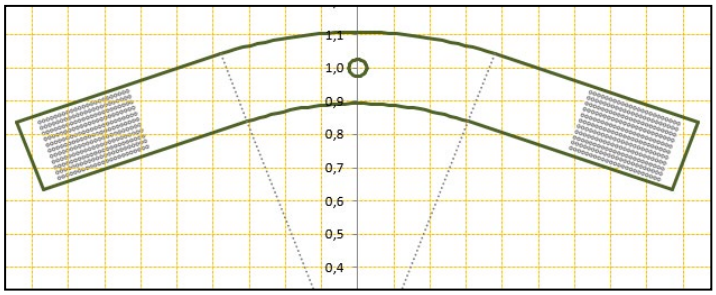
Manufacturing at Moelven in Töreboda

The progress in this WP includes a principle proposal of anchoring of tower base to the foundation. This solution is similar to the existing vertical joint between tower sections and use the same perforated steel plates to transfer loads from one segment to the other.

On the picture to the right, some steel plates for the Chalmers research turbine is shown. It is based on a document issued by Deutsches Institut für Bautechnik: “Allgemeine bauaufsichtliche Zulassung Z-9.1.770 Holz-Stahl-Klebeverbindungssystem (HSK-System)“. However it is verified for wind turbine towers or other structures that are subjected to fatigue. That’s way this research project will follow up and clarify these aspects by both additional laboratory fatigue testing activities and measurements at the Chalmers research turbine. The aim is to have a validated documentation of the structural integrity of this connection.



A similar solution at the tower base can be achieved by bending a corresponding steel plate along the dotted lines in the picture below, creating in a U-shape steel plate.



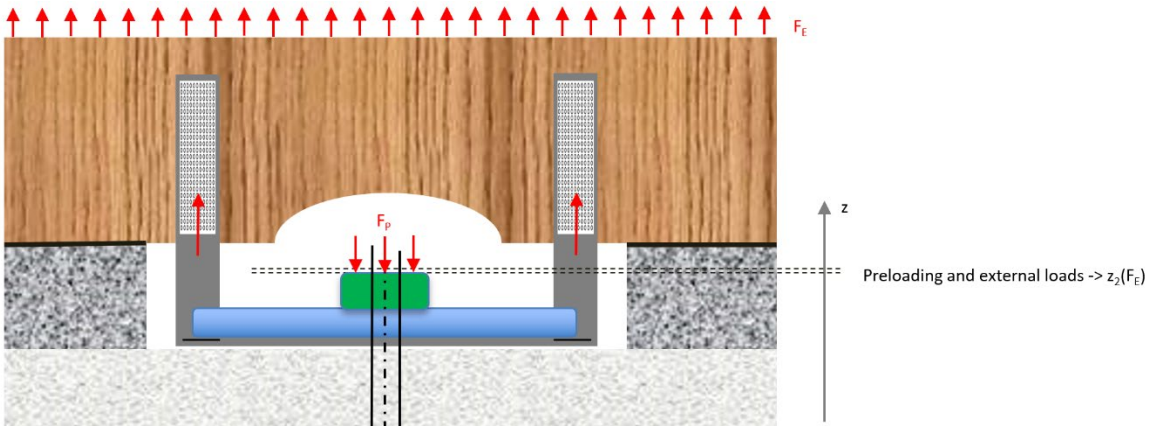
Looking at the solution from the side, The Principle for the Modvion bolt connection to the foundation is further described below:

The bolt nut is shown in green. The upper part of the nut is located at vertical level z_0 before any loads are applied.

When the bolt is prestressed, the structure in the area of the connection, including the foundation and the glued steel plate, is deformed. A preloading force of F_P results in a total average displacement $z_0 – z_1$, which are calculated by FE-methods. The displacement is shown in principle in the figure below. The static bolt stress is σ_{pre}.

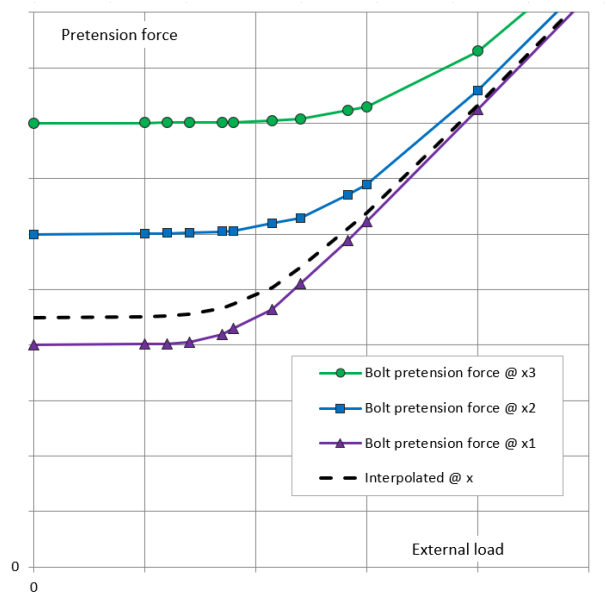
As the bolt is located in between the vertical parts, there is a symmetry, resulting in no angular displacement in this direction. In the opposite direction, the aim is to get neglectable angular displacement, which is obtained by correct location of the hole. A starting point is to locate the hole in the middle of the plate thickness, but due to the sweep shape it might be slightly moved. FE-calculations to verify.

When also adding external loads to the structure, i.e. membrane stress at the tower shell, in the positive direction of the z-axis, the corresponding vertical force F_E will pull the steel plates upwards. The location of the upper part of the nut will then come to a new position z_2.



The bolt displacement is then $z_2 – z_1$ and varies over time as function of $F_E = F_E(t)$. The corresponding bolt stress is calculated as $\sigma(t) = \sigma_{pre} + (z_2(t) – z_1)*E/L$, where E is the elasticity of the bolt material and L is the free length of the bolt.

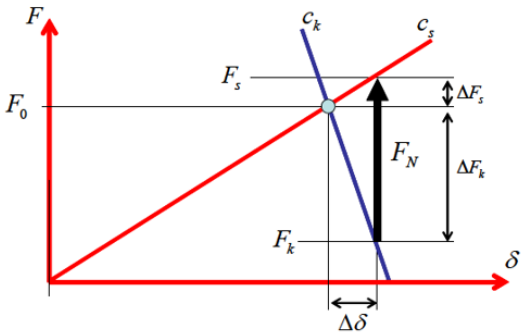
The relation between z_2 and F_E is not linear and depends on the bolt pretension. From other bolt joints, the following relationship has been observed by FE-calculations between bolt stress as function of external load depending on the bolt pretension force.



The corresponding relationship is to be calculated for this specific joint.

WP6: Methods for supervision of bolt pretension

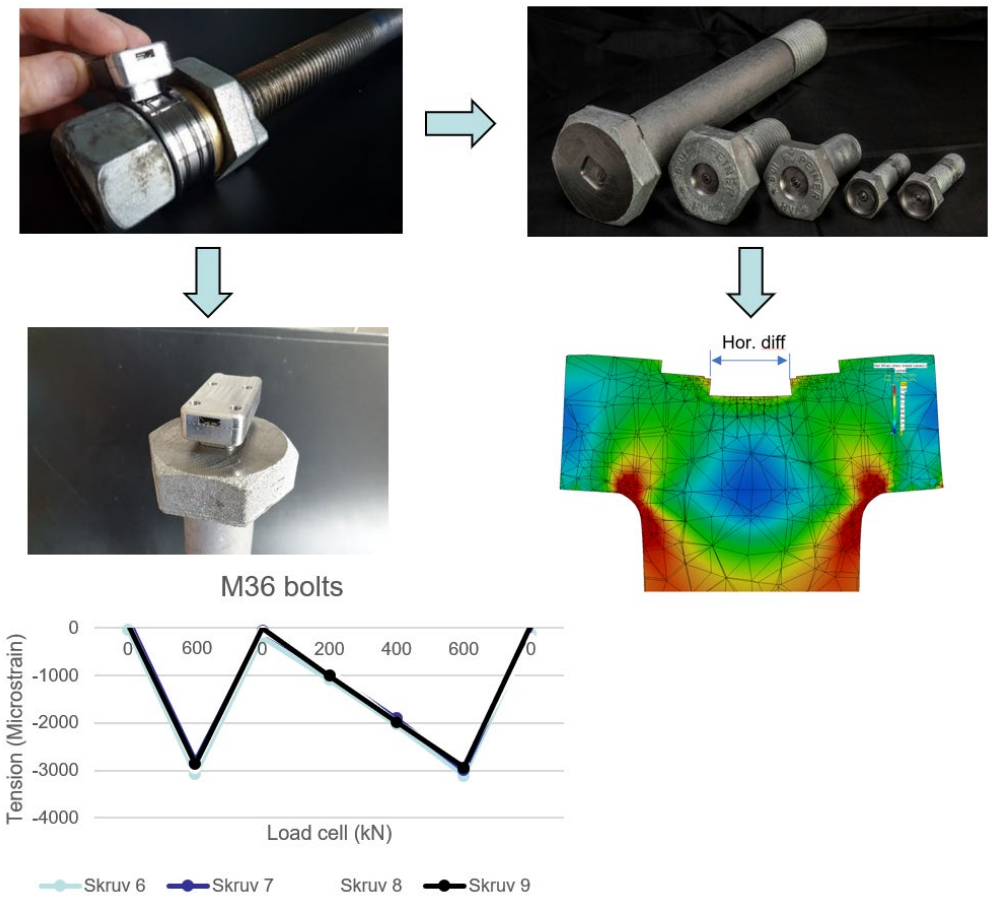
With better understanding and control of the pretension, a bolt joint design can be optimised with downsizing of both the bolt itself as well as the surrounding components



This WP6 include investigations of methodologies to understand and supervise pretension in tower bolt connections. The following steps have been executed:

- Brainstorming and ideas from project participants
- Definition of a test scheme and schedule for systematic workshop loading tests with relevant number and size of bolt connections.
- Execute theoretical calculations and FE-models of the bolt connection and nut to provide theoretical input to use in the test validation program.
- Manufacturing of a number of screws
- Systematic workshop tests according to the scheme and schedule.
- Compilation and documentation of results
- Investigation of the impact of different bolt size and configuration (geometry, bolt distance, flange size etc) of bolt connection
- Investigation of potential wireless configuration and methodology

The cooperation with the different partners is creative and the results are very promising, where some of the steps and results are shown below.



Workshops tests and FEM-modelling have resulted in important findings and improvements regarding mechanical design of the cavity, cavity position and pattern on the measurement object (bolt, nut or washer).

Work is almost finished, far earlier than expected due to intense work from all parts. Expenses are in line with budget and the results from the WP exceeds expectations.

Fulfilment of SWPTC's goals

The project contributes to the following goals of the Centre:

- Top-class research with the aim of producing optimum wind turbines subsystems, reducing operating and maintenance costs
- Swedish development and production of components and subsystems
- Reliable wind turbines resulting in a high uptime in any climate

Deviations from project plan

WP6: The execution and progress has been more rapid and successful than anticipated. The budget is close to fulfilment already during 2019.

Publications

No publications.

External activities

Presented the project at Vind2019.
Presented and published WP5 at Wind Energy Science Conference 2019 in Cork.

Project title	Site-Adaptive Analysis Methods to Predict and Enhance Lifetime of Wind Turbines
Organisation	Chalmers: M2 Dynamics, M2 Fluid Dynamics and Applied Mathematics
Project leader	Håkan Johansson
Other participants	Hamidreza Abedi, Quanjiang Yu
Report for	2019-07-01 – 2019-12-31
Participating companies	Greenbyte, Rabbalshede Kraft, Stena Renewable, EnBW Sverige

Project description

The project considers the sequence “from wind to fatigue life”, and by simulation investigate how the site-specific conditions (terrain, forest, etc.) affect the fatigue life of turbines. The project involves CFD simulations to investigate the flow field, wind turbine system simulations to evaluate how this flow field affects wind turbine operation and lifetime of drive train components, and development of maintenance algorithm to reduce down-time and repair waiting time.

More specifically, to investigate the flow field in complex terrain, an advanced numerical method is developed to investigate how the site-specific conditions (terrain, forest, etc.) affect the fatigue life of turbines. For this purpose, CFD (Computational Fluid Dynamics) will be carried out in a region of 10x10 square km surrounding the wind farm. Advanced CFD simulations (Large Eddy Simulations) give the fluid flow around each wind turbine in the wind farm located in complex terrain with heterogeneous forest. The commercial CFD software STAR-CCM+ will be used to model the airflow. The local flow field around the wind turbines will be fed into an open-source CAE tool called FAST (Fatigue, Aerodynamics, Structures and Turbulence) by which electric power production and fatigue loads can be computed. The wind conditions at the site will be taken from the meteorology mast and SCADA data from the wind turbines. The Röbergsfjället wind plant located in Dalarna is used in this project. The topology and the forest density of the site (Röbergsfjället) are obtained from Laser data (LAS file) from SLU. It is very hilly, partly covered by forest and consists of 8 2MW Vestas machines.

To investigate turbine fatigue life under varying loads, a previously developed system simulation model of a 2MW turbine is used to determine the drive train loads. To assess the internal drive train loads and estimate fatigue life of drivetrain components, a generic gearbox model is developed and studied.

Results

A generic gearbox, relevant to a 2MW machine has been defined to be used for comparative studies of wind turbine operation. This includes arrangement and specification of gears and bearings, as well as CAD model.

The mean flow and the turbulent kinetic energy profiles for all turbines at Röbergsfjället site have been extracted for a period of 100 minutes. The results show that the mean wind and turbulence intensity profiles depend on the turbines’ location due to the impact of the complex terrain. In addition, a higher turbulent kinetic energy is predicted for the complex terrain rather than the flat terrain despite the identical simulation’s boundary conditions.

A new preventive maintenance model was developed into an algorithm. A binary linear optimisation model was proposed whose solution may suggest wind turbine owners which components, and when, should undergo the next preventive maintenance (PM). The algorithm suggests how the wind turbine owners can apply the optimization model, how they can reschedule the maintenance. When applying already published data, it showed the cost has been reduced around 35% compare to pure corrective maintenance by a better planning methodology.

Moreover, the long-term maintenance scheduling model was further developed by considering contract and the end of lifetime. Using already published data, the model showed a good performance as well. By taking into account of the end of lifetime, the maintenance cost is reduced by 250 kSEK, which is 2.5% of the total maintenance cost.

Fulfilment of SWPTC's goals

The project aims at better prediction of wind turbine loads by considering also the particular site the turbine is operating. The project results so far address the SWPTC goals as follows:

- An extended service life with the aid of better load prediction, optimum operation and preventive maintenance.
    - Better prediction of wind turbine loads by more accurate wind field analysis considering the complex terrain.
- The development of maintenance methods, including fault detection, based on operational data in collaboration with design data.
    - Developed generic gearbox helps development of fault detection methods and evaluation of operation data
    - Developer algorithm and maintenance models enables further studies to develop a and efficient predictive maintenance scheme that is implementable on today's turbines.
- Reliable wind turbines resulting in a high uptime in a cold climate, in forests and offshore.
    - Improved understanding of wind conditions in in forest regions (which typically have also complex terrain) helps improving turbine operation.
    - The project address improved lifetime predictions based on detailed drivetrain analysis, better load prediction by more accurate wind field analysis considering the complex terrain, and predictive maintenance by better maintenance scheduling tools

Development and tuning of Digital Twin can help better coupling between design specifications and operational data. From better understanding of the influence of forest heterogeneity and topography effect on wind characteristics, improved operation of turbines in forest regions (which typically have also complex terrain) can be expected.

Deviations from project plan

The recruitment of Post-doc is delayed, currently expected to arrive at 1 March if Visa is granted.

Publications

No publications during this period.

External activities

No external activities during this period.

Publications

Journal papers

P. Veers, et al, *Grand challenges in the science of wind energy*, Science, 0036-8075 (ISSN), Vol. 336 Issue 6464 art. nr eaau2027

N. Espinoza, O. Carlson, *Field-test of wind turbine by voltage source converter*, Wind Energy Science, 23667443 (ISSN) 23667451 (eISSN), Vol. 4 Issue 3 p. 465-477
(Publication from a previous project within SWPTC.)

A. Roghani Araghi, G.H. Riahy, O. Carlson, S. Gros*, Enhancing the net energy of wind turbine using wind prediction and economic NMPC with high-accuracy nonlinear WT models*, Renewable Energy, 0960-1481 (ISSN)
(Publication from a previous project within SWPTC.)

External activities

International conferences

- WESC 2019, 17-20 June 2019, Cork, Ireland
- EERA JP Wind & SETWind Annual Event 2019, 24-25 September 2019, Amsterdam, The Netherlands

National conferences

- Vind 2019, 23-24 October 2019, Stockholm