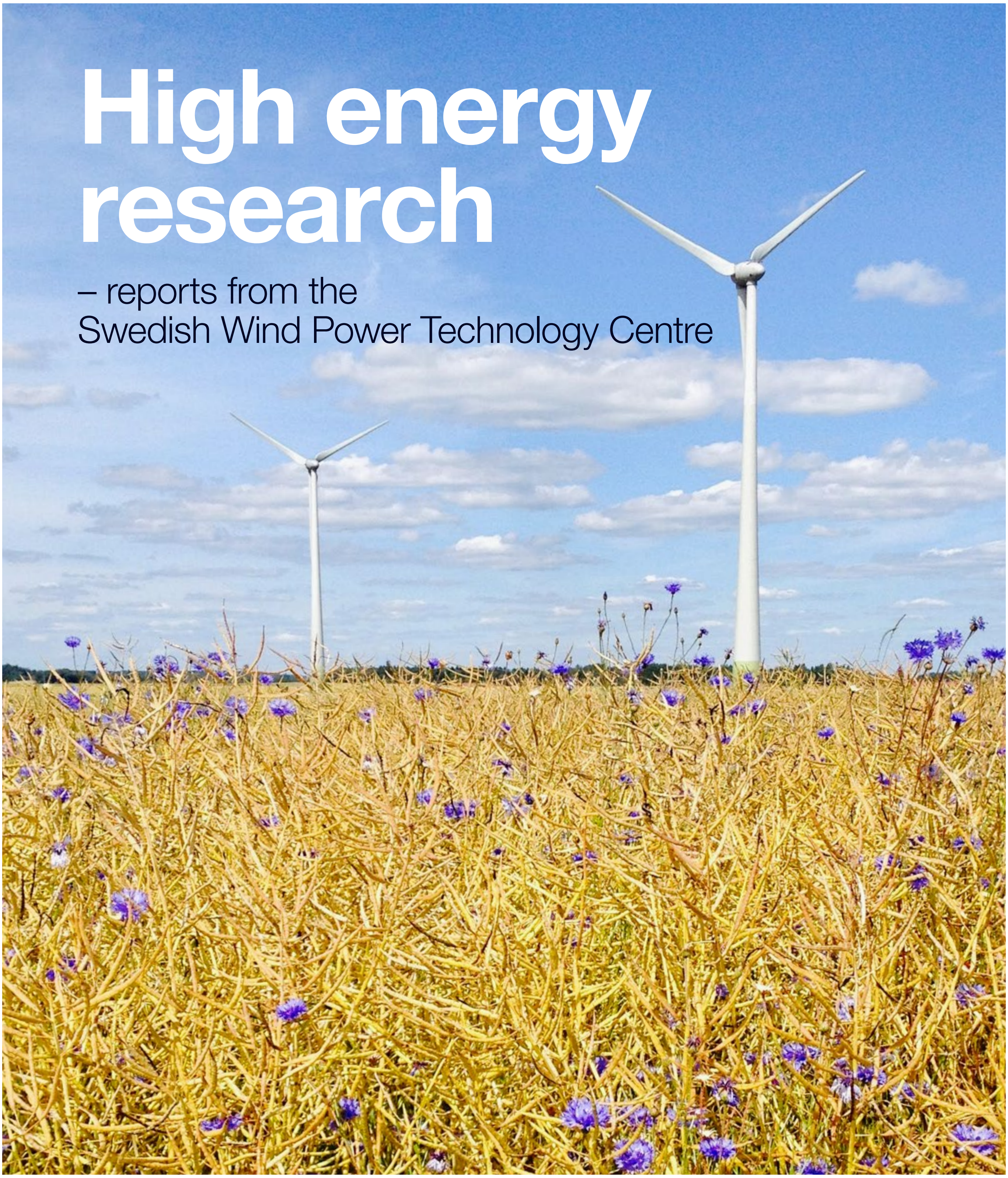
SWPTC
SWEDISH WIND POWER TECHNOLOGY CENTRE

High energy research

– reports from the
Swedish Wind Power Technology Centre



Smarter together

Photos: Göteborg Energi, Göteborg Wind Lab

WE NEED TO GET SMARTER! And we need to get smarter in so many ways. At the national Swedish Wind Power Technology Centre, SWPTC, we have put together the top-level knowledge that now represents part of Sweden's contribution to the wind power industry, which is a *knowledge industry*. With this knowledge we help build successful companies and create products and services for both our own market and the global market. We are helping build the necessary knowledge.

WE NEED TO GET SMARTER AT ENHANCING THE EFFICIENCY OF WIND TURBINES, power transmission and maintenance. The operating expenses in the wind power industry can be reduced further. When profit margins increase, as a result of smarter technology, the desire to invest increases as well, and ultimately the price of electricity falls for consumers. Consequently, at SWPTC we listen to industry and adapt our research to actual demand. This close collaboration also shows us all the benefit of finding synergies between knowledge, practical experience and economic efficiency.

WE NEED TO GET SMARTER AT LOOKING AFTER OUR EARTH. There is no time to waste in switching to green energy. In Sweden, we have decided that all energy productiontt must be renewable by 2040. Wind energy is one of the keys to achieving this target. The opportunities and potential in this field are huge. We believe in wind power. We believe in knowledge. We believe in our Earth.

WE NEED TO GET SMARTER TOGETHER. At our research centre, we can see the specific benefit of several disciplines working together at the same time. We can achieve more together. Now that we at SWPTC are entering our third stage, there will be a strong focus on such collaboration. Both between academic disciplines and with industry. In this popular science publication, we want to tell you more about our collaborative thought processes and actions to date.

Ola Carlson, Director
Sara Fogelström, Coordinator
Matthias Rapp, Chairman

Contents:

SWPTC

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We need more **lightbulb moments!**

Director Ola Carlson is proud that SWPTC involves close collaboration between theory and practice, and academia and industry. He now hopes for more lightbulb moments, for the general public as well.

When one party realises the benefit of the work of the other party, progress can be made. And it becomes clear that the benefits of wind power are key to Sweden's transition to 100 per cent renewable energy by 2040.

Photo: Anna Wallin, Chalmers University of Technology

"WE NEED MORE lightbulb moments that let wind turbine owners see how knowledge teamwork ultimately leads to better business. If a wind turbine has a longer life and fewer problems, it is far more economically efficient. The same is true for the general public. With understanding and a better price per kilowatt-hour, more people's eyes will be opened and they will understand why we need to have so many wind turbines," says Ola Carlson.

HE IS A PROFESSOR, and has been Director of the Swedish Wind Power Technology Centre (SWPTC) since its establishment. He is proud of the collaborative spirit at the heart of how the Centre works, and is now leading the Centre into its third phase. This time the aim is to forge even closer links between the various research disciplines.

"We focus on both theory and practice. We go out into the real world and take measurements, then we come back and do calculations. We are able to spin our theories, perform simulations, do experiments and take measurements, all at full scale. We cover the full gamut in our research."

IN THE SPRING, CHALMERS' own wind turbine is moving to Björkö. "Having our own research facility at our full disposal is a strength that is also fairly unique for a research centre," says Ola.

SWPTC has also managed to establish close relations with industry.

"Industry tells us what it needs and then we do the research."

In this way the Centre creates clear, specific value for everyone involved.

"At the same time, longer-term research is needed, ignoring the day-to-day and taking a broader view."

SWPTC FOCUSES ON TECHNOLOGICAL research, and its results have been published and presented in both Swedish and international contexts.

"Our research is at an international level, even though we are a relatively small contributor. In the years to come, we want to work even more internationally and take part in various projects on the international market," says Ola.

SWPTC IS THEREFORE INVOLVED IN ORGANISATIONS like European Research Alliance, European Academy of Wind Energy and IEA. These contact networks enable research to be conducted and findings to be presented with an even broader reach.

"We need to train new generations of engineers who are experts in wind power and can provide Swedish and international industry with knowledge," stresses Sara Fogelström, SWPTC's Coordinator.

"Wind power is now a major, fast-growing global market. This means good opportunities to create both economic growth and new jobs in Sweden," continues Sara, adding that Sweden has some of the leading manufacturers of wind turbine subsystems.

IN STAGE THREE, research will focus on large wind turbines and farms for installation in forest, mountain and offshore environments. Topics such as the ability to predict and calculate loads, optimised operation, preventive maintenance and cost-efficient integration in the power grid will be covered. Prominent Swedish system research like the research at the research centre is of great relevance to industry.

"The benefit is clear when we work closely with our industrial partners. This is essential," says Ola.

SWPTC

- Established in 2010. Stage two was completed in autumn 2018, and stage three started in 2019.
- Has an extensive range of partnerships with 26 industrial partners and various research institutions.
- 35 project were implemented during the first two stages.
- Published 38 articles during the second stage.
- Led to eight doctoral theses.

Fatigue is important knowledge

"A wind turbine is in principle nothing more than a big fatigue machine. This is why knowledge about fatigue design is so important," stresses project manager Anders Wickström. A fast new calculation method is now available.

Picture: SeaTwirl

A wind turbine is subjected to high loads, an essential factor to consider when designing a turbine. Unlike virtually all other machines, the load on a wind turbine is extreme. For example, a blade is subject to bending on every revolution, and at 15 RPM over 20 years, the number of bendings is really quite high. These cyclical loads, when the material is bent at a specific point again and again, lead to technical fatigue.

THE CALCULATION METHODS USED to date to design components for wind turbines have primarily been based on knowledge of onshore horizontal axis wind turbines. Building vertical axis turbines offshore, as the Swedish company SeaTwirl does, entails both major challenges and a need to find new methods.

IN ONE PROJECT, ANDERS and researchers at Rise and Chalmers developed a quick method adapted for fatigue design in a variety of wind conditions for SeaTwirl's turbines.

"It is also a very quick method. If you need to make constant changes to optimise the structure, you need to do so fast. With certain simplifications, we can now calculate in 15 minutes what would otherwise have taken months to work out," says Anders.

WHEN THE BLADES ON A wind turbine turn through one revolution, the load varies markedly. However, overall the blades' revolutions have a repeatable cyclicity, which is a precondition for the simplified calculation method. With listed company SeaTwirl now advancing from a first 35 kW prototype turbine to a large 1 MW turbine, the new tool will be used.

"Because we previously worked on the development of wind turbines in Sweden, we are able to take on this type of project. Without that, we would have had to start from the very beginning." SWPTC has successfully helped a Swedish company develop. The method can now be used in other contexts, including for horizontal axis turbines.

Project:

Analysis methodology for fatigue of wind turbine (TG4-23)

Project manager:

Anders Wickström,
anders.wickstrom@ri.se

Partners:

Rise, SeaTwirl, Chalmers

New solution in **tight spaces**

A new aid has been developed: a method for replacing cables inside the long, narrow blades on a wind turbine. The innovation solves a problem that previously meant long periods of downtime.

Photo: Lars Liljenfeldt, RISE Sicomp

A blade on a wind turbine doesn't just sit there 100 metres up in the air. It may also be 50 metres long and access inside it means that, at best, service personnel can crawl halfway along it. The space is too tight after that. However, many vital cables are located inside the blades.

"We are currently seeing problems with de-icing systems on turbines that are a little older, over ten years. The early systems were not as well-developed as those today and sometimes they break down," says Lars Liljenfeldt.

IN THE PROJECT he is managing, they studied various repair methods. In northern Sweden in particular it is important to de-ice the blades to avoid the risk of the turbines having to cease operation or being damaged due to ice on the blades. At the same time, the cables inside them are subject to wear and fatigue. Repairs often mean that the wind turbines are shut down for extended periods of time, and sometimes the blades have to be detached and lowered to the ground. This entails major costs.

"This helps keep our turbines going more efficiently."

"We needed to find a way of getting into the outermost 20 metres of a blade. So we created a small "wagon" that can be manoeuvred all the way. This permits us to replace cables in the blade without needing to detach the blades or shut down the turbine for as long as before," says Lars.

WITH THE NEW technique for tight spaces, they tried to laminate five metres of cable in a 50 metre wind turbine blade, with successful results.

"This helps keep our turbines going more efficiently."

Project:

Increased reliability of heating systems on wind turbine blades(TG6-21)

Project manager:

Lars Liljenfeldt,
lars.liljenfeldt@ri.se

Partners:

Swerea Sicomp (now part of Rise), Skellefteå Kraft, Blade Solutions

Blade tests in a **promising sector**

SEK 300 billion. This is what the annual market for manufacturers of rotor blades for wind turbines is estimated to be worth in a few years' time. Swedish company Winfoor is a market player.

Picture: Winfoor

Winfoor has its roots in Lund University and has been developing an entirely new type of rotor blade, the Triblade, for a number of years. Unlike other blades on the market, the Triblade has been developed to permit smaller, slighter, divisible blades. This would make things easier at all stages of the process, from lower manufacturing costs to simpler transport and installation," says project manager and CEO Rikard Berthilsson. "It is looking promising," he says.

THE THREE-PART BLADES are based on brand new structural engineering. The model could eventually be used to build blades longer than those we have today, which will be necessary when wind turbines increase in size.

AT AN EARLY stage of development, the triblade technology was tested in a wind tunnel at Chalmers as part of a project managed by SWPTC.

"This showed us that air flows over our blades as we had hoped it would," says Rikard.

HE POINTS OUT THAT it is good to have a centre for collaboration on wind power, at which research and specialist expertise can be concentrated.

WINFOOR'S DEVELOPMENT WORK IS being scaled up. During 2019, the idea is to undertake larger-scale tests, financed by the EU.

Project:

Triblade rotor blades preliminary study (TG2-21)

Project manager:

Rikard Berthilsson,
rikard@winfoor.com

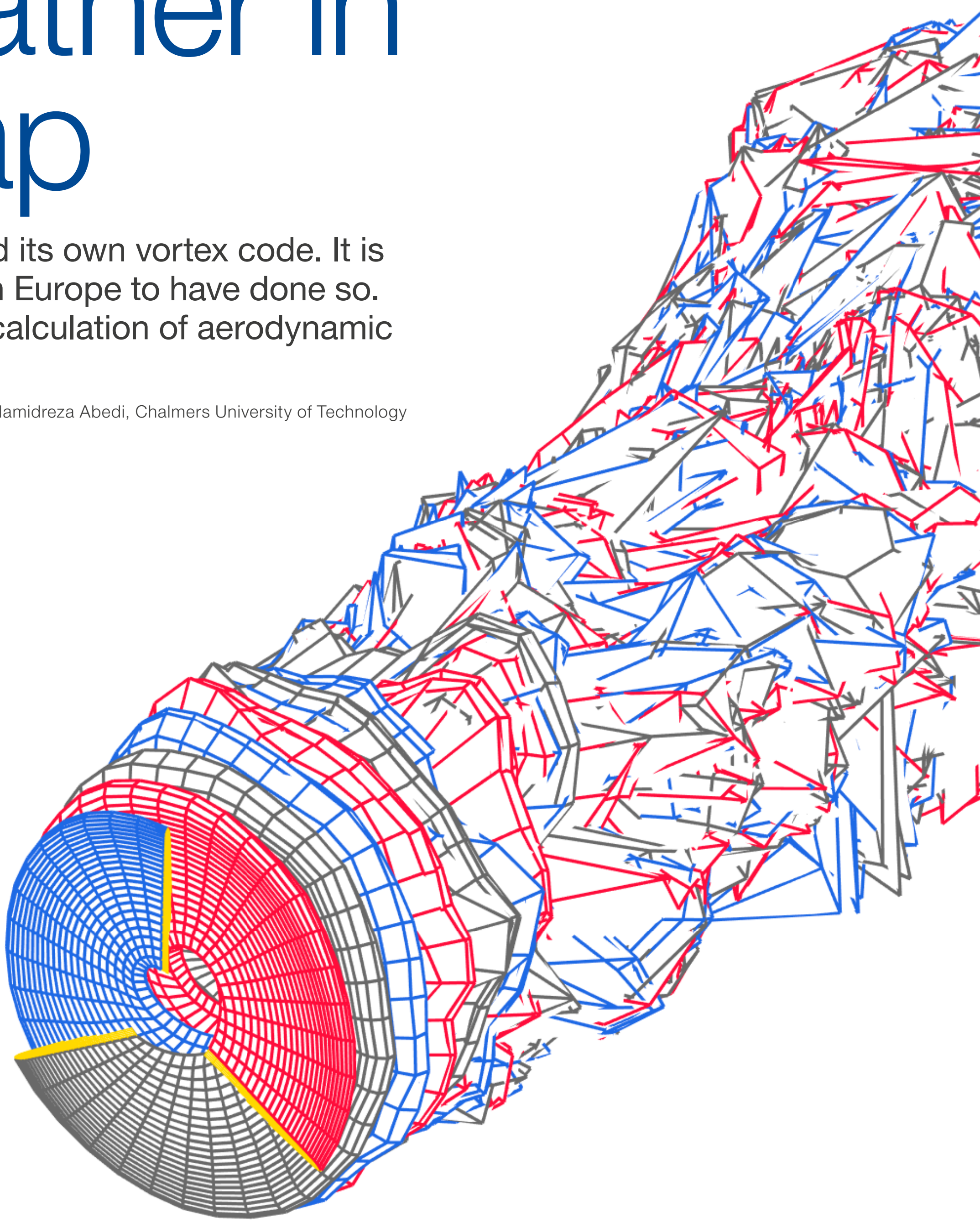
Partners:

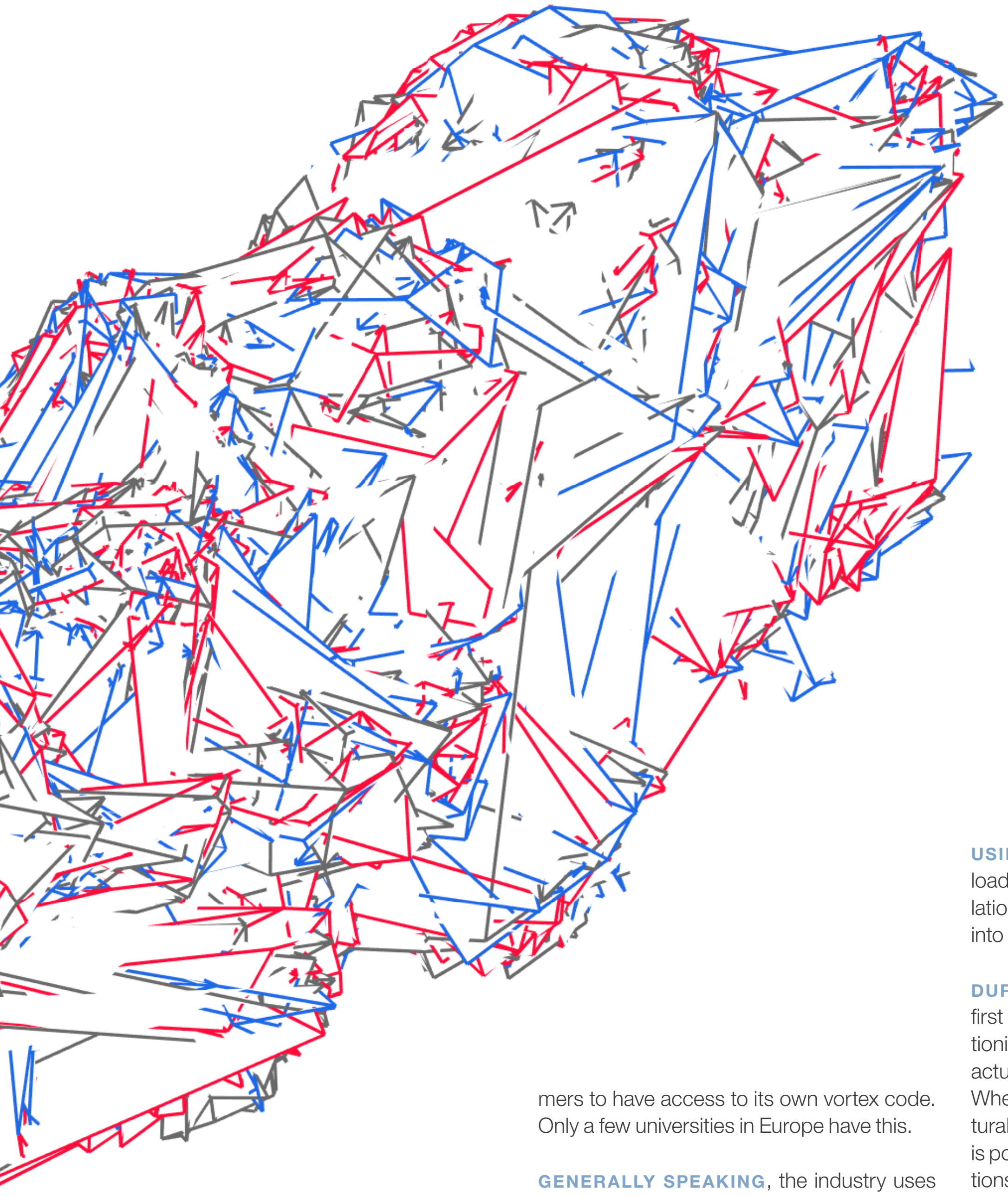
Winfoor, Chalmers

Vortex – a feather in our cap

Chalmers has developed its own vortex code. It is one of few universities in Europe to have done so. The code allows better calculation of aerodynamic loads on a wind turbine.

Picture: Hamidreza Abedi, Chalmers University of Technology





Whether you want to design a wind turbine or be able to predict how much power it will generate, you need to know a large number of different factors.

"It is incredibly complex and requires collaboration between disciplines. You can't work on your own. You have to work together," emphasises researcher Hamidreza Abedi.

WORKING AT SWPTC, he developed a vortex code; a positive step towards being able to say more about the overall conditions of a wind turbine. It is also a feather in the cap of Chalmers to have access to its own vortex code. Only a few universities in Europe have this.

GENERALLY SPEAKING, the industry uses the blade element momentum, BEM, method to calculate loads on a wind turbine. The method produces the relevant data relatively fast, but is only acceptable for certain flow conditions. An alternative to BEM is therefore the CFD, computational fluid dynamics, method. This produces higher output data reliability, but is considerably slower, as it may take weeks or even months for a simulation with a data cluster with hundreds of cores.

"The vortex code means that our calculations are more accurate than with BEM and faster than with CFD, although CFD is still more precise. We always have to weigh up the various factors when we choose which method to use," says Hamidreza.

USING vortex code to simulate aerodynamic loads produces a more stable, robust calculation model which takes the laws of physics into greater account.

DURING THE PROJECT, the work involved first building the code, then validating its functioning using experimental comparisons with actual operating conditions for wind turbines. When the results are then merged with structural, dynamic and verification calculations, it is possible to obtain a full picture of the conditions of a wind turbine.

"Now we have a vortex code that can be used to calculate aerodynamic loads for a wide spectrum of turbine conditions. The next stage would be to create an interface for all of these disciplines. We need fast, reliable methods instead of settling for old ways of working."

Project:

Aerodynamic loads on rotor blades (TG2-1)

Project manager:

Lars Davidson,
lars.davidson@chalmers.com

Partners:

General Electric, Chalmers

Shrinking offshore **giants**

Much of the future of wind power is offshore. As a result of Swedish company development and advanced research, there are now solutions for floating platforms that are efficient both to operate and produce.

Picture: Hexicon

Out in the great oceans, there are good conditions for building large wind turbines. However, one of the longstanding challenges is how best to create floating platforms. The Swedish company Hexicon has developed a triangular platform designed for two turbines. The wind turbines are installed apart from each other and the third corner is used to anchor the platform to the sea bed with cables.

THE PROBLEM WHEN WIND TURBINES are close to each other is that eddies are formed, with air wakes behind them. This phenomenon can also be observed in onshore wind farms, where the turbines in the first row generate more power than those behind them. In offshore installations, which cost a lot of money, it is therefore desirable to be able to use platforms as efficiently as possible. New research has shown that the platform may be made smaller than was first thought.

"Offshore platforms are like huge monsters. They can be 120 metres wide. If you can reduce the side of a platform by 20 per cent, it is possible to make major savings when each platform may cost over SEK 100 million. And if you have a farm of, say, 30 platforms, the saving is enormous," says researcher Hamidreza Abedi.

HEXICON'S NEATER STRUCTURE has many advantages, as the researchers were able to see. The strength of a floating platform is that is partially possible to compensate for the complex movements of the wind as the wind turbine can rotate with the wind on the floating platform. This not only maximises the energy yield, it also reduces the risk of damage due to loads on individual components as the turbine gyrates. At the same time, the platform moves with the movements of the waves, which makes the calculations more complex. There is interaction between two turbines on the same platform. This makes technical demands for how the turbine should rotate in the wind, and research is currently in progress to find new positioning systems. In the development project, the new results will be input as data for ongoing research work.

Project:

Analysis of floating wind power farms (TG4-22)

Project manager:

Lars Davidson,
lars.davidson@chalmers.se

Partners:

Hexicon, Chalmers

Wind and not bad luck – how Sweden's wind turbine fleet can move full speed ahead

Why do some wind turbines break down more often than others? SWPTC's major prestige project on difficult operating conditions has shown that "bad luck" has nothing to do with anything. Wind is just volatile.

Picture: Hamidreza Abedi, Chalmers University of Technology

Some wind power owners have experienced bad luck over the years. Turbines have broken down and stood idle, with long production stoppages and costly repairs. Gearboxes have been a particular problem. In one case, an owner was forced to replace as many as three gearboxes in nine years in just one turbine. "And yet, the explanation to owners from wind turbine manufacturers has been that 'some people have more bad luck than others'," says SWPTC's Director, Ola Carlson.

"Manufacturers have explained to their customers that a fault may have many causes. Perhaps there was a moulding problem in the factory or tricky material processes. This shows that it is hard to know why gearboxes actually break down."

EXTENSIVE studies were required to achieve a more clear-cut explanation model. Bad luck has nothing to do with it. That much is clear.

TO ARRIVE AT this result, a wealth of parameters were literally mapped – it was largely necessary to perform calculations of the local conditions in relation to the topography of the area. Where a wind turbine is located basically. Maps were an important starting point, helping to identify the topography, differences in height and whether the surrounding land is afforested or consists of open fields. This data was then added to existing wind measurements, after which aerodynamic calculations could be performed.

"Wind velocity is never the same over the full area of the rotor. When you calculate the wind field for a wind turbine, the calculations rarely follow a nice, straight line," says Ola with a smile.

IF YOU HAVE EIGHT WIND TURBINES in a farm, there are actually eight individual wind fields, all of which are different.

"So you need to be skilled at doing calculations to be able to predict the conditions for the different turbines. The computer works its backside off, so to speak."

THE CHALMERS MAINFRAME munched its way through the many parameters, and the results surprised the researchers.

"We were able to see that the wind fluctuates much more than we had expected. In exposed locations, the wind switches from side to side. One moment it blows at an angle of 15–20 degrees in one direction. The next at 15–20 degrees from the other. It may also blow obliquely upwards.

THIS PHENOMENON IS LARGELY explained by the topography. All obstacles such as hills and steep slopes affect the wind field of each turbine, as does each turbine's location in relation to other turbines. A turbine that is exposed to these constantly changing winds is subject to noticeably more mechanical load on its gearbox than a turbine that is nearby but on different terrain.

"The loads we are seeing on some of these turbines simply don't fit into the standard calculations. They are subject to extreme loads. In turn, this indicates that the standard for wind turbines is a little optimistic for a turbine on complex terrain," explains Ola.

In parallel, calculation models are being developed for how gearboxes and other mechanical parts in the nacelle are subjected to wear by wind gusts.

"We need to classify a wind turbine in the right wind class. In our calculations, we can see that turbulence increases when the terrain

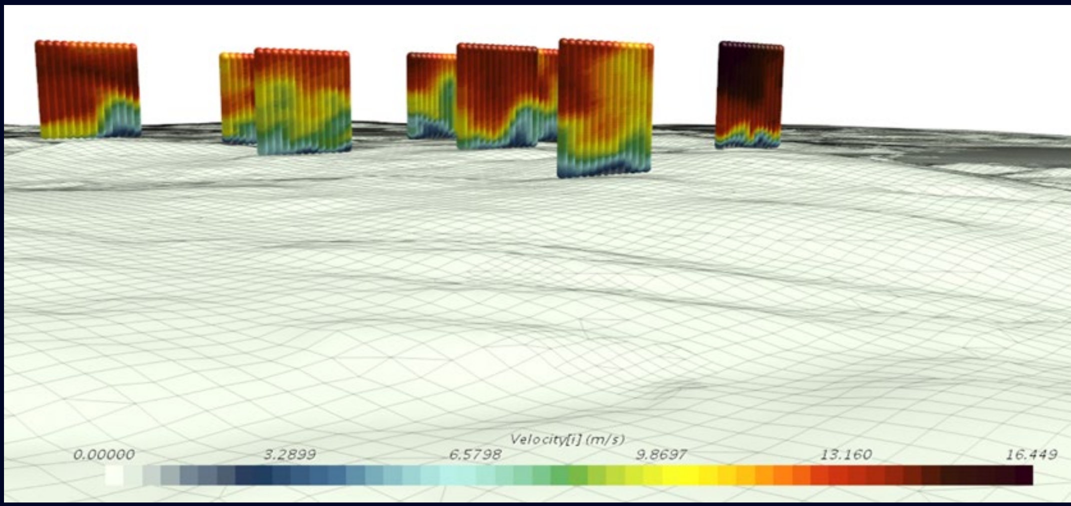
Possible measures in exposed wind locations

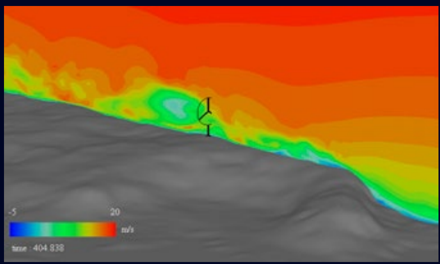
Reduce the rated output Even if you lower the output by as much as 15 per cent, the total losses will not be that much as the turbines only operate at full output for 10 to 15 per cent of their annual operating hours.

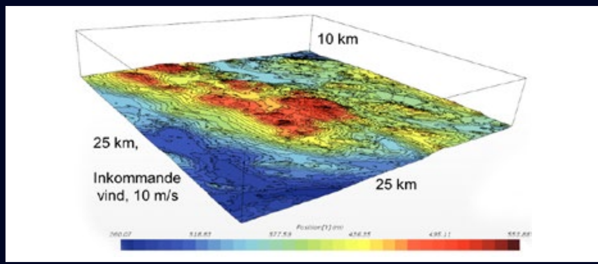
Local wind field. It is a good idea to carry out an aerodynamic analysis of the topography at the design stage ahead of installation. This must be done for every turbine in a wind farm, not just at one turbine, which is the standard procedure today. Buying services from experts in topography is a good investment.

Individual adjustment. It is possible to adjust individual turbines at low cost if procedures and software are in place. It should be possible for this to be a routine procedure that is done at the press of a button.

Make an inventory Make an inventory of existing wind turbines' individual conditions and adapt operations accordingly.







is very hilly. We have also found that, at a certain load level, the turbines do not age a great deal. However, once that level has been passed by just a little, they age much faster. Now we want to link this magic limit to the rated output of the wind turbine. Then we can suggest lowering the output in difficult wind conditions."

The Västgötaslätten plain has the right conditions to remain below this limit as the area has large open fields with a steady wind; perfect for wind turbines. It is more difficult to calculate the winds in the hilly Dalarna region, where the turbines get more of a battering," says Ola.

"Consequently, manufacturers must take this into account and design turbines and components according to the intended location of a turbine; more precisely than is currently the case."

Models can be used to simulate the results for every single turbine in a farm. One way of dealing with the impact of gusts on a gearbox may be to lower a wind turbine's rated output from, say, 2 MW to 1.8 MW to protect it.

"This is a working hypothesis. We don't have any exact figures yet. The point is that it doesn't involve any great production losses. Even if you lower the output by as much as 15 per cent, it doesn't mean total losses of that much as the turbines only operate at full output for 10 to 15 per cent of their annual operating hours."

Focusing on loads has proven to be a feasible approach. Tests reinforce the theory. Ola points out that this type of adjustment should not involve changing more than a few parameters in a computer program, "which would take an expert no more than a few minutes".

Thus, the blade is turned a little earlier than usual to limit mechanical loads from the wind. Another component for which fatigue should be assessed is the foundation, which is also affected by the distribution of mechanical loads.

"Consequently, the turbine should be designed for local conditions as early as the moulding stage. We have no results for this yet, but they will come."

"I would like to visit all turbines to take measurements and do calculations. For some, I would be able to say 'run at full output'. For others, I would recommend lowering the rated output by 20 per cent. I really believe that this would the best way to operate Sweden's wind turbine fleet."

Another parameter to be taken into account is how the drive system, with the generator and frequency converters, is affected by something like a lightning strike, as this ultimately also affects how long the gearbox will last. However, calculations show that this is not a problem provided the link between the generator and the gearbox is designed with a certain level of softness built in.

"A broad collaboration project like this, with experts in aerodynamics, structural mechanics, structural engineering, electricity and control engineering, is important if we are to progress. For a number of years, we have all worked at our separate skills. Now we need to work together. This is necessary so that we can combine all our skills," exclaims Ola.

Partnership with industry is important as well, as installing new sensors that measure loads more frequently than at present would be useful, according to Ola and his colleagues. With measurements at least once a second, the precision of the load calculations would be higher.

"Most people talk about the service life of wind turbines. We talk about the service life of each individual wind turbine, depending on its location. It's the peak values that eat away at service life, not an average value," says Ola, stressing the importance of this approach:

"I would like to visit all turbines to take measurements and do calculations. For some, I would be able to say 'run at full output'. For others, I would recommend lowering the rated output by 20 per cent. I really believe that this would the best way to operate Sweden's wind turbine fleet."

Project:

Wind turbines under harsh operation conditions (TG0-21)

Project manager:

Ola Carlson,
ola.carlson@chalmers.se

Partners:

Röbergsfjället Vind, Rabbalshede Kraft, Skellefteå Kraft, Awind, SKF, NCC, Chalmers

Hard facts about the Chalmers turbine

Foundation: Concrete anchored to the rock

Tower: 30 metre high wooden tower, new design from Modvion

Blades: Carbon fibre blades, eight metres long, manufactured by Marströms Composite

Generator/powertrain: Permanently magnetised, ferrites, direct driven

Power limitation: Three individual electrical pitch systems

Production: Low – a research turbine that produces research findings

The blades will soon **be turning**

Ola Carlson and Magnus Ellsén can soon take the turbine blades out of the basement when Chalmers' own turbine is put back into operation in its upgraded version. Light carbon fibre blades are just one of several new components.

Photos: Magnus Ellsén, Chalmers University of Technology

The blades are eight metres long, but only weigh 65 kg each. SWPTC's Director, Ola Carlson, and Research Engineer Magnus Ellsén can carry them easily. Themselves.

"The wonderful world of carbon fibre," says Ola with a smile.

THE TURBINE HAS BEEN his and Magnus's pet project ever since it was first installed in 1984.

"We have been involved throughout and know the turbine inside and out. It acts as a test platform for us. We are now finishing things off for the Centre's second part by completing the upgraded turbine."

IN SPRING 2019, the plan is for it to have moved from Hönö to Björkö. With a new tower, foundation, control computer and materials, there are many changes.

"The carbon fibre blades were built with knowledge from one of the Centre's earlier projects. Having our own wind turbine gives us a great deal of input for our research."

"So, this is a tremendous project. We researchers have our very own unique turbine. It's wonderful!"

IT HAS NOW BEEN REBUILT for the fourth time, after a period of downtime. Building your own turbine is a huge job, which is both labour-intensive and expensive. The project was made possible by means of close collaboration with Region Västra Götaland, and is a feather in the cap for both Chalmers and West Sweden as it acts as a quite unique prototype for wind power development. Its operation will provide new knowledge in several disciplines such as aerodynamics, electrical engineering, structural dynamics and control engineering.

"So, this is a tremendous project. We researchers have our very own turbine, and can choose whether we want to test different components, or how they all work together. It's wonderful!"

Project:

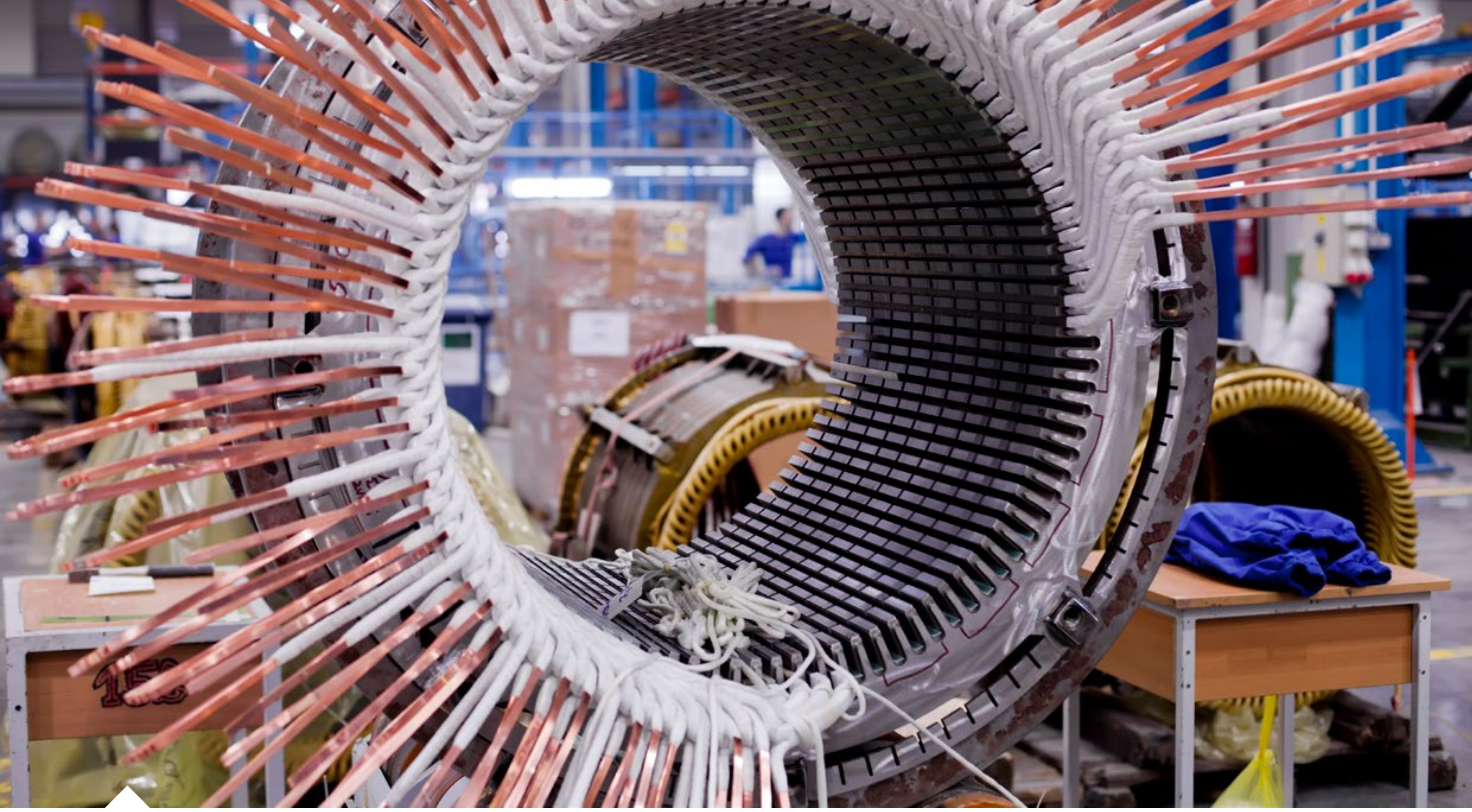
Chalmers wind turbine set in operation for research (TG0-22)

Project manager:

Ola Carlson, ola.carlson@chalmers.se

Partners:

Region Västra Götaland, Chalmers



Vibrations tell us about the health of the drive train

Changing the generator in a wind turbine is both expensive and time-consuming. A new method has now been developed in which several sensors in the drive train can issue warnings long before a major fault has occurred in the generator.

Photo: iStock

"Changing the generator in a wind turbine is no fun," says Ola Carlson.

THE GENERATOR IS LARGE, heavy and located at the top of the turbine. Having to change it is a nightmare for many wind power owners. In a project to model the turbines' electric drive train, the PhD student and the other researchers on the project found a way to detect damage and identify faults at an early stage. They simulated faults and then developed a model for the most common electrical faults that occur in a generator.

THERE ARE NOW TEMPERATURE GAUGES in the generator but the researchers found them far too imprecise as a tool as they indicate that a fault has occurred way too late. However, several temperature gauges in combination with measuring instruments for both changes in voltage and vibrations together offer the opportunity to make an accurate early analysis.

THE MOST COMMON ELECTRICAL FAULT in the generator occurs when there is wear to the insulation on copper wires as small flash-overs start to occur. If this continues, sparks are formed and, in a worst case scenario, there is a risk of fire in the generator.

"A belt-and-braces method for the powertrain."

"For an engineer to find two faulty wires among thousands depends on both luck and skill. What we found is that it is possible to detect a fault very early by measuring mechanical vibrations," says Ola.

EVEN IF ONLY A FEW wires have been damaged, small disruptions occur in the electric moment. In turn, this creates mechanical vibrations. With an accelerometer installed, you can receive a signal indicating vibration disruption. The method was tested with good results in Chalmers' laboratories.

"We now propose that more sensors be installed in turbines, in particular accelerometers. You can then detect faults in the windings before heat is generated and fire damage is caused. You could say that this a belt-and-braces method for the drive train."

Project:
Models of electrical drives for wind turbines (TG1-2)

Project manager:
Ola Carlson,
ola.carlson@chalmers.se

Partners:
Göteborg Energi, Chalmers, General Electric, ABB

Making use of the random

Is it possible to calculate what random winds do to a wind turbine? A newly developed method is able to make some use of the random to calculate the expected life time of a wind turbine.

Photo: Göteborg Energi, Göteborg Wind Lab

Having had a project on vibrations in mechanical structures, we now know more about the importance of structural dynamics. This knowledge benefits the emerging Swedish wind power knowledge industry.

ONE CONDITION WHEN you build a wind turbine is that it must be able to withstand certain assumed wind conditions during the 20 years in which it is expected to operate without faults. However, how should we understand, for example, how gusts affect the remaining service life of a turbine until it reaches a state of mechanical fatigue?

"Manufacturers design turbines to cope with what they presume will happen to them. They do this by experience and based on assumptions about the wind. But gusts are random and weather is difficult to forecast," says project manager Thomas Abrahamsson.

WHAT THE RESEARCHERS worked on is the importance of the actual outcome of the random situation as the decisive factor. Assessing the life time of something that operates under random, stochastic weather conditions usually requires extensive, time-consuming mainframe calculations. By enhancing the efficiency of how the calculations are performed, there is now a tool for analysing the remaining life time of an ageing wind turbine much faster and more easily.

WITH THE NEW, enhanced knowledge, taking into account both physics and practice, engineering science can now develop its design to be even better in the next step.

"With greater insight into the conditions, we have refined the methods that actually focus on virtually everything that vibrates on account of a random phenomenon," says Thomas.

"Consequently, it can also be used for vehicles and railways, for example. We actually don't fully know what the ground looks like on which trains and vehicles travel. We are also subject to random phenomena there!"

Project:

Validation of Wind Turbine Structural Dynamics Models (TG4-1)

Project manager:

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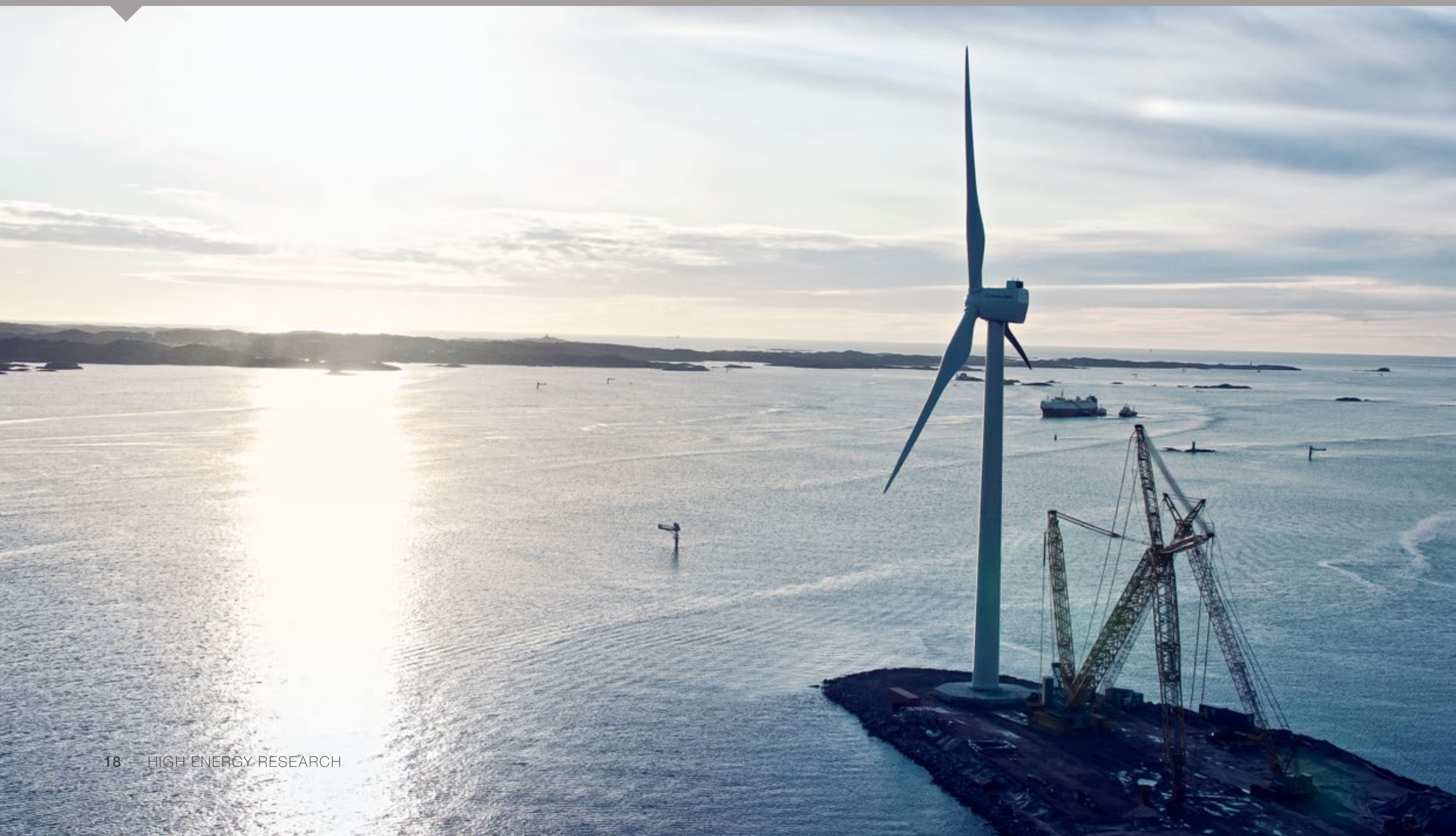
Partners:

General Electric, Chalmers



Benefit with a **wow factor**

The Göteborg company Greenbyte makes wind power more profitable using smart software. The company has grown fast. The need for cheaper production and transition to renewable energy can no longer wait.

Photo: GreenByte

It began as an idea among a few friends at Chalmers. Greenbyte's CEO, Jonas Corné, wrote his master's thesis in industrial economics on wind power, with Ola Carlson, Director of the Swedish Wind Power Technology Centre at Chalmers, as supervisor. Today, Jonas is both amazed at having built up an international company with 70 employees in just a few years and frustrated that things didn't happen even faster.

"When we create value for our customers, the owners of wind turbines, their profitability increases. And if profitability increases in the industry, the transition to renewable energy will be even faster. I believe that everyone underestimates the threat posed by climate change. As individuals, we fail to notice the small changes that happen day by day. The transition to renewable energy sources has to take place even faster," says Jonas with great emphasis.

"When you measure the wind, you are actually measuring future cash flows."

TECHNOLOGY, MONEY AND CLIMATE are related. When Greenbyte began operating, its work mainly involved measurement of wind conditions and feasibility planning.

"When you measure the wind, you are actually measuring future cash flows," says Jonas.

In a few years, the company had customers worldwide, and continued to demand data collection at its new turbines. The company developed software for monitoring and analysis systems, and grew fast. The new software meant that Greenbyte had access to large volumes of data, currently from as much as seven per cent of European turbines plus those in other parts of the world.

"It felt as if we could almost use the data to look into the future. If we made more use of this data, our customers would be able to generate even more energy from their turbines. With software that permits customers to generate more renewable energy, the transition to a renewable society will be faster," Jonas repeats.

AT THIS STAGE, THE COMPANY APPROACHED SWPTC, the importance of which Jonas emphasises, both as a national knowledge base and as a hub for wind power development in West Sweden. In addition, his own experience from Chalmers was so pleasurable that he and his colleagues at Greenbyte were happy to look for opportunities for collaboration. Based on data from all the sensors at customers' wind turbines, they wanted to predict how long components, in particular gearboxes and generators, would last.

They joined forces with existing research into component wear. One clear condition was that a scheduled production stoppage to replace worn components enhances the value of the turbine for its owner compared with a production stoppage that is not scheduled. In the research project with Chalmers, the large volume of data was compared with knowledge about component wear, and a service which is now called Greenbyte predict was developed.

"The existence of SWPTC is important to build industry knowledge. We have employed several people from there and collaborated on a number of research projects and degree projects. This type of knowledge exists otherwise mostly abroad. It is needed to build successful companies in Göteborg," says Jonas, who has now also employed the PhD student who developed the concept.

With the new service, anyone buying a wind turbine is also less dependent on a supplier service contract, which represents a considerable part of the cost for an owner. In this way, the industry is subject to competition, fostering faster development," believes Jonas.

"By looking into the future, we can predict when the components will break down, increase the availability of turbines, increase generation and make the contracts owners have with suppliers subject to competition. I am convinced that the more profitable it becomes, the more will be invested in the industry."

"By looking into the future, we can predict when the components will break down."

Project:

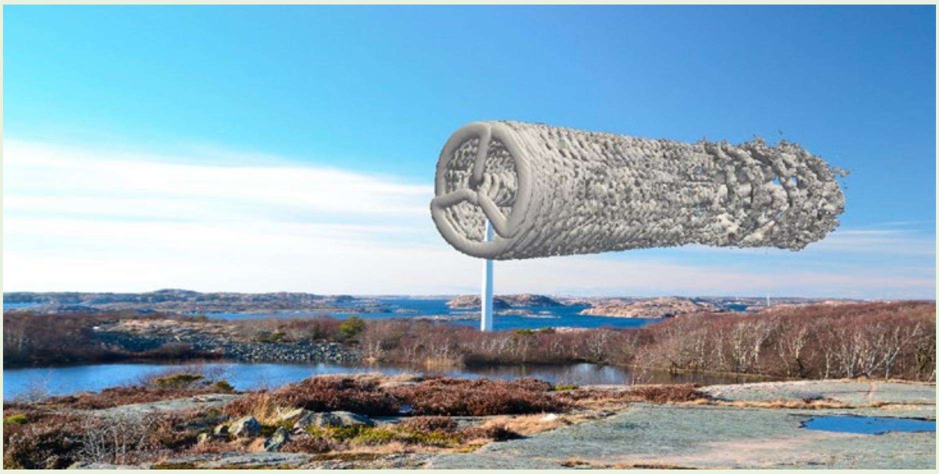
Load and risk-based maintenance management for wind turbines (TG5-1)

Project manager:

Ola Carlson,
ola.carlson@chalmers.se

Partners:

Göteborg Energi, Chalmers, SKF, Connected Wind Services



Possible to create good wind locations in Swedish forests

When the best wind locations start to run out, it is time to find new ones. Wind power in forests is sometimes problematic, but by creating clearings, the problem can be solved. It is easy to turn difficult wind locations into good ones.

Picture: Johanna Matsfelt, Chalmers University of Technology

In Sweden, we have no shortage of forest land, but wind turbines often wear out there ahead of time, unfortunately. A turbine that is located near a forest suffers more damage than one in a more open landscape. Experience shows that they break down more frequently. Gearboxes in particular need to be replaced more frequently. New data shows now that the fatigue loads on the blades on a turbine in a forest may be as much as 300 per cent higher than normal. This is problematic for a country such as Sweden in which two thirds of the land area is afforested.

IN TWO PROJECTS, the conditions for wind turbines in forests were quantified and possible applications of this knowledge were investigated. The results offer new opportunities with apparently simple measures.

"I hope that, in the future, people will want to cut clearings in the forest. It would increase the wind velocity, reduce turbulence and thus reduce maintenance costs. At the same time, power generation would increase, even in locations that are otherwise far from ideal for a wind turbine," says PhD student Johanna Matsfelt.

IN THE PROJECTS, using new applications of existing methods, researchers recorded how the turbulence varies over a continuous period of time. The result is that it is now possible to provide a more accurate description of the loads to which a turbine is subjected, which, in turn, are propagated to the gearbox and bearings.

"We previously lacked such accurate data on how individual gusts affect bearings. Now we have been able to generate air movements around the entire turbine, the pressure on all of its surfaces. The highest load is on the hub. This is where the bending moment is highest," says project manager Lars Davidson.

THE TYPICAL PHENOMENA for forest landscapes include a special turbulence as a result of heat exchanges. Hot air rises in general, but in the forest trunks and leaves retain the heat. This causes turbulence above the forest. Simulations have also show researchers more about how the wind behaves above the treetops, according to the type of forest.

"Many people are more interested in models than actual results. However, we focused on the knowledge about heat storage in forests and the type of turbulence that occurs there, based on actual measurements. We then made comparisons with various types of clearing to see what would be most beneficial to power generation and wind turbines," says Johanna.

THE NEW UNDERSTANDING and knowledge obtained offers turbine manufacturers the opportunity to design components even better and thus increase their service life. Johanna is enthusiastic:

"In the future, we will need to locate most new wind turbines in forests in Sweden. If we create clearings, we can control the wind in a beneficial manner. I hope that measurements will enable us to make specific proposals to owners about how they should create these clearings to improve power generation."

Projects:

Fatigue loads in forest regions (TG2-2) and Wind power in forests – the effects of clearings (TG2-22)

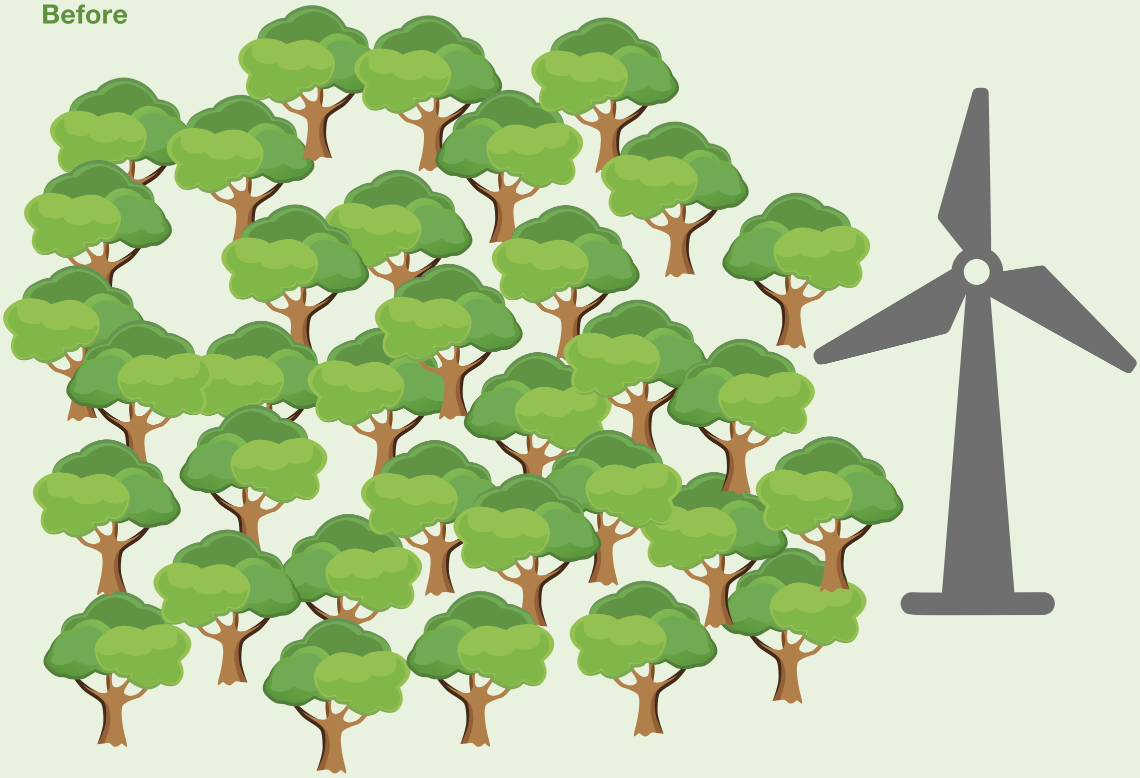
Project manager:

Lars Davidson,
lars.davidson@chalmers.se

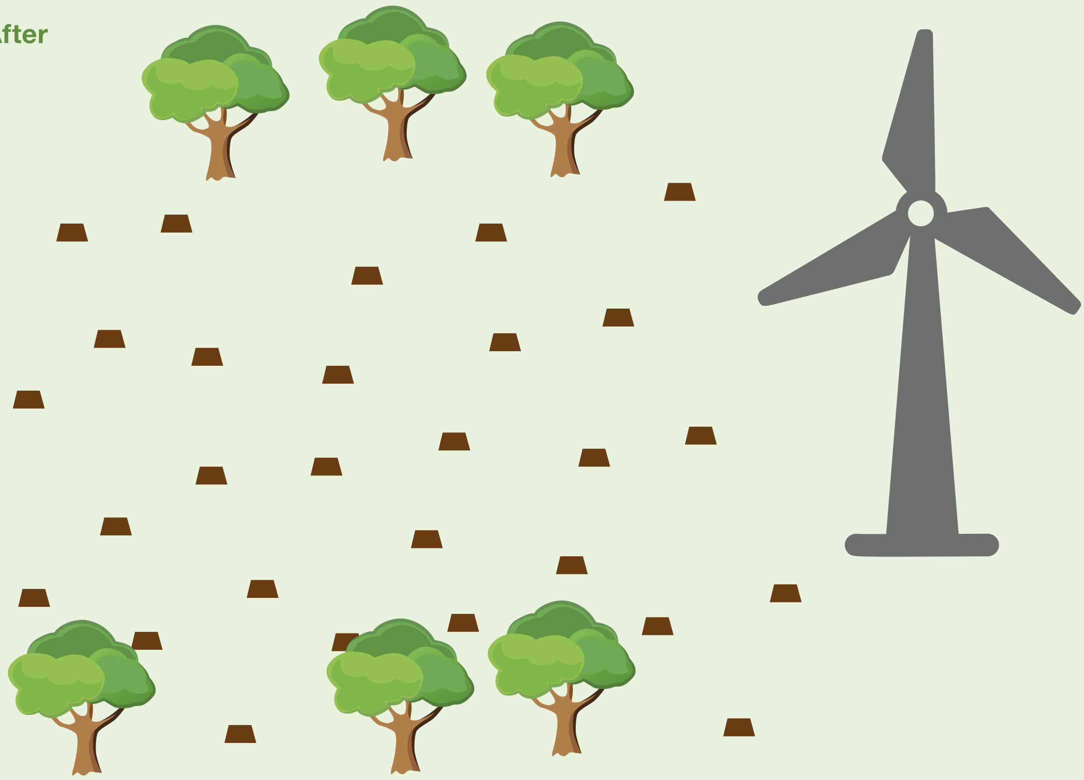
Partners:

Meventus, Stena Renewable, Nordex Energy, Göteborg Energi, Chalmers

Before



After



Superthin oil film **the solution to the puzzle**

Bearing damage is a huge problem for the wind power industry. Even small flashovers can wreck ball bearings to the extent that operations are affected. Now we are beginning to understand why.

Pictures: Abhishek Joshi, Chalmers University of Technology

The answer to why ball bearings break and cause stoppages ought to be found in the superthin oil film that lubricates the balls inside the bearing. It is no thicker than a few thousandths of a millimetre, much thinner than a hair.

THE LUBRICANT IS ELECTRICALLY insulating. And yet this is where flashovers occur. Sometimes just a few Volts, sometimes up to several tens of Volts. However, the consequences are more far-reaching than it was previously possible to explain. Using measurements on a small bearing in a laboratory, an attempt was made to understand exactly what was happening.

The answer to why ball bearings break and cause stoppages ought to be found in the superthin oil film that lubricates the balls inside the bearing.

“We found that when electrical discharges have passed through the oil film once, they continue. There is a breakdown in the oil, something is destroyed in the insulating properties,” says project manager Jörgen Blennow.

IT IS COMMON FOR small flashovers to occur during power generation.

“Not that much current is involved. When it passes through a concentrated point, it gets extremely warm at precisely that point,” says Jörgen.

THE LEAKAGE CURRENT MAKES THE METAL melt, and small pits are created in the ball bearing. The damage focuses the current’s pathway still further. The current density per square millimetre increases. And so it goes on. “More and more damage is caused to the bearing until it, in turn, generates mechanical vibrations. And ultimately it breaks.”

THE PROJECT ALSO INVOLVED testing how different parameters affect the occurrence of flashovers.

“We tried to see whether, at microscopic level, we could decide whether there was a threshold at which operation is entirely safe. The answers were not all that easy to interpret. However, we were able to show one thing. The electrical field strength is important. This means that the voltage in itself is not as important as the electrical field in the oil film.

THE ELECTRICAL FIELD is an expression of voltage divided by distance. A thicker oil film in the ball bearing would therefore increase the size of the electrical field, and reduce the risks. However, the thickness of the oil film is also affected by factors such as temperature, rotational speed and contaminants. This was also mapped during the project.

Project:

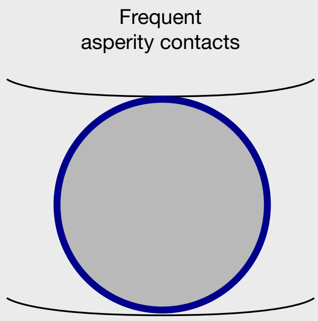
Characterisation and modelling of bearing current activity (TG5-2)

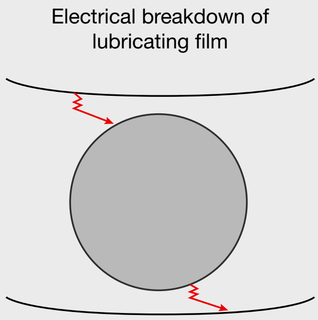
Project manager:

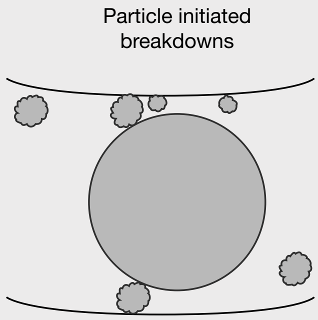
Jörgen Blennow,
jorgen.blennow@chalmers.se

Partners:

Göteborg Energi, Connected Wind Services, SKF, ABB, Chalmers







Using the inherent ability **of wind turbines**

On a really windy day, the force of the wind against the shaft of a wind turbine is over 30 tonnes. However, there is no obvious link between wind strength and how and when a turbine's components wear out. The researchers now want to explain why.

"These are really big forces. We want to understand the situations in which the drive train is subject to extremely fast wear. Sometimes we see rapid fatigue, at other times it is not at as fast at all. We studied which components most affect how this can be calculated," explains project manager Håkan Johansson.

THE PROJECT CAN NOW PRESENT a new sensitivity analysis based on quantified data. This shows that the rigidity of the different bearings and their location in the wind turbine are the most important structural parameters you need to know to calculate the life time of a mechanical drive train with a good level of accuracy.

WHEN STUDYING THE wear of a wind turbine, it is always essential to see what happens in different wind conditions. The bearings are affected in different ways, according to the wind's behaviour. The axial forces are high with strong wind and there are also bending and oblique forces that are propagated along the drive train.

IT IS A KNOWN FACT THAT turbulence and sideslip have the greatest impact, rather than wind strength. Consequently, it is also interesting to be able to measure irregular wind better. An anemometer, a small wind meter, is usually located on the nacelle of a wind turbine. To understand the large variations of the wind and their impact on a turbine, Håkan proposes that new measurement methods be developed.

"We should make use of the wind turbines' own abilities. They are by far the best wind meters as they measure the wind over the entire surface covered by the blades, which is larger than a football pitch.

SUCH MORE COMPLETE measurement, combined with a sensor at the blade root, would provide a clearer description of the force and the moments that are propagated into the drive train. These values, combined with data about the bearings, would provide a more accurate calculation of the life time of the components.

Then we gain this knowledge and create the conditions for better control, we can calculate when the turbine is damaged more than it earns by power generation. This would enable us to establish more favourable wind power operation. It's all about adaptation."

Project:

Modeling drive train dynamics from online measurement data (TG3-22)

Project manager:

Håkan Johansson,
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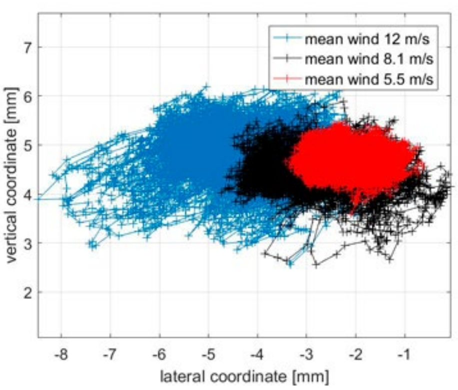
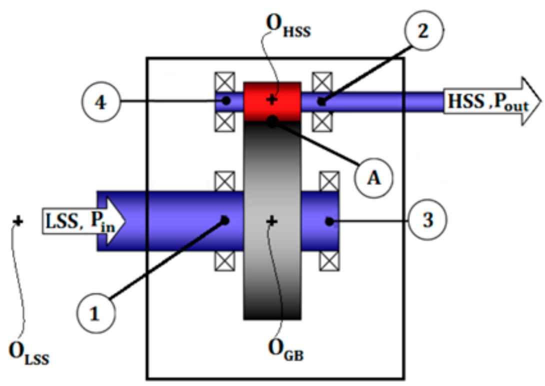
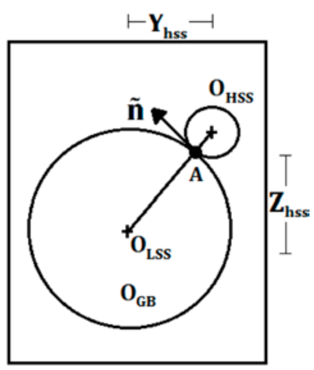
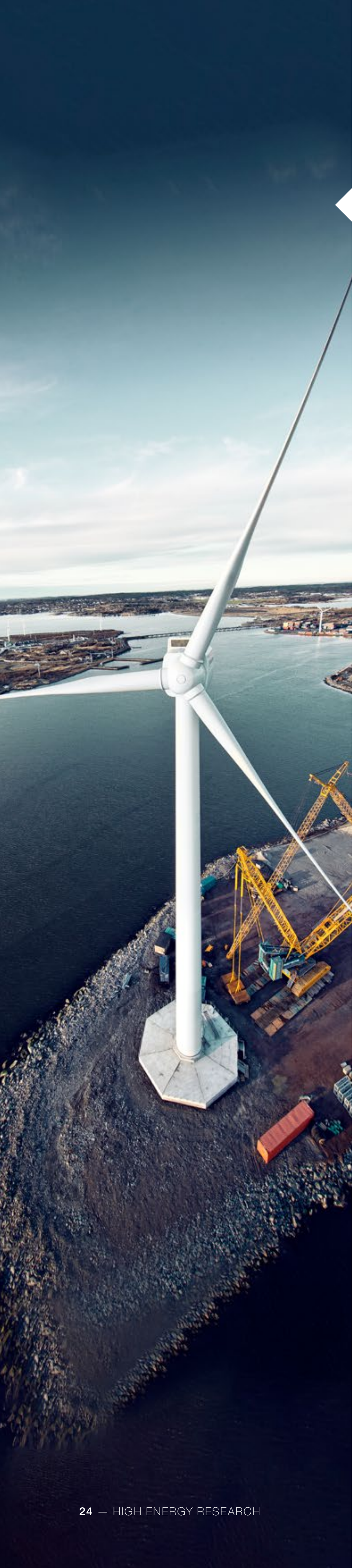
Partners:

General Electric, SKF, ABB, Chalmers









Frequency converters **solve problems**

In some countries, they use a bow and arrow to short the grid and test the stability of wind turbines in the event of grid disruption. There is now a more controlled method that generates power faults without affecting the grid at all.

Photo: Göteborg Energi, Göteborg Wind Lab

To test the power grid, the international standard recommends creating voltage dips by connecting resistors between the grid and a wind turbine. However, this method affects the grid itself and does not offer the opportunity for tests at different frequencies. Using frequency converters is a controlled, reliable method that is not invasive in relation to the grid. The method was refined in a unique project.

"In Sweden, we have not used methods as drastic as shooting metal wires over power lines using a bow and arrow. However, very few have used frequency converters for this purpose. We are now able to show that it works well," says project manager Ola Carlson proudly.

> *"The method works well. We tested it in a way that has never been done in Sweden before.*

WHEN FREQUENCY CONVERTERS were introduced in wind turbines, it was one of the major technological advances in the industry. However, it is very unusual to use them in this context. In a positive partnership with Region Västra Götaland and Göteborgs Energi, the method was tested at full scale on the 4 MW turbine Big Glenn in the Port of Göteborg.

"The method works well. We tested it in a way that has never been done in Sweden before. We create voltage dips and, in practice, it would be enough for a manufacturer to test one turbine of each type. Otherwise, spot checks would be enough," says Ola.

TO CONNECT a wind turbine to the grid, it has to meet set standards, grid regulations, showing that it works not only under normal conditions but also when the grid is subject to stresses such as cables being dug up or lightning strikes along overhead lines. In Sweden, disruption rarely lasts more than milliseconds before the power supply continues along parallel cables. However, even brief disruption may lead to surge discharge in the turbine, which then shuts itself down.

"This must not happen. In a worst case scenario, half of Sweden would be without power if turbines were to fail. Turbines must work. But the question is how to ensure that they really take account of this type of disruption," says Ola.

THE EQUIPMENT WITH frequency converters that is used is expensive and bulky, but it offers great potential as any changes in voltage and electrical faults can be tested. In line with increasing requirements from grid companies as wind turbines increase in number, it is essential for more efficient test methods like this to be developed," says Ola.

Project:

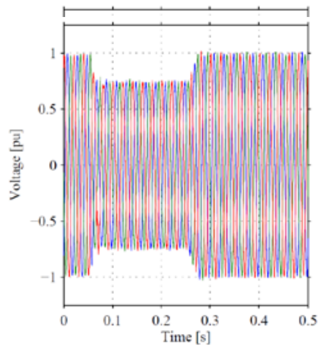
Model verification and testing of wind turbines systems by VSC-based testing equipment (TG1-4)

Project manager:

Ola Carlson,
ola.carlson@chalmers.se

Partners:

General Electric, ABB, Region Västra Götaland, Göteborg Energi, Chalmers



Smarter service, less stress

Imagine if wind power engineers had an app on their phones that told them when it was worth replacing parts that had not yet failed. This may soon be reality. It's all about mathematical calculations.

Photo: Shutterstock

The parts in a wind turbine are currently replaced either when a contract stipulates it or when something fails.

"If instead we could shut the turbine down in advance and replace several components at the same time, we would be carrying out preventive maintenance. This could best be done at times when the weather forecasts were for light winds, i.e. low power generation," says project manager Michael Patriksson.

IN A JAS FIGHTER engine wear is a matter of life and death for a pilot. Based on this knowledge, Chalmers mathematicians have developed calculation models that can be used to develop a useful mobile app. The principles for optimal maintenance are roughly the same, although the wind turbine situation is probably more about estimated production losses than life and death.

"When do we save money by shutting the turbine down in advance?"

MICHAEL IS READY to provide an answer based on a mathematical calculation involving many parameters. Two models have been developed; one for servicing the entire wind turbine and one for smaller components. SWPTC's researchers focused on the latter, short-term model.

"When do we save money by shutting the turbine down in advance?"

"It includes only the most essential components that an owner or designer wants to track. The app supplies predictions for what needs to be replaced within, say, the next two months."

MICHAEL POINTS OUT THAT SERVICING a wind turbine often involves working in inaccessible spaces, removing large components and time-consuming waits for everything from cranes to spare parts. An indicator that gives good advance notice permits the work to be planned and booked and for several things to be done at once. Michael Patriksson and his colleagues have shown that this carries a financial benefit.

"Your eyes cannot tell you if it is worth replacing parts that have not yet failed. We are now ready to launch the best mathematical optimisation model we are able to design. The model will soon be finished. I hope that a software company can package the app because it would be great for it enter widespread use."

Project:

Optimal maintenance of wind power plants (TG5-21)

Project manager:

Michael Patriksson,
mipat@chalmers.se

Partners:

Greenbyte, Rabbalshede Kraft, Stena Renewable, Göteborg Energi, Röbergsfjället Vind, Chalmers

Based on new knowledge

An offshore wind turbine faces so many more design and strength challenges than an onshore wind turbine. However, the precise knowledge about what and how has been limited. We are now beginning to know more.

Photo: iStock

When the wind rages against the blades of a wind turbine, what is actually happening down in its foundation? This question is pertinent for the industry as the conditions are completely different from when a bridge is built, for example. In addition, the conditions for onshore and offshore turbines are different. Now that the offshore industry is being developed due to demand for increase in global production of renewable energy, knowledge building is a key issue for everyone wanting to design and plan optimised offshore turbines.

APART FROM CAPRICIOUS WINDS, offshore wind turbines are subject to things like currents and waves. The Iseawind project, with construction giant NCC as its industrial partner, studied innovative solutions.

"A wind turbine has to withstand the conditions at sea. If we are to extract energy, the structure must be robust. Consequently, this new knowledge about how to build the foundation is key to a sustainable future energy supply," says project manager Rasmus Rempling.

THE PROJECT WAS INITIATED BY NCC, which wanted to see how concreting could be developed for wind power in general, and offshore wind farms in particular. It was previously common to use monopiles, a metal tube driven down into the seabed, to anchor wind turbines. Lately, the aim has been to find out what would be a suitable foundation for Swedish conditions and the loads to which it and the turbine as a whole would be subjected. The project collaborated with Leibniz University in Hanover, Germany. Together, they conducted experiments and numerical analyses to study different types of material fracture and possible loads on different structures.

THE PROJECT also tested and worked with innovative planning methods, known as set-based design. Set-based design can be used to evaluate a large number of alternatives and choose the right technical solution according to environmental aspects. The method is suitable for both offshore and onshore wind power.

The industrial partner NCC is pleased with the project and has already begun to incorporate parts of the findings into its operations.

"We can see both how we are developing individual top-level expertise in the company and how the results are bringing new commercial opportunities. NCC's vision is to steer the industry towards the most sustainable, environmentally friendly solutions. The project is a perfect match for our vision," says Head of Research and Innovation Christina Claeson-Jonsson.

Project:

Iseawind – innovative structural engineering approaches for design of off-shore wind power plant foundations (TG4-21)

Project manager:

Rasmus Rempling,
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Partners:

NCC, Chalmers

Stability with **new research**

High-voltage direct current, HVDC, is gaining ground for power transmission from wind turbines over large distances. The problem is that turbines and HVDC stations do not speak the same language. The aim now is to build more stable systems.

Photo: Power Cluster

HVDC technology is faster, more efficient and cheaper for the transmission of power from offshore wind turbines onto shore. This means that high-voltage direct current systems are regarded as one of the most appropriate choices for connecting large offshore wind farms to the power grid where the distance to the grid is more than 50 kilometres.

> *"Broader understanding is required to avoid unnecessary investment costs in the technology."*

CONVERSION TO HVDC takes place on a separate platform to which several turbines can be connected, which brings financial benefits. Transmitting power as direct current also minimises losses compared with alternating current. The technology has also started to be used in countries with high transmission distances such as China, and in some cases Sweden.

HOWEVER, SOMETIMES undesired phenomena occur in different parts. In Germany, fire even broke out in connection with a wind farm, caused by system integration problems.

RESEARCHERS HAVE NOW STUDIED how to increase the stability of the otherwise efficient transmission method. Using simulations and analyses, they developed guidelines to benefit the various operators in the industry. When you manage wind farms worth billions of dollars, you need to be more than just accurate. You need to get things right from the start.

"Broader understanding is required to avoid unnecessary investment costs in the technology. We wanted to know why the wind turbine and the HVDC station interact and how to minimise that. This knowledge was previously unavailable," says project manager Massimo Bongiorno.

THE CONCLUSION IS THAT THE INSTABILITY associated with HVDC transmission primarily consists of resonance in the electronic components, both in the turbine and at the HVDC station. Research has shown that control systems are at the crux of the matter.

"There are several components in control systems that trigger resonances. Now that we know what they are, we also know how to adjust control systems to avoid resonance. This knowledge about HVDC interaction is entire new. We have not seen it in previous research," says Massimo.

Project:

Electromagnetic Transient study of wind farms connected by HVDC (TG1-21)

Project manager:

Massimo Bongiorno,
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Partners:

ABB, MHI Vestas Offshore Wind, Vattenfall, Svenska kraftnät, Chalmers

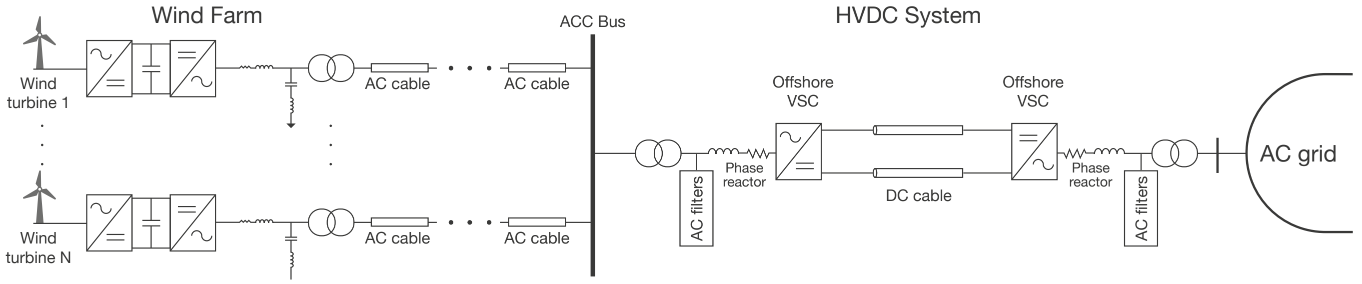

Photo: Anna Hagnell

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www.swptc.se

SWPTC
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