“Integrated Ice Sensing and De-icing System to Improve Wind Turbine Efficiency in Cold Climates”

Project executive summary

The **overall aim** of the WINDHEAT project is to respond to a vital, urgent and strategic market need of the involved SMEs who will, in different ways, all benefit economically from the production of proven innovative technologies for the deployment of Wind Turbines in cold regions with levels of reliability and generation cost hitherto not possible. This was achieved by the development of a **validated intelligent blade coating** that will enable the **detection of ice** as it forms and accrues, and an **efficient heating** (de-icing) **system with spatial discrimination capability** to solely target the areas where ice is forming.

To realise this, WINDHEAT focused on three main technological objectives. The first technological objective of the project was the creation of a low cost robust and reliable sensing system for the real-time detection of ice formation on wind turbine blades, capable of discriminating ice accretions when they occur and to identify their location. The second technological objective was the creation of an ultra-efficient, spatially discriminating, light weight and durable de-icing coating for turbine blades compatible with standard coating processes. The third and final technological objective was in charge of combining the two previously described ones, together with an implemented intelligent control unit, to create a final novel ice detection and de-icing system for wind turbine blades governed by a robust and high-performance intelligent control system.

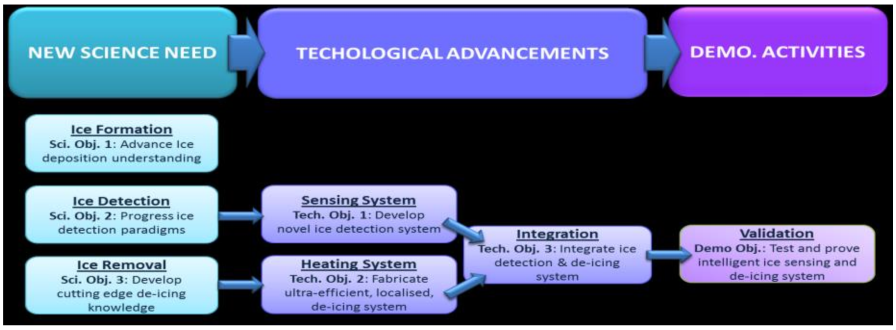
The different exhaustive tests run for the verification of the implemented system were useful to validate and demonstrate that the selected approach is not only valid for ice detection and ice removal on wind turbine blades, but also provides a very high performance at a reduced cost.

Project context and main objectives

The overall project aim is to respond to a vital, urgent and strategic market need of the involved SMEs who will, in different ways, all benefit economically from the production of proven innovative technologies for the deployment of Wind Turbines in cold regions with levels of reliability and generation cost hitherto not possible. This was achieved by the development of a validated intelligent blade coating that will enable the detection of ice as it forms and accrues, and an efficient heating (de-icing) system with spatial discrimination capability to solely target the areas where ice is forming.

World energy demand is increasing at an exponential rate: projected to more than double by 2050 and to more than triple by the end of the century and incremental changes in current energy supply technologies will not suffice to meet this burgeoning demand. Recent estimates suggest that wind contains sufficient energy to supply the energy needs of the planet several times over. Technological and cost barriers related to wind turbine icing are currently constraining the siting of wind farms in geographies with extreme climates. These areas often exhibit vast potential for wind energy generation and thus represent a large untapped resource. This project has removed these limitations by improving overall energy efficiency in such environments by at least 18% (leading to a cost reduction of at least 10.5%) by minimising the energy required to remove ice on the Wind Turbine blades, scaling down aerodynamic losses brought by icing structures and by reducing stress failures caused by heavy ice deposits. Moreover site safety will be markedly improved by reducing the likelihood of large amounts of ice being expelled from rotating turbine blades.

To realise this, WINDHEAT focused on three main scientific objectives. The first scientific objective of the project is centred on reviewing and improving current understanding of ice formation on Wind Turbines; the second, focuses on investigating possible approaches for ice detection and the third objective investigates relevant ice removals approaches and mechanisms. The scientific objectives logically led to three technological objectives: development of an ice detection system, fabrication of a de-icing system and an integrated intelligent ice detection and de-icing system. Effort was then spent validating the integrated technological advances under real and simulated conditions and providing the proposed solution.

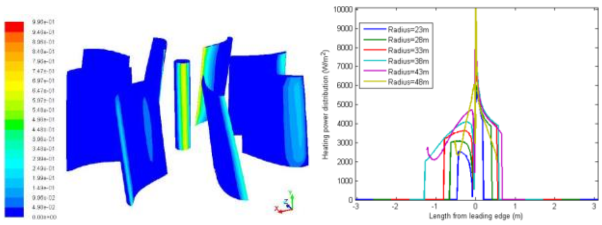


Project objectives summary

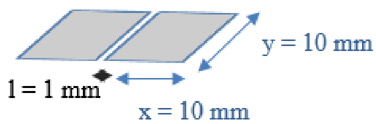
By applying WINDHEAT technology, the involved SMEs will be able to overcome the current obstacles in the sector by adding key value to their existing products, incorporating a unique product that can provide a unique key advantage, reaching a wider market, reducing electricity generation cost by at least 10/15% and contributing to the environmental profit of green electricity generation.

Main S&T results/foregrounds

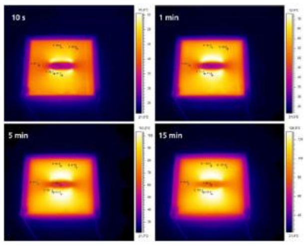
A first in-depth study was made to update, complete and advance current understanding on the precise deposition and growth mechanisms of ice on and around wind turbine blades. An **ice accretion simulation software** (“**MATICE**”) was developed from scratch, which allows predicting the icing rate and location on 2D and 3D air foils at different conditions. This was useful to evaluate the regions of the wind turbine prone to ice build-up, ice-sensing and de-icing devices preferred location and de-icing estimated power consumption.



With these results as a reference and after an exhaustive analysis for all the possible **ice-sensing** strategies, the most appropriate method was selected and then some sensor prototypes were built and tested to validate the selected approach, covering project Milestone 1. As a result of these tests, the particular details about the sensor were decided, including electrical, physical, chemical and geometrical considerations. These sensors were then scaled up for embedding them into real blade components and tested satisfactorily, being able to detect ice under all different conditions and all different ice types, being also capable of discriminating between liquid rain water and solid ice situations and not providing any false alarms, which resulted in an optimal design from the power consumption point of view, achieving a sensor implementation which is not only valid for detecting ice on wind turbine blades, but also optimal from the material, size, shape, geometry, accuracy, endurance, robustness, repeatability, sensitivity, response time, power consumption, price and aesthetic point of view .



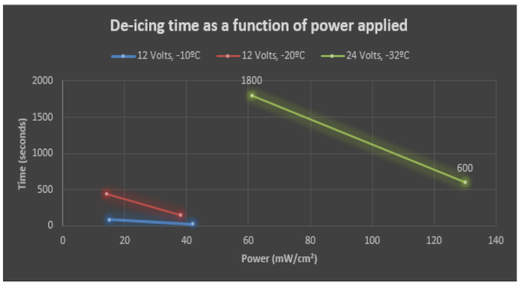
In a parallel step, an ultra-efficient, spatial discriminating, light weight and durable **de-icing** coating for turbine blades compatible with standard coating processes was developed. For this, some first electrical and thermal analysis were carried out and, then, the best approach for depositing the created CNT de-icing units was studied. Some first prototypes were created, covering Milestone 2 and tested for evaluating film stability, adhesion, energy consumption and de-icing capability as a function of the applied power. Then ice sensing integration was foreseen to evaluate uniformity in heat distribution by using an infrared camera.

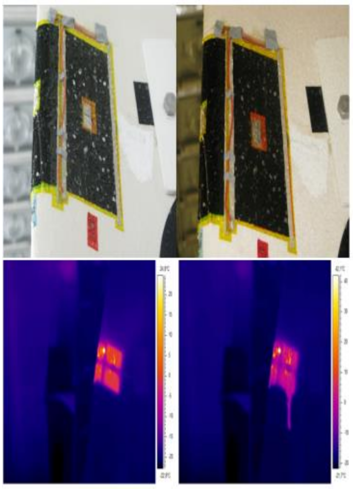


In order to read ice sensors data, process them and, as a result of this processing, act on the de-icing units when required, a complete **intelligent control system** in hardware and software terms was designed and implemented, including the interfaces, input conditioning electronics and sensor interfaces, microcontroller running the sensor polling sequence and decision software, output signals to actuate on de-icing units and the user interface of the application (allowing operation evaluation and traceability in both online and offline modes). Careful consideration was given to operating conditions, designing all the parts in the WINDHEAT system to be capable of operate in harsh environments.

Finally, all these independent parts were integrated, completing Milestone 3, in gradual steps. Some first preliminary tests were conducted for different types of blades, demonstrating that the WINDHEAT system is **valid for both VAWT and HAWT**. These tests were run in the climate chamber developed during Work Package 1.

The last step was implementing the WINDHEAT system on a real wind turbine and conduct the corresponding tests to fully validate the entire strategy under normal and extreme conditions.





An illustrative dissemination video has been built for showing the main WINDHEAT system features and advantages and can be found at http://youtu.be/pDK9Cy-byjY .

The *WINDHEAT* solution has contributed to achieve an Integrated Ice Sensing and De-icing System to Improve Wind Turbine Efficiency in Cold Climates. In order to reach these objectives, *WINDHEAT* project has worked fulfilling the three main technological objectives and the project has delivered three key results with significant IP potential:

1. A demonstrated low cost robust and reliable sensing system for the real-time detection of ice formation on wind turbine blades:
   - ✓ An ice sensor as small as 21mmx 10 mm has been proven to be valid for both Horizontal Axis Wind Turbines and Vertical Axis Wind turbines, not minding blade size.
   - ✓ Ice sensor is not intrusive in the blade geometry, preserving all the aerodynamic properties and, therefore, not impacting wind turbine energy generation performance.
   - ✓ Ice sensor accuracy is bigger, by far, than the actual accuracy required to detect ice formation.
   - ✓ Ice sensor allows a clear discrimination between water and ice.
   - ✓ Ice sensors have been validated to operate properly in a very wide range of temperatures, from ambient temperature to temperatures as low as -32ºC. Even in this corner case, where detection becomes a bit more difficult, satisfactory results have been obtained.
   - ✓ Ice sensor shows perfect repeatability when exposed to several cycles of operation.
   - ✓ Ice sensors are capable of detecting ice formation in all different forms (snow, ice…) and do not generate any false alarms, which implies power optimisation.
   - ✓ Ice sensors can be manufactured at a very low cost.

2. A demonstrated ultra-efficient, spatially discriminating, light weight and durable de-icing coating for turbine blades compatible with standard coating processes:
   - ✓ Ultra-efficient, which is results in low de-icing power consumption.
   - ✓ Spatial discriminating, which allows areas differentiation.
   - ✓ Light weight, with a de-icing unit thickness < 0.5 mm.
   - ✓ Durable de-icing coating, which is protected by a high performance clear coat.
   - ✓ Compatible with standard coating processes, which reduces manufacturing costs.

3. A demonstrated novel ice detection and de-icing system for wind turbine blades governed by a robust and high-performance intelligent control system:
   - ✓ Inexpensive small-size control system electronic hardware unit has been built.
   - ✓ Easy and cheap electro-mechanical integration, allowing input/output access on wind turbine blades while keeping the electronics in a safe location.
   - ✓ Hardware and software filtering strategies included to avoid potential interferences and signal spikes.
   - ✓ Additional monitoring capabilities included, allowing real time evaluation of the WINDHEAT system under control.
   - ✓ Specific intelligent decision software capable of detecting ice formation in early stages and acting on the de-icing units to remove it.
   - ✓ Configurable parameters for optimal operation.

Potential impact and use and dissemination activities performed

Through the execution of the research tasks, *WINDHEAT* is improving the current solutions available in the market, providing, in summary**:**

- ✓ Ice measurement at a higher number of locations and at low cost, allowing targeted ice removal.
- ✓ Infrequent maintenance and cleaning, reducing operational costs.
- ✓ Coating with less filler material (between 2% and 5%) and corrosion resistance increase.
- ✓ Thinner and lighter layers due to their high conductivity.
- ✓ High energy efficiency (by an estimated improvement of around 15%-20% vs comparable systems).
- ✓ Parasitic loss of energy reduction of around 5%-10% (vs comparable systems, greater vs. alternative strategies such as hot air steams).
- ✓ Innovative advanced intelligent control system with higher accuracy and robustness.
- ✓ Significant cost reduction in energy generation (estimated to be around 10%).

Four main potential markets have been identified:

- Wind power market. Wind power is presently supplying 1.92% of the world's electricity demand and, by 2020, is expected to produce 9.1%. An average global growth rate of 15.5% per year is envisaged for new annual installations through to at least 2015. Wind power market is expected to grow from 66.8 Billion€ (NB. 1 Billion = 1000 Million) in 2011 to 111.7 Billion€ in 2015 and to 142 Billion€ in 2017. The European market remains at the head of the worldwide market accounting for almost 95% of the global market. At present, there are over 12,000 wind turbines in Europe.

- Small Wind Turbine market. Power generation from small wind turbines is an increasingly important part of the broader market for renewable distributed energy generation. As a consequence, the installed capacity Europe is expected to expand from 86MW in 2010 to 933MW in 2017 with a compound annual growth rate of over 40%. In parallel, the market value associated with the small Wind Turbine market is forecast to reach 3.123Billion€ by 2017 from 429M€ in 2010.

- Blade market. The value of the blade market is often estimated simply as a percentage of the turbine market. It is generally assumed that blades account for 15% to 30% of the total purchase price of wind turbines.

- Coatings market. The global market has experienced 4% growth in volume and 5% growth in value over the last five years. In terms of value, the global paints and coatings market reached an estimated 77 Billion€ by the end of 2010. This global market figure is expected to increase with a relatively modest compound annual growth rate of 3.2% for the 5-year period of 2010 to 2015 and reach €90 billion by the end of 2015.

From a market prospective, there is no point in developing a successful technology if this market is not aware of their existence. For this reason, a strong effort was paid on proceeding with the necessary actions to disseminate the WINDHEAT system main features, novelties and development results, showing the main advantages to create a disruptive product for all the potential customers.

Several dissemination activities have been carried out, supported by communication materials, such as a video, internet presence (including WINDHEAT website update and also including each partner website update to continuously provide with latest news), articles, posters, press releases and international fair presences. However and far from being a "completed task", dissemination activities have to and will continue out of the scope of the project in order to reach a higher penetration in the market to ensure a final success for the implemented WINDHEAT system.

Consortium members and contact details

Consortium members and contact details can be found in WINDHEAT website: http://www.windheat.eu/