# Wind turbine blade anti-icing and deicing system Summary of DeICE-UT project – 7th EU Framework Programme

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**Abstract:** A concept of the anti/deicing system is presented. The main system components: actuators, supply system as well as HMI are briefly described. Results of the verification of the system in a climatic chamber are presented. Concluding remarks about system's efficiency are provided.

**Keywords:** ice detection; ice removal; supply system

## 1. Introduction

Production of electrical power becomes more and more environmentally friendly nowadays. New techniques of electric power generation come in including the use of modern power generators. Among the ecological friendly technologies the wind power offers many advantages, including larger power densities (offshore wind generators with nominal power higher than 5 MW are under examination [4]). One of the biggest challenges connected with wind farms is their location. Due to wind conditions such farms are often located in sea water near the coasts or in the arctic zones. This causes additional difficulty in turbine maintenance and operation. One of the unsolved issues is icing of the blades and the turbine hub. Icing of the blades influences not only the overall weight but also operating parameters of the turbine [1, 2].

Similar problems exist in aircrafts and in space shuttles. Scientists and engineers develop and examine various methods of preventing ice formation and/or removal. Methods like covering the surface of the propellers or wings by special paints or functional layers as well as resistive heating are mainly used in aeronautics. Due to the fact that the blades of a wind turbine are made of different types of materials (laminated composites) and have different shapes other methods of anti-icing and deicing are required. One of the methods was suggested and validated by a consortium established for realization of the European project "DeICE-UT deicing of wind turbine blades" financed by the European Union 7th Framework Programme [FP7/2007–2013] under grant agreement no 605138.

In the paper the idea of such anti-icing and deicing system is presented. Hardware and software system is briefly described. Moreover, integration with ice detection system and actuators is also presented. Finally the trials in climatic chamber and achieved results are given.

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## 2. General System Overview

General system construction is discussed in this chapter. After ice formation/detection the overall control unit analyzes the operating conditions and uses one of two possible deicing methods:

a) ultrasound or shear force actuator matrix implanted in blade surface (in pulsed or continuous mode);
b) mechanic, centralized shaker mechanical ice removal with variable shaker frequencies. Many different matrix arrangements of the actuators and shaker mounting positions were taken into consideration.

The supply systems needs to allow pulsed and continuous operation of both – piezo actuators and a mechanical shaker. The design demands for the supply signals were (in case of the shaker) a modulated, sinewave signal with controllable amplitude between zero and 0.4 kV with adjustable frequency up to 80 Hz, with 1 Hz resolution.

It was also demanded that the supply parameters were set using a centralized HMI system. The HMI system should deliver the functionality of PC computer based control and parameter storage.

The final trials were conducted in a climatic chamber allowing to decrease the temperature to the level of –40 °C. Different types of ice formed on the surface of the blade were investigated.

## 3. Supply System Design

As it was mentioned in the previous paragraph a specially designed supply system was dedicated to deliver the power to anti-icing actuator matrix (ultrasound transducer) and the mechanical deicing shaker. Separate power electronic circuits were designed and prepared in order to fulfil requirements of each actuator.

**Fig. 1. Shaker unit used for the prototype construction**
Rys. 1. Zastosowany szejker przemysłowy

### 3.1. Shaker Unit Power Supply

As the initial step an industrial shaker unit was proposed. Industrial shakers include a magnetic excitation coils and a moving armature or a rotating mass excitation. An industrial shaker NEG 50300 by Netter Vibration was chosen. It is based on an AC induction machine rotor coupled with dislocated mass. A 250 W system was ordered with the maximum force of 3020 N. 400 V, 3 phase supply system is used for the induction machine. Purchased shaker is presented in Fig. 1.

In order to fulfill the supply requirements a following system was proposed: full bridge power controller with current feedback, supplied from industrial 3×400 V AC grid, with DSP based real time control. Proposed controller unit conceptual construction is presented in Fig. 2.

Based on above mentioned assumptions a power unit (based on intelligent power module by Toshiba) and a control board were designed. Based on prepared

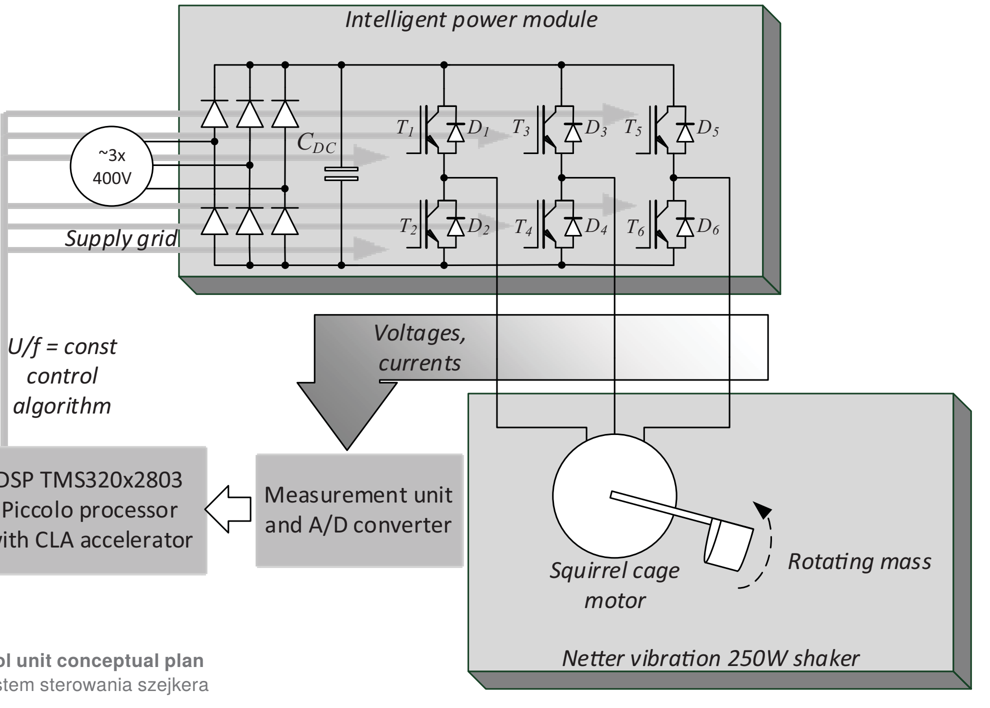


**Fig. 2. Shaker control unit conceptual plan**
Rys. 2. Koncepcja system sterowania szejkera

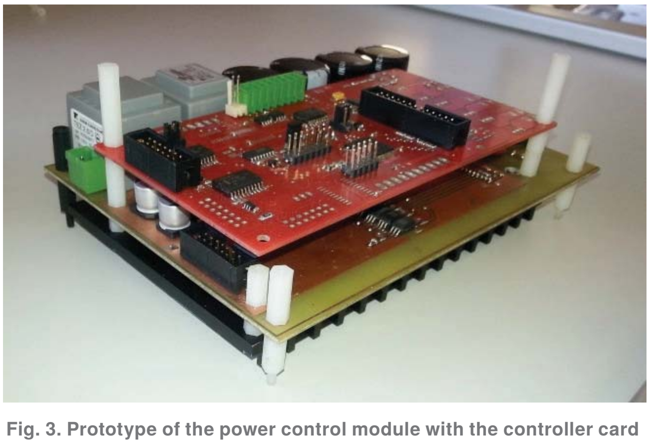

**Fig. 3. Prototype of the power control module with the controller card**
Rys. 3. Prototyp modułu mocy układu sterowania

**Fig. 4. Prototype of the shear force transducer power control module**
Rys. 4. Prototyp wzmacniacza dla przetworników siły

PCBs, prototypes were constructed. The power module with control board, after assembly, is shown in Fig. 3.

### 3.2. Transducers

It was assumed that the ultrasound shear force actuator matrix of four force transducers will be used. Each transducer will be supplied using a high bandwidth power amplifier with voltages up to 120 V peak-to-peak. Reference sinusoid will be provided by the Direct Digital Synthesizer (DDS) and DSP converter board.

Apex power amplifiers were used with controllable DC link voltage. Output power was investigated as a function of supply voltage frequency and DC link voltage. Command sinusoid was obtained using integrated DDS generator (Analog Devices AD9833) and automatic power adjust algorithm [3]. Final prototype construction for a single force actuator is presented in Fig. 4.

## 4. System Integration

In order to make the system fully usable all components: actuators, supply and icedetection system as well as based on PC HMI system had to be integrated. Instead of ice-detection and HMI systems other components were briefly described, hence, now mentioned two elements of the system will be more precisely characterized.

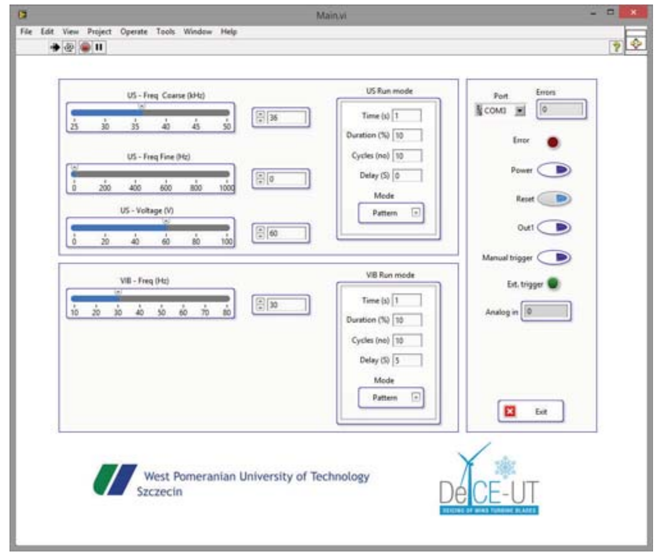


**Fig. 5. Controller software interface**
Rys. 5. Ekran systemu sterowania

### 4.1. Ice Detection System

To sufficiently detect ice formation Labkotec Oy LID-3300IP Ice Detector for Wind Turbines and Meteorological Stations was used.

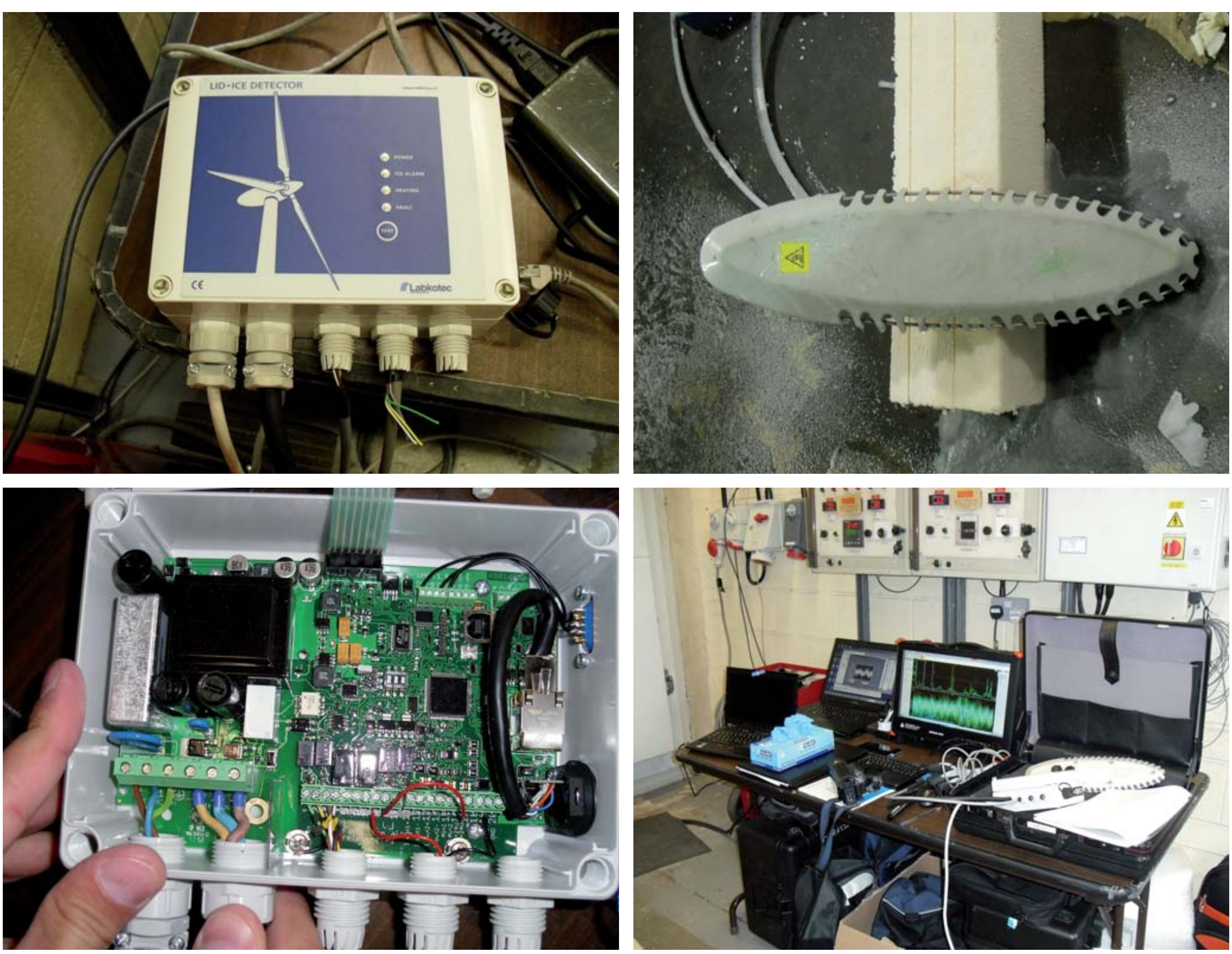


**Fig. 6. Components of ice-detections Lobcotek LID 3300IP system**
Rys. 6. Elementy Lobcotek LID 3300IP – systemu detekcji oblodzenia

**Fig. 7. During ice formation process**
Rys. 7. Proces formowania lodu w komorze klimatycznej

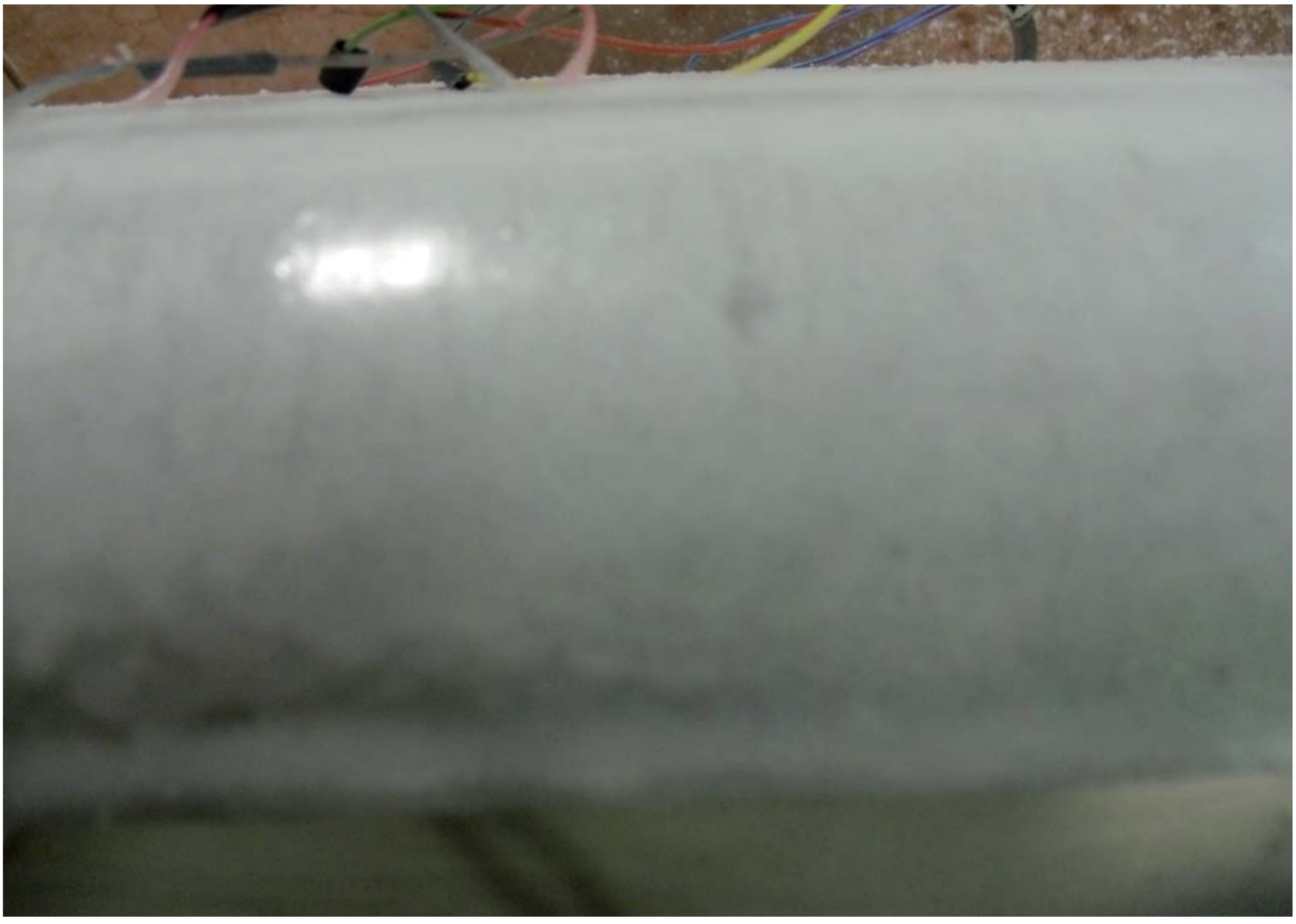

**Fig. 8. Rime ice type formed during the tests**
Rys. 8. Lód typu grzebieniowego uformowany na potrzeby testów

Fig. 9. Snowflakes ice type formed during the tests
Rys. 9. Lód typu płatki śniegu uformowany na potrzeby testów

This system allows for detecting ice formed on dedicated standalone sensor. The sensor needs heating in case of leading another ice detection process. Hence, the sensor was connected via two delivered by producer wires (signal and heat suppling) with the main brick of the system. The main job was electrically connect dedicated two-wire relay output with DeICE supply system 24 V DC input. This connection allows for activating the supply system just after detecting the ice, by Labkotec Oy LID-3300IP Ice Detector. As there are a relay output and 24 V DC input the source of 24 V DC was needed as well. Hence, described as not use at moment connections was used as delivering the 24 V DC supply to the signal sending/receiving circuit.

### 4.2. Software Layer of the DeICE System

The developed software (Fig. 5) was proposed for overall system integration, control and testing. Basic properties include:
– system state control,
– triggering actuators in test mode,
– communication with Ice Detection System LID 3300 (switching on heating).
– shaker frequency setting,
– shaker operation mode (test / continuous work) selection
– force transducer operating mode and frequency settings.

For both power supply systems a supply pattern control is possible. A pattern allows us to set followed parameters:
a. Time – in case of working in cyclic mode this is the period between two consecutive supplier triggers,
b. Duration – it is the active period of the device used – if 100, supplier works continuously,
c. Cycles – number of cycles used in a pattern,
d. Delay – time between the switching off of system one and turning on the system two.

Using developed software system it is possible to generate whichever sequence of supplying both systems (SH-waves and Shaker), i.e.: after triggering the system (manually – test-button or automatically – continuous work – from ice Detection System).

## 5. Climatic Chamber Trials

The tunnel trials were lead between the 15th of July and 17th of July. In order to evaluate the performance of the anti-icing and deicing system all components were integrated. The Ice Detection System (Labkotec LID 3300IP) was also integrated on this stage – presented in Fig. 6.

Apart from the sensor of Ice Detection System the main electronic part of the Anti/Deicing system (supplier) and measurement components were putted into chamber. Special Styrofoam box was built in order to prevent directly icing of the power supply and measurement system. However, supply system operation was validated for low temperature and high humidity operation. The HMI part of the Anti/Deicing system as well as oscilloscopes and recording measurements devices were placed outside the chamber.

To fulfill the requirements stated in description of work many experiments were led. Both, Anti-icing and deicing systems were valuated separately for different type of ice formed.

As it is well known there are many types of ice dependently on the conditions of forming it. As the process of icing was

**Fig. 10. Broken ice after shaking system operate**
Rys. 10. Połamany lód po działaniu systemu z szejkerem

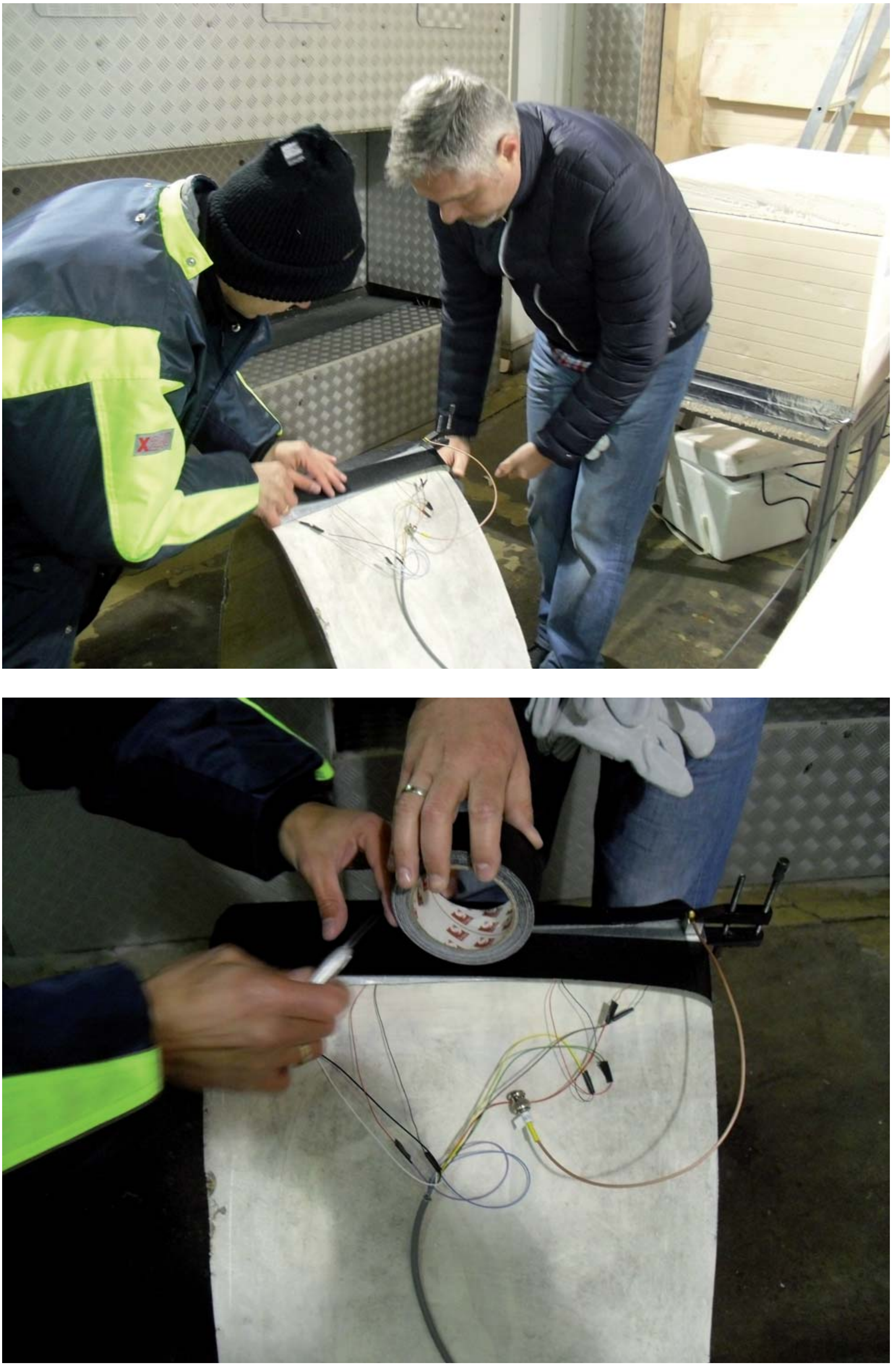

**Fig. 11. Curved aluminium shield mounted on the edge of the peace of the blade**
Rys. 11. Zakrzywiona osłona aluminiowa zamontowana na krawędzi fragmentu łopaty

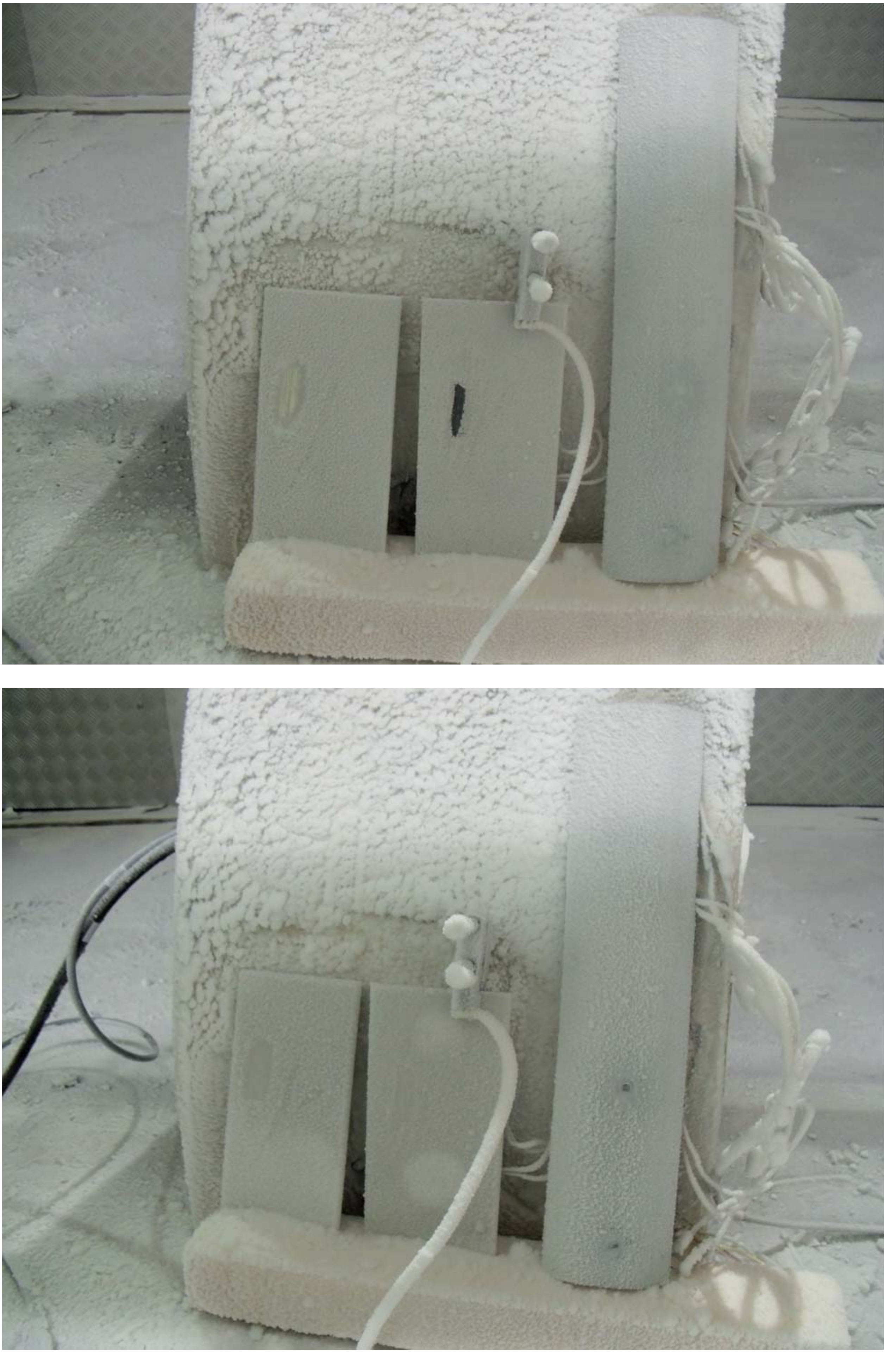

**Fig. 12. The aluminium shield with and without ultrasound transducers mounted on the blade edge**
Rys. 12. Osłona aluminiowa z i bez zamontowanych na krawędzi przetworników ultradzwiękowych

performed manually it was rather hard to form all of types of ice – the ice formation process are presented in Fig. 7.

Nevertheless, mainly two types rime (Fig. 8) and snowflakes – like snow (Fig. 9) of ice were formed dependently on the distance between the iced object and the nozzle of the water gun.

## 6. Results of Deicing

The method of deicing of the blade was based on using the shaker system. As described in previous chapters the shaker was mounted in the root of the blade. The rotating mass in the shaker was arranged in a way to avoid the destruction of the blade. After ice formation the shaker system was set in motion. Initially the operation with frequency used for simulations was validated. Not achieving as positive results as planned other operating frequencies were used for tests. The best results obtained led to cracking and removal of the rime ice type (Fig. 10). In this case small parts of the ice formed on the surface dropped from the blade. In case of snowflakes ice there was no visible effect of shaker system action.

## 7. Results of the Anti-icing System Operation

Anti-icing system was based on ultrasound transducers. As presented in previous reports of the consortium, after simulation research, it was decided to mount the matrix of for such elements on the aluminum shield. Shaped shield was mounted on the edge of the blade (Fig. 11). The validation of the SH-wave system was led on the basis of comparison between iced surfaces of the aluminum shield with and without operating transducers. Moreover, as proper mounting of the shield in such low temperatures was challenging, the anti-icing system was also validated using only the shield – not integrated with the blade edge (Fig. 12).

It was observed that using the ultrasound system it was not possible to prevent the ice formation. However, the ice formed in the face of operating anti-icing system is much more susceptible on mechanical removal. The ice formed on the shield with operating ultrasound transducers is characterized by thinner ice surface.

## 8. Summary

The tunnel trials were lead in order to verify the requirements of the project and technologies chosen for ice removal. The climate chamber trials allowed the validation of designed and built devices as well as general assumptions about the anti-icing and deicing methods. The supply system manages to operate in low temperatures (lower then –20 °C) and delivers requested supply signals with required parameters (frequency and voltage). Due to the manual ice formation method it was hard to validate the system for wide range of ice types and forms. For used ice types (rime and snowflakes) the deicing (shaker) system turned out to be effective in case of rime type of ice. In some cases the system allows only for breaking (cracking) of the ice but not for ice removal. In the case of the anti-icing system (ultrasound) the ice formed on the shield with operating transducers was characterized by weaker adherence of ice to the shield. Hence, it is proposed to use a combined anti-icing and deicing system to achieve expected results.

### Acknowledgment

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### References

1. Cattin Cattin R., Russi M., Russi G., Four years of monitoring a wind turbine under icing conditions, IWAIS XIII, 2009.
2. Homola M.C., Virk M.S., Nicklasson P.J., Sundsbø P.S., *Performance losses due to ice accretion for a 5 MW wind turbine*, "Wind Energy", Vol. 15, Iss. 3, 2012, 379–389, DOI: 10.1002/we.477.
3. Yun S.T., Sim J.M., Park J.H., Choi S.J., Cho B.H., *Adaptive Phase Control Method for Load Variation of Resonant Converter with Piezoelectric Transformer*, 7th International Conference on Power Electronics and Drive Systems, PEDS '07, Bangkok, 2007, 164–168, DOI: 10.1109/PEDS.2007.4487696.
4. https://www.boem.gov/Offshore-Wind-Energy/ (02.02.2017)

# System odmrażania oraz przeciwdziałania obladzaniu się łopat turbin wiatrowych. Podsumowanie projektu DeICE-UT – 7. Programu Ramowego Unii Europejskiej

Streszczenie: W artykule prezentowana jest koncepcja systemu odmrażania i przeciwdziałania obladzaniu się łopat turbin wiatrowych. Opisano główne komponenty systemu, m.in.: układy wykonawcze, system zasilania oraz komputerowy system sterowania. Zaprezentowano także wyniki, przeprowadzonej w komorze klimatycznej, walidacji systemu. W ostatniej części zebrano spostrzeżenia dotyczące efektywności działania systemu.

**Słowa kluczowe:** detekcja oblodzenia, usuwanie oblodzenia, system zasilania

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