Annual Report

period 10
2020-01-09 – 2020-12-31

SWPTC
SWEDISH WIND POWER TECHNOLOGY CENTRE

Table of content

Centre

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 Electrical Engineering
Report for	2020-01-01-2020-12-31
Project leader	Ola Carlson
Project coordinator	Sara Fogelström
Board members	
Chairman of the board	Matthias Rapp and Elisabet Falemo
Academic partners	Luleå University of Technology, RISE, RISE Sicomp, Lund University, Chalmers University of Technology
Industrial partners	Bulten, Centrica, EnBW Sverige, Energiforsk, Greenbyte, Modvion, NCC Sverige, Rabbalshede Kraft, Stena Renewable, Svk, 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 with several cross-disciplinary projects.

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
Two projects started during 2019 and two more projects were approved during this period. All projects are broad projects and include at least two areas of expertise. The two new projects are both senior research projects. The project portfolio covers four of six research areas of the programme description.

At the end of the reporting period, the Centre projects employ one PhD-students, two post docs, nine researchers and three senior researchers. Another four senior researchers are connected to the Centre but are not working directly in a project. Around 20 people from the industry partners also work with SWPTC projects. During this period the Centre has generated about 24 full-time equivalent of work.

Finances
At the end of the report period, the Centre has received 11 600 000 SEK in cash, whereof 69 % comes from the Swedish Energy Agency, 18 % comes from industry partners and 13 % from the academic partners. The total cash budget for whole duration of stage 3 of SWPTC is 24 million SEK.

During this period, two new projects were approved, leading to four ongoing projects. Together with the management cost of the Centre, the four projects cover 100% of the total budget of the Centre.

Up to and including this period, the industrial companies have carried out 60 % of their total share of in-kind, and the academic partners have carried out 57 % 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 financial report.

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

Deviations from project plan
No project is significantly behind their time plan.

Publications during this period
Two technical reports were published during this period.

External activities
SWPTC organised the wind power conference Vindkraftsforskning i fokus 2020 in October 2020 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 May and in October. EAWE has also held to strategy committee meetings that SWPTC has participated in. SWPTC has also participated in two board meetings within European Energy Research Alliance (EERA), in February and in June, as well as in the EERA DeepWind 2020.

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

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	Rasmus Rempling, Chalmers, Hamidreza Abedi, Chalmers, Jesus Armesto Barros, NCC, Nilla Olsson, NCC, Alexandre Mathern, NCC, Tobias Larsson, NCC, Erik Dölerud, Modvion, Carl-Johan Åkerström, Modvion, Geir Söderin Modvion, Jonas Nilsagård, TensionCam
Report for	2020-01 01– 2020-12-31
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

The purpose is to study and assess in detail, by simulations, different loading conditions, tower heights and material compositions in tower and foundation; as well as, cross-sectional forces in critical sections of the tower-nacelle attachment, tower-foundation anchoring and hot-spots for fatigue in tower and foundation.

The topographic map around Chalmers wind turbine, including the sea surface and ground, has been extracted from Airborne Laser Scanning (ALS) 3D-data with the horizontal resolution of 5x5 [m2], obtained from SLU (www.slu.se). It was imported into STAR-CCM+ as the STL format to generate the computational grid for the numerical simulations. A high-fidelity CFD method - the so-called Large-Eddy Simulation (LES) - has been performed to model the airflow around Chalmers wind turbine.

WP3: Product and Processes

The design, construction and management of wind power plants are essential areas when it comes to promote national up-scaling of the wind power as an energy source. The purpose of this work package is to investigate solutions that are cost-effective in all three areas and the following activities are planned:

- Identify a generic design tool that can design with regard to sustainability and buildability aspects of foundation and tower.
- Investigate the degradation of concrete foundation and how this degradation can be slowed down by a better design and construction process.
- Investigate Stakeholders' needs of a monitoring system of tower and foundation.

A parametric design tool is been developed. Eurocode checks as well as other requirements from turbine manufacturers are been implemented. Equilibrium checks have already been implemented and focus is now set into static design checks for ultimate and service limit states. Parallelly some research has been done about how to implement multicriteria analysis in an effective way here.

WP4: Intelligent supporting structure
The purpose of this work package is to investigate monitoring systems that can act as an intelligent agent for Stakeholders with the following objectives:

- Investigate systems for monitoring of construction and management of wind power supporting structures.
- Investigate a futuristic system of monitoring and artificial intelligence.
- Apply and evaluate sensors on structure, both for casting process and management purposes. This will be done at Chalmers laboratory facilities and in adequate environment, such as an operating wind power turbine.
- Investigate how the increased knowledge from monitoring can be used to design and deliver a product with higher quality to a lower cost.

The work within this work package was initiated January 2020 and a detailed activity plan was done in cooperation with the other work packages. With the objective to enable a cost-effective solution that require a minimum of maintenance, the first activity was an interview study with stakeholders. The purpose was to gather knowledge about wind power foundations and especially about design issues, construction process, and sustainability and durability aspects. The interviewees have been involved in several wind turbine projects. They were identified to represent different positions, at different stages in construction and maintenance, different companies, and both research and development.

The results from the interviews are now being analysed to clarify what aspects of construction and maintenance that could be improved and how an intelligent monitoring system could be used to deliver optimized plats with a minimum of maintenance.

WP5: Innovative wood tower
The purpose is to increase the knowledge of wooden wind turbine towers in order to prove that wooden towers are commercially viable alternatives to conventional steel towers. This includes to investigate innovative design solutions to avoid a steel transition piece between the wooden tower and foundation and to increase knowledge of fatigue strength properties of wood and joints by laboratory tests.
Measurements and feedback from the Chalmers wind turbine at Björkö will be used for experiments and validation.

Laboratory tests have been carried out to analyse the shear strength. Based on the result from the tests, the design shear strength of the bondline has been calculated according to Eurocode recommendations.

The testing was carried out in accordance with procedures in ISO 6891:1983

The Chalmers research turbine at Björkö has been successfully erected during this summer.

Not only the bending resonance frequencies are crucial but also the corresponding torsional one. Therefore, structural dynamic analyses of tower torsional oscillation modes for different towers and dimensions have been conducted.

WP6: Methods for supervision of bolt pretension
This work package was finished already in 2019.
An extension has been started, which is presented in a separate project.

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
    - Yes, this research project has involved several areas of expertise.

  - The development of the design tool in WP3 is expected to help minimizing material use and designing in a way that improves buildability and therefore reduces material costs. The tool helps finding optimal values for preliminary design and it is expected that it will soon optimize with more thorough checks.
- Swedish development and production of components and subsystems
  - Yes, all partners are Swedish companies.
  - The work in WP3 has increased the NCC knowledge on wind turbine foundation design. At the same time, the tool will help in finding more sustainable and less expensive designs that will make NCC more competitive against other international actors.
  - The work in WP5 has increased the Modvion knowledge on structural integrity of different glue connected wooden parts and further knowledge of structural dynamic behaviour.
- An extended service life with the aid of better load prediction, optimum operation and preventive maintenance.
  - Yes, the work on the design tool in WP3 reveals different and important aspects of the design of a foundation. Arising questions about how to lay the reinforcement or ratios between different dimensions, among others, increase the knowledge on the structural supporting system.
- The development of maintenance methods, including fault detection, based on operational data in collaboration with design data.
  - Yes, based on the interview study with stakeholders, knowledge about wind power foundations and especially about design issues and the construction process, will lead to decreased maintenance needs.
- Reliable wind turbines resulting in a high uptime in a cold climate, in forests and offshore.
  - Yes, the purpose of the project is to increase reliability of wind turbines, with higher availability, in any environmental condition.

Deviations from project plan

WP3: The implementation of the Eurocode checks in an automatized tool is showing to be more time consuming that expected. ULS and SLS checks were expected to be finished during autumn 2020 to the continue with fatigue and other issues in the workflow of the script. This is delayed and it is now expected to be finished during the first months of 2021. It is though important to complete this task properly as the quality of future steps will rely in them.

WP4: The investigations of stakeholders' needs were planned to be performed within WP3 but have been moved to WP4. This was done to enable analysis of what parameters could be relevant for monitoring in both construction and management of wind power supporting structures.

Publications

No publications.

External activities

- Presentation at the conference "Vindkraftsforskning i fokus"; October 13, 2020
- Interviews with Stakeholders; Q2-Q3 2020

Miscellaneous

Some publicity related to the Modvion tower is found at the following links:
https://www.svenskttra.se/publikationer-start/tidningen-tra/2020-4/extrema-laster/
https://www.ri.se/sv/vad-vi-gor/projekt/innovativa-tratorn

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

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, Saptarshi Sarkar, Serik Sagitov, Sara Fogelström, Chalmers, Pramod Bangalore, Greenbyte
Report for	2020-01-01 – 2020-12-31
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

The mean flow and the turbulent kinetic energy profiles for all turbines at Röbergsfjället site have been extracted from the CFD simulations 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. The forest heterogeneity has been extracted and included in the simulation model, and its influence on turbine performance have been studied. It is seen that the heterogenous forest assumption has a substantial impact on the mean flow profile (wind shear) and turbulence kinetic energy (turbulence intensity). Moreover, large variations of wind field over the turbine swept area are noticed.

The system simulation model (using FAST software) of a 2MW turbine has been tuned to better match SCADA data. Torsional 5 degrees of freedom and 10 degrees of freedom models of the drive train has been developed and integrated in the system simulation model and bearing internal loads can be predicted from given wind field simulations (thus closing the loop “from wind to fatigue life”).

The wind field from simulations considering complex terrain and different forest model (homogenous and heterogenous) have been used as input to turbine system simulation models of a 2MW turbine. Preliminary results show that bearing fatigue loads based on torsional response from drivetrain (not considering yaw moments and wind inclinations) differ considerably between homogenous and heterogenous forest assumption. Moreover, when synthetic wind fields with same wind shear, mean wind and turbulence intensity gives very similar response to wind fields extracted from CFD. It should be noted, though, that the wind parameters differ between turbine locations and met mast. It is therefore

a topic for further study of how well a single met mast can represent the wind characteristics considering the location of turbines within a reasonable sized park on km-scale in complex terrain.
To further detail the internal forces of drivetrain, 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. This model is currently being implemented in simulation software SIMPACK.

A next preventive maintenance model was further developed. A binary linear optimisation model was proposed, whose solution suggest wind turbine owners which components, and when, should undergo the next preventive maintenance (PM). The model is being evaluated in the context of gearbox replacements, using realistic costs for multi-MW onshore wind turbines in Sweden. It was studied how the optimal time for PM depended on different assumed incremental cost (i.e. the “lost” value of the working gearbox when replaced before it fails). The model was also used to study seasonal effects; lower electricity costs during summer had a significant effect on the optimal next PM. It was also demonstrated that the model can be used to update a long-time planning of a series of PM events.

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

Deviations from project plan

The late arrival of Post-Doc delayed some work packages. The Post-Doc is in place and the time-plan have been revised. The end time of project has been postponed to April 2022**.**

Publications

No publications during this period.

External activities

Quanjiang presented his work as interim seminar (midway through PhD studies) at CAM (Computational and Applied Mathematics) seminar series Jan 22, 2020 entitled “Mathematical modelling and algorithms for preventive maintenance of wind turbines, including the next maintenance plan, the end of contract and of system life”.

Extension of WP6 Methods for supervision of bolt pretension

Project title	Extension of WP6 Methods for supervision of bolt pretension
Project number	
Organisation	RISE
Project leader	Anders Wickström
Other participants	Others from RISE: Johan Sandström, Göran Malmqvist, Alice Moya Nunez, Rikard Norling, Jakob Blomgren, Kaies Daoud och Fredrik Ahrentorp From Chalmers: Magnus Evertsson
Report for	2020-01-01 – 2020-12-31
Participating companies	TensionCam Systems, Bulten, Rabbalshede Kraft, Stena Renewable

Project description

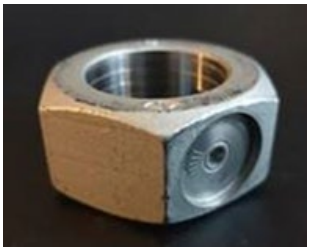
Methods for measurement of pretension in bolts do exist but are for various reasons not used on a general basis. With better and cheaper control of pretension, a bolt joint design can be optimised with downsizing of both the bolt itself as well as the surrounding components. This project will provide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

WP1 Validations by laboratory tests, field measurements and FE-analyses

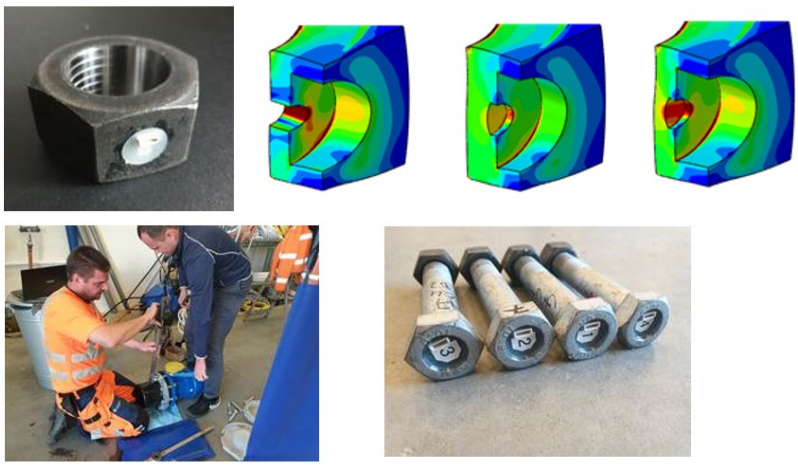
The purpose is to find the best solution for an ordinary bolt connection, i.e. a bolt and a nut. A circular pattern on top of the bolt head has been shown to be the best option. This option is to be further optimized by systematic FE-analyses.



But for some cases, for example the tower base connection to the foundation, there are no bolt heads but the bolt threads only. Therefore, other ways to check the pretension are to be investigated. An idea is to use the nut and create a pattern at one or several plane surfaces of the nut, as shown in the picture.

The shape of the bolt head cavity, for best measurement resolution, has been optimized by systematic FE-analyses. The resolution of the pretension has been validated by workshop test for the most promising cavity patterns

Implementation and validation of nut at existing wind turbine foundation connections ongoing.

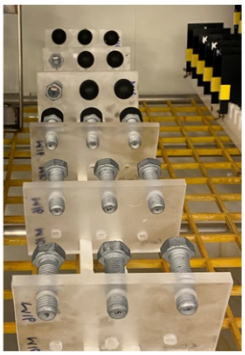


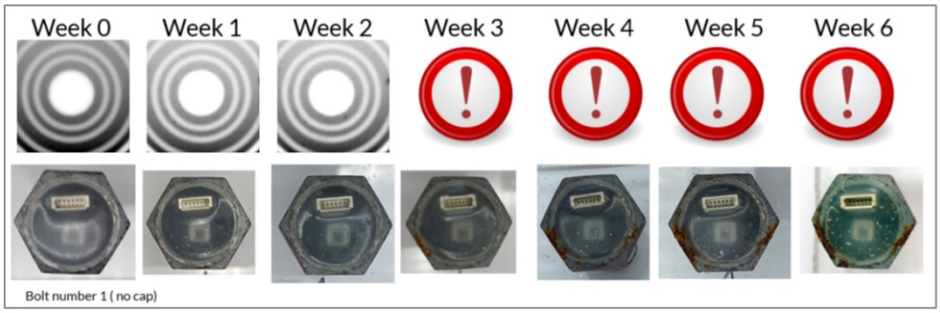
Lyckat test med M48 bricka i Borås

WP2 Environmental resistance
Avoiding corrosion on bolts and/or surrounding components requires a combination of factors to have been accounted for in the design process. This involves not only the protective coating, but also things like the choice of material for the bolt and any parts in contact, and the geometry can also result in crevices or poor drainage.

This work is about testing modified components in a well-controlled accelerated corrosion environment. The corrosion attack of the parts is then analysed. The sensors were tested (image reading using the software Miaxis) after every week of exposure to determine if the image's quality was affected by the exposure in the climate chamber. In addition, each bolt was examined using a light optical microscope do determine the extent of the corrosion damage, or to inspect for any defects in the protective silicone.

All the tests according to the defined test matrix have been conducted. The analyses are still ongoing but good insight in how the corrosion attack occurs on the bolts and sensors have been obtained. Relative comparisons of corrosion rates have been carried out, related to the quality of application of potting silicone and the use of protective plastic caps. Knowledge has been gained on what corrosion mechanisms are predominant in the accelerated tests.

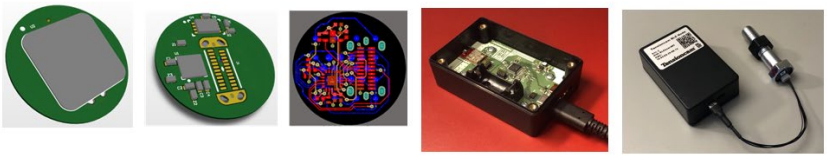


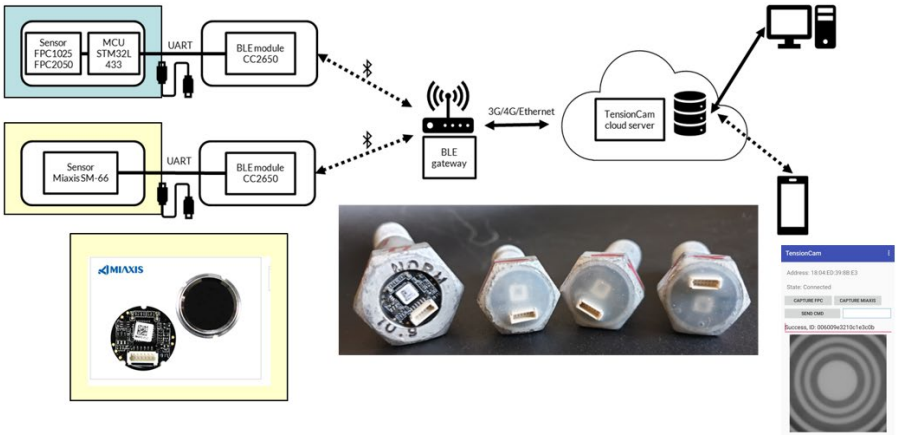


WP3: Remote reading of bolt status
The aim of this work package will enable remote reading of bolt status using a low-power wireless module. The wireless standard is to be selected based on an analysis of the system requirements. A wireless data transfer interface will be developed in order of enable remote reading of the bolt status.

The following tasks are completed:
Evaluation of hardware solution has been executed. Two different concepts have been compared: Bluetooth low energy (BLE) and Passive NFC RFID. Based on a set of criterions, the BLE solution has been selected to fit bet for the application. From that knowledge, a system design and fabrication of demo hardware have been completed. This hardware has then been in benchmark with commercial hardware, Miaxis.

Evaluation of appropriate wireless protocols has been executed. From that knowledge, the BLE module is now able to communicate, through the Gateway, to the cloud and into the web application. That means that the complete system is now functioning.





WP 4: Scientific aspects, optimization and documentation
No results from this period.

Fulfilment of SWPTC's goals

The high level SWPTC's goals are listed below followed by comments on fulfilment in this specific project.

- Top-class research with the aim of producing optimum wind turbines and subsystems and of reducing operating and maintenance costs.
    - Yes, this research project has involved several areas of expertise. A number of experienced researcher at RISE have cooperated and worked within their fields of expertise to obtain the successful project results.
- Swedish development and production of components and subsystems.
    - Yes, all partners are Swedish companies
- An extended service life with the aid of better load prediction, optimum operation and preventive maintenance.
    - Yes, the purpose of the new innovative product is control the bolt pretension in order to execute preventive maintenance for optimum operation.
- The development of maintenance methods, including fault detection, based on operational data in collaboration with design data.
    - Yes, the purpose of the new innovative product is fault detection, based on data from the installed sensors.
- Reliable wind turbines resulting in a high uptime in a cold climate, in forests and offshore.
    - Yes, the purpose of the project is to increased reliability of wind turbines, with higher availability, in any environmental condition

Deviations from project plan

Work package 4 has been delayed due to Corona-safe education at Chalmers taking significant longer time. In 2021 the situation will improve. As this work package will continue until 2021-12-31, there is time to catch up.

Publications

No publications during this period.

External activities

- Presentation at the conference "Vindkraftsforskning i Fokus"; October 13 2020.

Frequency services from wind power in the Swedish power system

Project title	Frequency services from wind power in the Swedish power system
Project number	
Organisation	Electric Power Engineering, Chalmers University of Technology
Project leader	Ola Carlson
Other participants	Håkan Johansson, Viktor Berbyuk, Saptarshi Sarkar, Magnus Ellsen, Sara Fogelström at Chalmers, Mattias Persson, Hjalmar Pihl, Erik Weihs, Camille Hamond at Rise Paul Thomassen, Loup Suja, Felix Rittel, Simis
Report for	2020-03-01 – 2020-12-31
Participating companies	Rabbalshede Kraft, Stena Renewable, Centrica, Svenska Kraftnät, Energiforsk

Project description

There is a strong expansion of wind power in the Swedish electric power system and future scenarios indicate that wind power will be a dominant source of power during windy periods as early as 2022. An important part of the electricity grid's stability is that the frequency (50Hz) is maintained. Today, mainly hydropower plants are used to do this. In the future power situation, it is of great importance that wind turbines are also used to keep the frequency stable. The project will develop, simulate and test frequency control with wind turbines. The standard built-in frequency control will be tested in commercial wind turbines and the plants will also participate in the bidding of ancillary services. Furthermore, existing frequency control services will be tested and developed at Chalmers wind turbine. The technical function and demand for wind turbines to control the frequency in the electricity grid will be verified and evaluated. This also includes analysis of wear and how the lifetime of the pitch system and gearbox is affected. The results will also show the economic potential of wind power operators to participate in the frequency regulation market.

Results

A review of the requirements for frequency services in the Nordic region has been done in the project. The review specify technical requirements, information on bid-size and market structures regarding the different products. There are five frequency regulatory services in the Nordic region for balancing production/consumption, these are FFR, FCR-N, FCR-D, aFFR and mFFR. FFR handles the transient frequency changes that occur during low inertia situations, FCR-N stabilizes the frequency in small changes in production and consumption, while FCR-D activates during disturbed operation. The aFRR service restores the frequency to 50 Hz, while the mFRR relieves the automatic services to restore the frequency to 50 Hz.

A literature review shows that recent publications have defined three different strategies for the procurement of kinetic energy for regulatory services such as FFR and FCR-D; f-independent, Δf-dependent and the Δf&df/dt-dependent modes of operation. The kinetic reserves provide regulation temporarily without curtailment. However, their ability to respond depend to some extent on wind speed. Since wind power is not dispatchable in the traditional sense, all control strategies rely on wind forecasts to be traded on the electricity market. The Grid code requirements already require services such as Fast Frequency Reserve and Frequency Containment Reserve - Normal to be provided by wind turbines. Hence, this functionality then needs to be coupled through SCADA systems to bidding by balance responsible parties. Down-regulation from a variable speed wind turbine can be performed through pitch operation or alternating rotor speed. Pitch angle seems to be widely used, however the increased wear and tear possible cost for this mode of operation needs further investigation.

Models of wind turbines to simulate frequency control have been developed during this period. A simple model with drivetrain, wind speed, power of the wind turbine and pitch control as well as a more realistic model that also takes into account the mechanical parts and its wear in frequency control are up and running, the simulation work is about to start.

Based on wind turbine operations, the economic outcome of different bid strategies for frequency services from wind farms are calculated, valued for the ones used today as well as some examples of upgrades, the work has started at Rise.

Frequency control with all suitable frequency support services, developed in the project will be tested in real operation on Björkö at Chalmers wind turbine. The turbine has been erected during this year and now all hardware is in place. The control system programming is on the way.

The work with frequency control with the most appropriate frequency support services will be tested in real operation on a 2-5 MW wind turbine is in progress. The project is working on finding available wind turbines.

Fulfilment of SWPTC's goals

The project fulfills the following of SWPTC's goals:

- Top-class research with the aim of producing optimum wind turbines and subsystems and of reducing operating and maintenance costs.
- An extended service life with the aid of better load prediction, optimum operation and preventive maintenance.
- Reliable wind turbines resulting in a high uptime in a cold climate, in forests and offshore.

The goals will be fulfilled by:

- Showing the economic outcome for the wind turbine operator when wind turbines participate in frequency control compared to producing only electric power.
- Presenting and evaluating the frequency support services used internationally.
- Developing and optimising the operation of a wind turbine during the provision of frequency support services.
- Developing, testing and demonstrating frequency support services at Chalmers wind turbine.
- Providing frequency support services in the operation of a commercial wind turbine and a wind farm.
- Explaining the change in lifetime of turbine, by using load calculations during frequency support services in a wind turbine.

Deviations from project plan

The project is a bit late with the simulation modelling. It has also been slow progress in finding available wind turbines to take part in frequency control. Neither problem will affect the outcome of the project.

Publications

Two technical reports have been written during this period:

- Frequency control from wind power, Literature review, Mattas Persson, Rise, 2020-09-07
- Frequency regulation services, FFR, FCR-N/D, aFRR, mFRR, Erik Weihs, Mattas Persson, Hjalmar Pihl, Rise, 2020-09-07

External activities

The project has been presented at the wind power conference Vindkraftsforskning i fokus on the 13 October 2020.

The project has also been presented in meetings with wind turbine owners to attract new partners, with wind turbines, willing to take part in the frequency ancillary service market.

Publications

Reports

Frequency control from wind power, Literature review, Mattas Persson, Rise, 2020-09-07

Frequency regulation services, FFR, FCR-N/D, aFRR, mFRR, Erik Weihs, Mattas Persson, Hjalmar Pihl, Rise, 2020-09-07

External activities

National conferences

- Vindkraftsforskning i focus 2020, 13 October 2020, Online

Miscellaneous

- Interviews with Stakeholders with project Supporting structure, Q2-Q3 2020
- Quanjiang presented his work as interim seminar, Jan 22, 2020, *Mathematical modelling and algorithms for preventive maintenance of wind turbines, including the next maintenance plan, the end of contract and of system life*