



## Designing the wind turbine of the future

[www.windtrust.eu](http://www.windtrust.eu)





# Better Components. Better Wind Turbines.

In Europe we want to achieve a **clean and reliable energy supply** at the lowest possible cost. Wind energy will play a key role. The concept that we in the wind industry must continue working on is **reliability** - of wind turbines and of their most important components.

For the Windtrust project, key industrial players and research centres from all over the continent have joined forces to demonstrate the technical and economic feasibility of innovative and more reliable solutions.

All Windtrust partners have completely reviewed the design of certain components. We have created a **new generation of components** that improve the reliability of onshore as well as offshore machines.



**Fernando Garcia Ayerra**  
Chief Engineer Technology  
Development at Gamesa and  
Technical Coordinator of Windtrust

All the money invested in R&D in Europe is focused towards reducing the cost of wind energy, which will hopefully reach the final consumer.

Although the cost of the enhanced parts will probably be higher, the reduced cost of repairs and less downtime has increased the amount of energy produced. This increase exceeds the additional costs, and we are proud to say that our innovative technologies have helped **reduce overall costs by 14-22%**.

Asia is now the fastest growing market for the installation of new turbines, and its cumulated wind energy capacity is soon expected to exceed that of Europe.

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**Technology innovations** that enhance turbines and reduce costs are needed to propel the wind sector and maintain Europe's technological leadership.







## Q&A: **Oliver Joy**

WindEurope, formerly EWEA, is the voice of the wind industry, actively promoting wind power in Europe and worldwide. **Oliver Joy, WindEurope's spokesperson**, explains how the wind industry is evolving.

### **What is the current state of play of wind power in Europe?**

Wind energy already plays a significant role in the European power sector. Today wind energy can meet 11.4% of Europe's electricity demand with a cumulative capacity of 142 GW at the end of 2015.

In 2015, the wind industry installed 12,800 MW in the EU - more than gas and coal combined.

Wind power plants across Europe are operating on a similar scale to traditional thermal power generation, delivering clean, affordable and reliable electricity to European citizens. This deployment has been underpinned by the development of an industrial base making Europe a global leader in wind energy.

### **How do you see the wind power sector in 2030?**

In a central, business-as-usual, scenario, wind will meet a quarter of Europe's electricity consumption with the right set of policies in place. This scenario will help remove 705 Mt CO<sub>2</sub> by not delaying climate mitigation actions to the next generation.

Aiming higher and pursuing more ambitious wind power deployment would bring significant additional benefits in terms of greenhouse gas emissions savings, energy security and macroeconomic benefits.

The transformation of the energy mix will also lead to a net job creation in the European Union with 334,000 direct and indirect jobs in the wind industry alone in the central scenario.

### **How do we reach this high ambition level?**

In 2015, we saw record investments of €26.4 billion in onshore and offshore wind. Keeping this momentum will be critical to the EU's standing as a global leader in renewables.

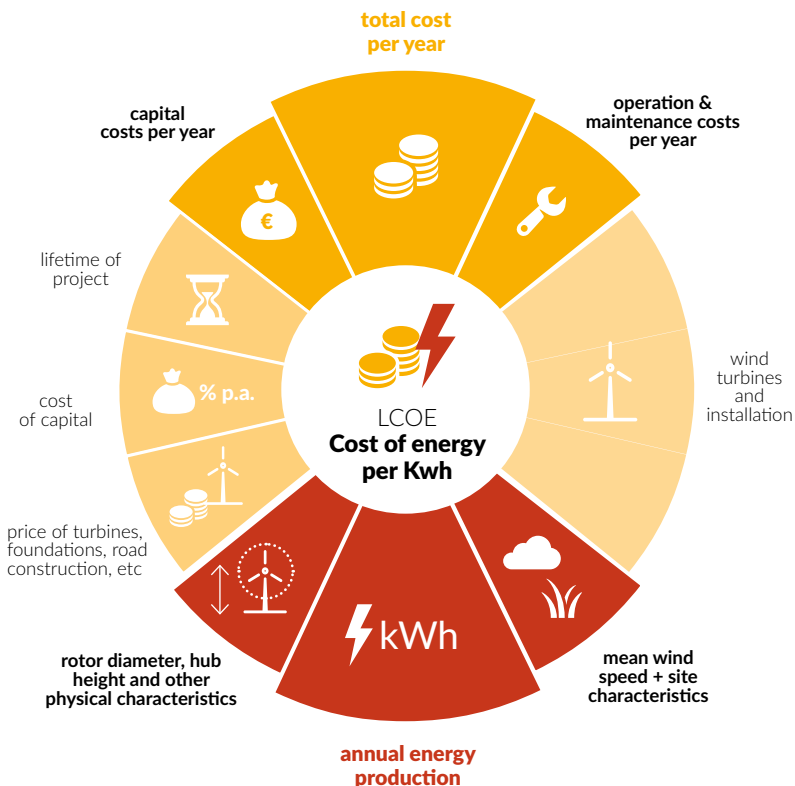
The industry has taken strides in cutting technology costs and the finance community sees wind energy as an increasingly valuable asset.

Europe should capitalise on its first-mover advantage in developing wind energy, the most cost-effective climate change mitigation technology available to us. Wind energy's potential to 2030 and beyond will largely depend on more ambition from policy makers. To this end, a robust governance system should be agreed to ensure Member States collectively deliver on the 2030 binding renewable energy target.



Source: LM Wind Power – Jan de Nul ©mennomulderphotography

# Calculating the cost



**LCOE (levelised cost of electricity)** is a metric used to measure the cost of electricity produced by a given process. It is calculated by accounting for all of a system's expected lifetime costs, which are then divided by the system's lifetime expected power output (kWh).

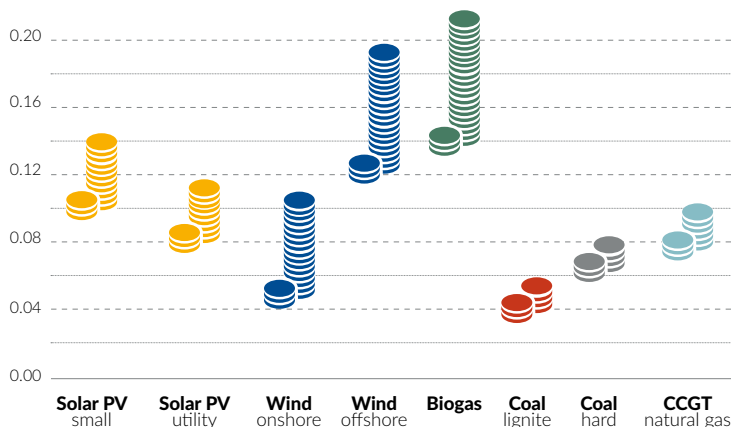


# Is wind energy expensive?

As a financial tool, **LCOE is very valuable for the comparison of various generation options**. A relatively low LCOE means that electricity is being produced at a low cost, with higher likely returns for the investor. If the cost for a renewable technology is as low as current traditional costs, it is said to have reached "grid parity". As

evidenced in the graphic below, **onshore wind energy is now hovering around grid parity** in high resource areas. Were the LCOE to also include the societal costs from fossil fuels – externalities such as health costs and other adverse effects from CO<sub>2</sub> emissions – onshore wind would be even more competitive.

## Levelised cost of electricity in € per kWh

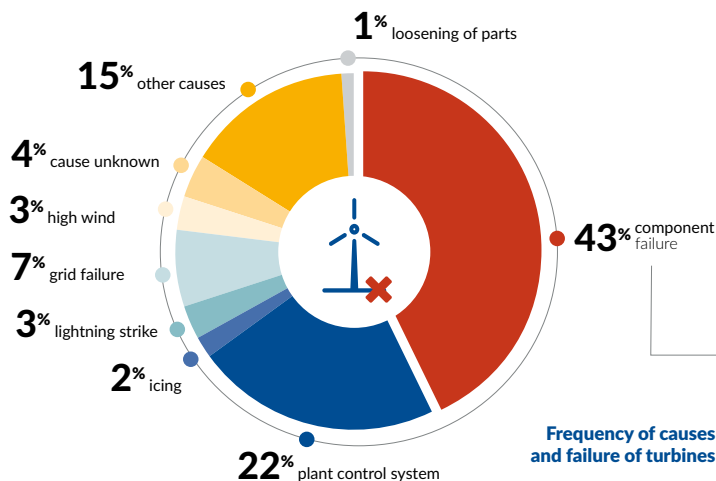


Source: Fraunhofer ISE, Germany November 2013

# Reducing the cost

The cost of generating wind energy is intrinsically linked to the reliable functioning of the turbine. On the one hand, **reliability has a significant impact on the total energy production**. Damaged or faulty parts reduce the performance of a turbine, meaning that it generates energy less efficiently. If a component experiences a total failure, this could put the entire turbine out of action resulting in a significant loss in energy generation.

On the other hand, **reliability problems have a direct impact on the cost of a wind project**, especially affecting operation and maintenance (O&M). Replacement parts and unscheduled or frequent maintenance work can be expensive - **O&M costs account for between 20-25% of the LCOE** -> cost of an onshore wind project making them the second largest cost after the upfront capital expenditure.



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# The Windtrust method

In the middle of every difficulty, however, lies opportunity. Experts predict that **future cost reductions in wind energy will largely hinge on driving down these operation and maintenance costs**. As shown in the graph opposite, the failure of certain turbine components is the single largest cause of turbine downtime. Innovations which can improve these components are therefore like gold dust – in one stroke able to increase energy production and reduce costs.

For the Windtrust project, the partners wanted to identify components with very high improvement potential.

Windtrust partners first analysed which components have the highest failure rates, and which contribute most to overall turbine downtime. In order to ensure maximum impact the partners considered two additional parameters: the cost of each failure, and its impact on security. Taking into account all of these factors, three components were selected – the rotor blades, the power electronics and the wind turbine controller.

To enhance these components, and achieve the highest level of reliability and availability, **the partners collaborated to optimise the design, operation and maintenance phases**.

**Rotor blades** . Improved durability and aerodynamics increase energy production and reduce maintenance costs, also extending the overall lifetime of the turbine.

**Power electronics** . Better designed module results in lower failure rates and maintenance costs.

**Controller** . Smarter controller maximises energy production and helps detect and mitigate against faulty conditions, thereby prolonging machine life.



# Rotor Blades

Windtrust has optimised the use of carbon fibre to increase durability and reduce component weight, thereby extending the overall life of the wind turbine. Upgraded erosion protection has also improved aerodynamic performance and reduced maintenance costs.

Source: LM Wind Power

Blades are tested in the four major load directions at LM Wind Power's dynamic testing facility in Denmark.

# Improved Rotor Blades



Rotor blades play an essential role in the capacity of wind turbines to produce electricity. However, rain, hail and other particle impacts can lead to blade edge surface erosion if unprotected. The problem is particularly acute for offshore wind turbines, installed in a harsh environment with heavy rain and salty water. Erosion damage causes blades to lose mass and disturbs their aerodynamic flow leading to a significant reduction in turbine efficiency and energy production.

To increase the profitability of wind turbines both onshore and offshore, Windtrust experts have been testing new technologies to enhance rotor blades. In the past, manufacturers have developed various solutions to protect the blades from erosion. These include the application of tape or a gel coating to the blade edge meant to extend the service life.

These current protection systems lack durability and suffer from a high repair frequency, leading to increased maintenance costs.

To address this issue, a new protection system called ProBlade has been developed and tested by LM Wind Power in Denmark. This innovative edge protector is made of a polyurethane brush-on coating applied to the blade and has proven to be more durable than previous protection systems. Thanks to a specially designed machine located in LM Wind Power's technology centre, the ProBlade has been subjected to accelerated rain erosion testing.

This innovative solution is five times more resistant to erosion than tape, and over fifty times more durable than the gel coat.

After final testing takes place in September 2016, the ProBlade will be ready for widespread adoption.

Additionally, Windtrust partners have been working with innovative materials such as carbon fibre to build a new generation of blades, which are lighter and more resistant to erosion. Renowned for its stiffness and extreme



lightness, carbon fibre increases the durability of the blades without affecting their weight.

According to experts from Gamesa, the use of carbon fibre blades could extend the overall life of the turbine to thirty years.

The newly developed materials and

technology will significantly increase the performance of the blades while lowering the costs of maintenance and down time.

For offshore wind production in particular, maintenance is an essential issue. In that context, limiting the amount of repair work and downtime related to erosion could have a large impact on the price of offshore wind energy.



Source: LM Wind Power



## Q&A: **Michael Drachmann Haag**

At LM Wind Power's technology centre in Kolding, Denmark, researchers are developing innovative solutions to improve the reliability of turbine blades. Among these experts, **Michael Drachmann Haag, lead engineer at LM Wind Power**, has been working for ten years on leading edge protection.

### **Why is it important to develop solutions to protect the blades from erosion?**

The condition of the leading edge surface of a wind turbine blade significantly affects the energy generation efficiency and hence the energy generation of a wind turbine. Ten or even five years ago, leading edge erosion mostly occurred in the most extreme environments, such as the west coast of Scotland where blades faced massive amounts of rain and wind. But, in the hunt for an improved cost of energy through higher tip speeds, leading edge erosion is becoming much more dominant.

### **What solutions have the Windtrust project advanced?**

At the rain erosion test centre, we have been testing the endurance of protective coatings on aluminum samples shaped like a blade. In a specialised machine, three whirling arms rotate at high speeds under an artificially generated rain field,



with a rotational speed up to 600 kilometres per hour. Our extensive research programme has led to the development of a novel leading edge protective solution that has surpassed all current test standards. This new coating developed at LM Wind's technology centre lasts over five times longer than the industry standard.

### **What impact will these solutions have on the wind energy market?**

Add-ons for blades are like software upgrades for a mobile phone: when an upgrade comes, suddenly the appearance, functions and battery lifetime are improved.

When we design blades to reduce leading edge erosion, there will be leaps in technology but there will also be incremental change. With the Windtrust project, we have done both. As a consequence, the newly developed materials will significantly increase the performance of the blades while lowering the costs of maintenance and down time.



Source: LM Wind Power



partners



countries




years



enhanced  
components



**14-22%** 

LCOE reduction

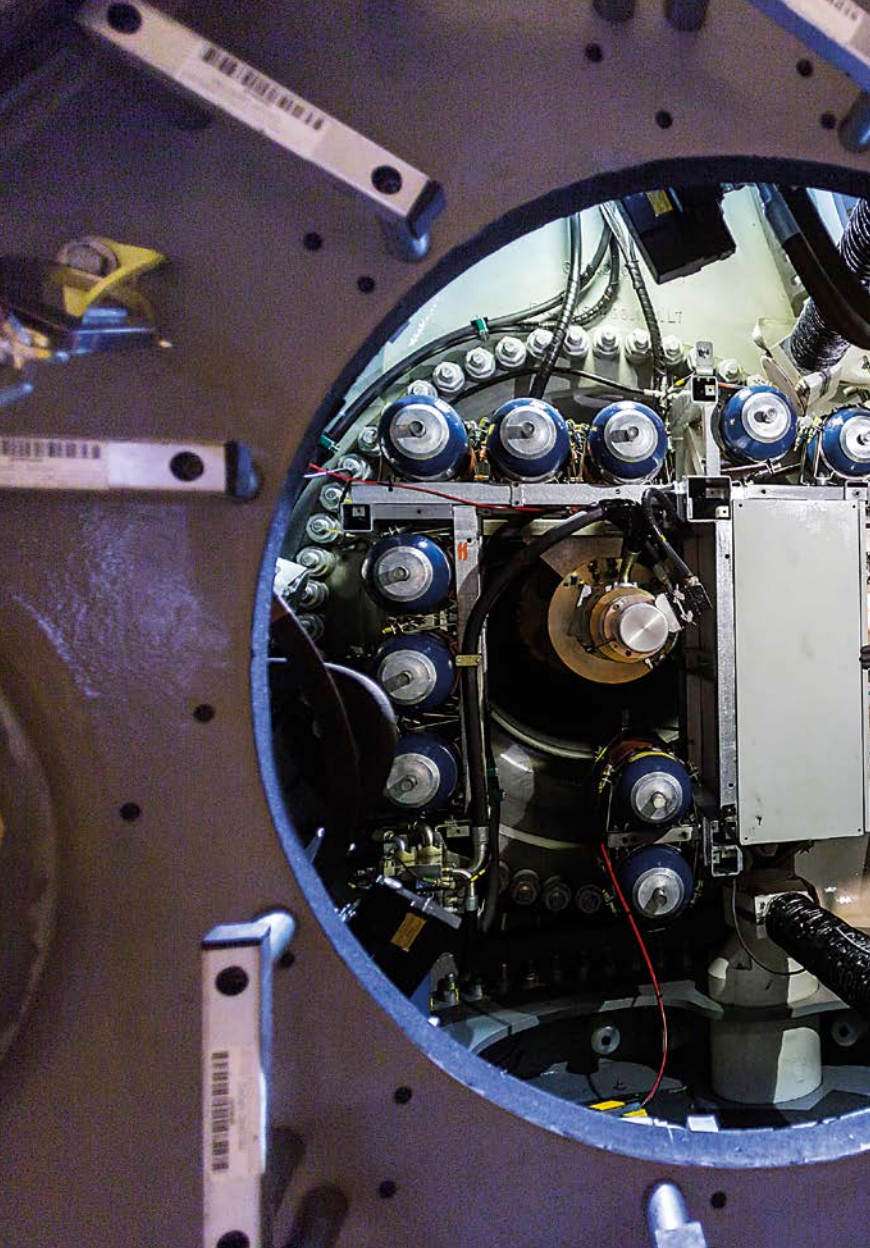
**30** 

years new  
turbine lifetime

**>2** 

decibels  
quieter

Experts carry out a routine inspection at La Cámara  
wind farm in Spain. Image source: Gamesa







# Power Electronics

Windtrust has optimised the power electronics by reducing the number of components and interfaces. New assembly technologies have helped reduce the total volume of the inverter, and increase overall reliability.

An operation and maintenance expert working in the hub of a wind turbine. Image source: Gamesa

# Optimised Power Electronics



The voltage and frequency of electricity generated by turbines must be adapted before it can be transferred and used. This vital task is carried out by power electronics which convert the mechanical energy of the blades into electricity. The converter has a generator and a line inverter to feed a voltage waveform into the electricity grid. The inverter with the power electronics is a major functional block and essential for wind energy generation. It is located in the nacelle or in the base - depending on the design of the wind turbine.

Existing, low voltage designs of wind turbine inverters have reached their limits in terms of capability, weight and size.

Next generation inverters need to be more reliable, more compact and less expensive to bring down the costs of installation and operation.

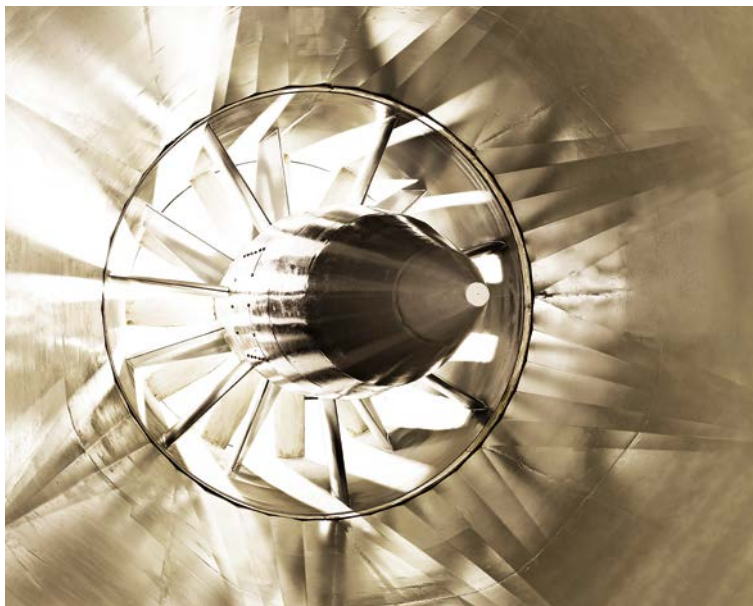
In order to achieve the highest possible level of reliability, German firm

Semikron has optimised the design of its power electronics component by focusing on three aspects: humidity protection, scalability, and reducing the number of parts.

Throughout the wind turbine's life the converter can be exposed to vibration, humidity and pollution. These three factors can result in power losses as well as additional maintenance costs. In the framework of the Windtrust project, the climate protection of the power electronics has been improved to exclude condensation and water impact, a typical cause of failure.

As turbines increase in size, power electronics modules have to be combined in order to convert power of 6 MW or more. Semikron has made the component more compact, with its new intelligent power module having a 30% higher power density than previous models. This will also help limit the overall weight of the nacelle.

The reliability of the power electronics is an accumulation of the reliability of its different parts. The general rule is: the more parts used in the design of



Source: LM Wind Power

the device, the more defects that can happen. Recognising this, Windtrust partners have built a new generation of semi-conductors, reducing the number of active elements and consequently the number of breakdowns.

The new power module designed by German firm Semikron is made of 50% fewer parts than other examples on the market.

Additionally, researchers have developed an algorithm to foresee and anticipate a problem before a breakdown occurs. Thanks to these improvements, repair time will be reduced by 70% and wind turbines will be able to function in highly polluted or humid environments. This newly optimised design has gone through rigorous testing, showing a significant improvement in both reliability and durability, making traditional modules redundant in this rapidly changing market.



## Q&A: **Thomas Grasshoff**

Semikron, one of the world's leading manufacturers of power modules and systems, is setting its sights on overhauling power electronic components as part of the Windtrust project. **Thomas Grasshoff, Semikron's Head of Strategic Marketing**, explains why optimising power electronics is important to reduce the cost of wind energy.

### **What are the specific challenges with power electronics?**

One challenge for power electronics is the scalability - building blocks have to be combined to achieve power up to 6 MW or even more. The power electronics can also be exposed to dust and humidity, and low temperatures can cause condensation.

If condensation reaches areas of different voltage, a catastrophic failure can happen.

Today, only expensive sealing and heating systems prevent such a situation. Another critical area is the dynamic load conditions during wind turbine operation. The power electronics have to adapt to a change in conditions in a millisecond range. This causes fatigue to components, which heat up and cool down. This is known as power cycling.



### **What are the key improvements you are working on as part of Windtrust?**

The basic idea is to make power electronics more compact, increase reliability using less parts and boost protection. SKiN, a new assembly technology of power semiconductors, is being adopted. It improves the reliability of power electronics and is a pre-condition of making the inverter smaller.

The need for compact systems, high reliability and low cost means that new technology approaches are demanded and the traditional modules used in power electronics will gradually vanish from the market.

The key here is the reduction in system costs. With smaller power electronic components, racks, connectors and cables are all reduced too.

### **What impact could the changes have on wind turbine use and what will this mean for consumers?**

If the costs of wind energy go down, and parity with fossil energy sources is achieved, more wind turbines will be installed. Energy prices will stabilise, or even go down in the future. As onshore farms enter lower wind areas the need for more efficient and reliably energy production, as that pursued by Windtrust, is a must. The future is also in offshore, where costs must also go down and reliability increase is paramount.





A high-angle, fisheye photograph looking down into the interior of a wind turbine tower. The structure is circular with multiple levels of metal walkways and railings. The walls are made of light-colored concrete or metal panels. The perspective creates a strong sense of depth and circular geometry.

# Turbine Controller

Windtrust has tested control algorithms that maximise the balance between energy production and machine life. The new, smarter turbine controller has reduced fatigue loads and helps in the detection, characterisation and impact mitigation of faulty conditions.

Going up. The view inside the tower of a wind turbine. Image source: Gamesa

# Smarter turbine controller



The unpredictable character of the wind is one of the main challenges faced by operators.

Turbines often also face a wide range of temperatures, from freezing during winter to 40° during summer.

Offshore turbines must be able to cope with harsh weather conditions such as violent gusts of wind occurring while the turbine is in operation.

These extremes pose a threat to the structural integrity of the turbine, and can limit the overall service life.

Wind fluctuations also affect the ability of the turbine to generate energy. Even at optimal wind sites with steady, strong winds there are variations in speed and direction which can limit the performance of the turbine.

To address these issues, wind turbines are equipped with software control systems which automatically track local wind conditions and make small

adjustments to the turbine accordingly. The controller regulates turbine orientation, blade pitch, and generator gearing, in order to prevent damage to the wind turbine and maximise energy production.

The angle at which the turbine faces the wind and the alignment of the blades are crucial to the production of energy. To optimise energy generation and increase the overall life of wind turbines, Windtrust project partners have been working on a smarter wind turbine controller able to correct inaccurate positioning of wind turbine components.

Gamesa has devised several solutions to ensure the optimal alignment of the wind turbine controller to the approaching wind. For this purpose, researchers have scanned the power obtained from different offsets of the wind sensor and selected the optimal offset for power generation. Experts also managed to optimise the ability of the controller software to react to unusual

weather conditions thanks to the use of external wind flow measuring devices providing more accurate measures.

Windtrust partners enhanced the control of the two most common variables of blade positioning, the 'pitch' and the 'yaw'.

Pitch control is specific to the blades and their 'angle of attack' with respect to the incoming wind, while yaw refers to the horizontal rotation of the entire wind turbine. In that sense, Gamesa has been developing control algorithms to enhance the pitch and yaw

controller. The two control methods are used to either optimise or limit power output. At low wind speeds the controller seeks to optimise, to run the turbine at maximum efficiency and extract all available power. When winds are stronger than ideal, the controller looks to limit the generated power and to avoid damage to the wind turbine components caused by extreme loads. In this way, Windtrust project partners have created a smarter wind turbine controller, that has increased power generation and realised significant reductions in operation and maintenance costs.



Source: LM Wind Power





# Turning down the volume

Noise pollution is one of the main public concerns associated with wind power. Therefore the ability to reduce noise emissions will have a large impact on the wind energy market in the future, especially as wind turbines are likely to be placed closer to urban areas where noise regulations are more restrictive. What most affects the noise level of the turbine is the speed of the blade tips and the rotor diameter.

The expansion of blade lengths allowed wind farms to be installed in low wind speed sites, but it also raised the noise level of the turbines.

Much of noise emitted from operating wind turbines is the aerodynamic noise generated by the passage of air over the blades. Consequently, sound emissions depend on weather conditions such as wind speed, wind shear or atmospheric turbulence. One of the ways to deal with noise issues is to stop the wind turbine in certain wind directions or run the turbine in low-noise mode. However, both of these actions have a negative impact on the energy gen-

eration. The smarter wind turbine controllers developed by Windtrust have provided a solution, selecting the best angle of attack to optimise the balance between power generation and low noise emissions.

For modern turbines however, the dominant source of noise is the trailing edge at the outer part of the blades. One of the latest developments in this field are serrated plastic panels, that are mounted on the trailing edge of the blade. Due to their innovative design the flow and diffraction (breaking) of the sound waves on the trailing edge is changed, lowering the overall noise of the turbine. The lightweight structure and simple mounting process make them an attractive choice not only for new turbines, but for those already installed.

By bringing the noise level under the authorised limit, more machines can be installed.

At wind farms installed in noise-restricted areas, turbines equipped with this innovative technology will be able to run at an optimal setting and have higher annual energy generation.

# From designs to prototypes

All Windtrust innovations were rigorously tested and validated to demonstrate their technical and economic feasibility. A number of different tests were carried out.

Source: LM Wind Power



## Validation of the innovative blades components

As a first step, each modification to the blades, such as the innovative edge protector or the carbon fibre structure, were tested individually at CENER's laboratory. A full scale blade design was then validated at CENER's testing centre.

## Verification of the effect of flow control devices

The new flow control devices were

mounted on the blades of an operating GAMESA wind turbine to allow comparison with standard controllers as regards to power, load and noise performance. A series of measurement campaigns were carried out, allowing for tests with different control units and finer measurements. These were completed by aero elastic simulations carried out by CENER, and by additional field testing and validation by LM Wind Power. This led to a refined characterisation of the product's in-field performance, installation and repair requirements.

## Erosion protection tests

Together with the flow control devices, GAMESA tested the innovative erosion protection materials on the leading edge of an operating GAMESA wind turbine. Impacts of rainfall, temperature, particle erosion and UV intensity



were measured and compared with reference samples in order to evaluate the expected life-time of the blade.

### Validation of the impact of the new power electronics

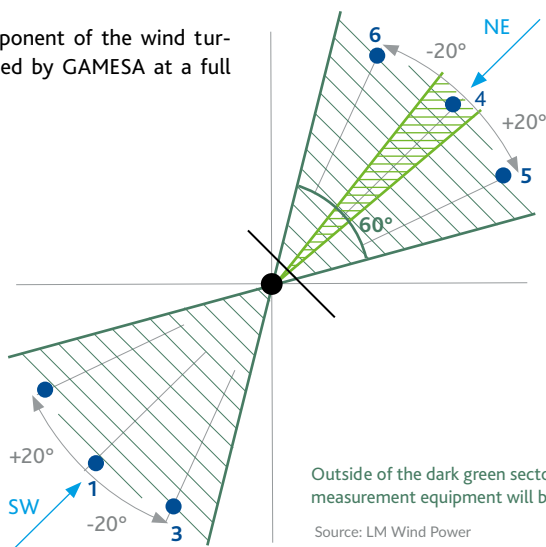
A converter module with the enhanced power block developed by SEMIKRON was tested in a real wind turbine environment, coupled with a generator running at both rated and maximum power. Detailed measurements of currents, voltages, temperatures, harmonics and efficiencies have been compared with existing technologies.

### Wind turbine control technologies tests

This key component of the wind turbine was tested by GAMESA at a full

scale wind turbine, to be able to evaluate the wind turbine behaviour in real life conditions (i.e. with different air density, humidity, etc.).

Altogether, the prototypes have proved to significantly increase the overall availability of wind turbines by increasing its durability while decreasing the failure rates and hence the need for maintenance. Even though the new technologies were mostly validated in onshore conditions, these could also greatly benefit to offshore applications, where erosion and maintenance costs are particularly critical.



# Windtrust AQA

## Any Question Answered



### What?

The Windtrust project aimed to reduce the cost of wind energy generation by further improving the reliability of three key components of the turbine: the rotor blades, the power electronics and the wind turbine controller.

### Why?

Innovate technologies are needed in order to improve the competitiveness of wind energy technologies and maintain Europe's technological leadership. The solutions designed in the framework of the Windtrust project will ensure a higher level of reliability and availability of wind turbines, thus leading to a significant reduction in operation and maintenance costs.

### How?

The project partners embraced a holistic approach, optimising the design, operation and maintenance phases for each of the three components. They then demonstrated the technical and economic feasibility of their innovative and more reliable solutions on a 2 MW onshore turbine in Spain.

### Did it work?

Testing showed that the resulting reduction in total cost (LCOE) is between 14 and 22%. The innovations are expected to have an even larger impact on wind turbines of larger capacity and offshore developments. The new design will also extend the service life of the turbine up to 30 years. Noise control innovations resulted in a minimum 2 decibel reduction in turbine sound emissions.

See more about the project at : [www.windtrust.eu](http://www.windtrust.eu)

# Consortium



To reach its objective of reducing the cost of wind energy generation, Windtrust brought together 9 partners from 6 European Union member countries (Belgium, Denmark, Germany, Greece, Spain and United Kingdom). Coordinated by Spanish firm Gamesa, the partners included key industrial players and research centres. The collaboration spanned a period of three years, having begun in September 2013.

For more information about the project, visit [www.windtrust.eu](http://www.windtrust.eu) or contact the Windtrust communications team:

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**Windtrust innovations could  
reduce the cost of wind energy  
generation by up to 22%**

[www.windtrust.eu](http://www.windtrust.eu)



Source: Gamesa



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