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Subject: Addison Wind Energy LLC CUP – FOR THE RECORD
Risk of Wind Turbine Ice Throw & Required Safety Setbacks, Wind Turbine Ice Sensor Reliability, Wind Turbine Icing Safety Issues, and Adequacy & Safety of Current Wind Turbine Designs

Dear Attorney Riffle:

The purpose of this letter is to address the limited evidence presented by the Applicant on the following subjects:

- the risk of wind turbine ice throw & required safety setbacks,
- wind turbine ice sensor reliability,
- wind turbine icing safety issues, and
- adequacy & safety of current wind turbine designs

EXECUTIVE SUMMARY

The Applicant's limited evidence on each of these matters is not only incomplete an inadequate, but it is also highly misleading and ***directly contradicted*** by the wind industry's own research, investigation and authoritative technical papers that have been published and available since at least the mid-1990s. This evidence establishes the following:

1. The wind industry's *"authoritative ice throw guidelines"* recommend an ice throw risk of 10^{-6} –or one strike per million square meters per year. At this risk level, a minimum ice throw safety setback for a 50 meter rotor diameter wind turbine in heavy icing conditions is 400 meters (1,312 feet). For an 82 meter rotor diameter wind turbine in heavy icing conditions, the minimum ice throw safety setback is 656 meters (2,152 feet).

2. The wind industry technical research establishes that *"the reliable detection of ice is an indispensable requirement for the operation of wind turbines in cold climates."* However, the wind industry's studies over many years establish that de-icing and anti-icing systems have not proven reliable. In addition, the available ice sensors are not reliable. The wind energy technical papers report: *"It is important to produce definitions and specifications for measurement of icing and for ice sensors. This information is also required e.g. for safety standards of wind turbines."* In fact, standardized conditions for ice sensor design and calibration *"are not available yet and have to be defined."*

3. Wind turbines operating in cold climates present an inherent, significant and recognized public safety risk—and the scope of the risk is much broader than ice throw. Wind turbine icing, and the resulting unbalance, resonance, over power and fatigue, can affect the structural integrity of the wind turbine itself.

4. The technical literature raises serious and on-going questions about the adequacy and safety of current wind turbine designs. There are reportedly no structural safety design standards for wind turbines operating in icing conditions, notwithstanding the fact that 400 large wind turbines (500 MW) are operating in cold climates. The technical papers expressly state that it is up to the project developer and turbine buyer to ensure that the windmill is adequate for the site conditions.

    a. In 2000, wind industry technical research reported that *"there still is little knowledge of precisely [how] the turbine is loaded under icing conditions."*

    b. In 2001, the urgency of the design problem was noted: *"Monitoring the operation and loads of the large wind turbines is urgently needed in order to verify the design loads, not only concerning icing but also for wind farm and complex terrain operation."*

    c. In 2002, wind industry technical research reported that the wind turbine and component industry and operators are *"poorly aware"* about the occurrence and frequency of icing and lack knowledge about safety problems caused by icing especially iced blade safety problems.

    d. By 2003, not much had changed—wind industry technical research was still reporting that *"there is very little knowledge and data about the parameters needed to use the produced [theoretical ice and snow accretion on structures] formulas in the most proper way."*

    e. In 2003, it was also noted that atmospheric icing occurs during a much wider range of temperature and humidity than usually expected—which may lead to significant error in wind turbine design loads used in many countries. A 5-year, $4.3 million study was launched to address the many issues.

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A. THE RISK OF ICE THROW & REQUIRED SAFETY SETBACKS

As you know, during the Plan Commission's discussion of the Addison Wind Energy LLC CUP application, Chairman Bingen specifically inquired about the risk or probability of an ice throw or blade throw event. Interestingly, neither the Applicant nor any of the witnesses that the Applicant called to testify—*including both Foth & Van Dyke and NEG Micon*—have answered the question or provided the information and data that Chairperson Bingen specifically requested, notwithstanding the fact that this information is and has been readily available to those in the wind industry.

For example, attached as **Exhibit A** is a 1998 professional paper authored by Dr. Henry Seifert of Deutsches Windenergie-Institut (Germany) (Germany's Wind Energy Institute), and Colin Morgan and Ervin Bossanyi of Garrad Hassan and Partners Ltd. (UK). The title of the paper is: ***"Assessment of Safety Risks Arising from Wind Turbine Icing,"*** which was presented in April 1998 at BOREAS IV, a conference held in Finland every two years beginning in 1992. The BOREAS conferences (I in 1992 through VI in 2003) are part of an ongoing international effort to assess issues associated with wind turbine operation in cold climates, and icing in particular.

Dr. Henry Seifert, et al.'s April 1998 paper is particularly noteworthy for a number of reasons including the following:

1. The April 1998 paper was prepared by experts in the wind industry that have specifically studied—and are continuing to study—wind turbine icing;
2. In June 2003, the April 1998 paper was explicitly referenced by Mick Sagrillo, President and a founding member of the Midwest Renewable Energy Association (MREA) and a Wisconsin wind energy proponent. Mr. Sagrillo described the April 1998 paper as the *"one excellent paper done on the risk assessment of injury or property damage due to the shedding of ice;"*[1]

[1] http://www.awea.org/faq/sagrillo/ms_ice_0306.html Sagrillo, Mick. *"Home-Sized Wind Turbines and Flying Ice."* AWEA website. June 2003. Note, however, that Mr. Sagrillo references and mischaracterizes certain statements in the April 1998 paper. For example, Mr. Sagrillo states: *"The paper concludes that the risk of anything or anyone being hit by ice from a wind turbine is '10-6 strikes/m2/year, which is the typical probability of (being hit by a) lightning strike in the UK' (The authors are from the UK.)"* In fact, what the April 1998 paper concludes is that ***IF*** the appropriate safety setbacks (e.g., 400 meters in heavy icing conditions with a 50 meter rotor diameter turbine) are observed, ***THEN*** the statistical risk of ice throw is one event per million square meters per year. Mr. Sagrillo's article is highly misleading because it fails to make any mention at all of the critical and required safety setbacks necessary to achieve the statistical 10^{-6} risk level. Notwithstanding the wind industry's extensive and ongoing work on the issue of wind turbine icing and ice throws for more than 10 years (as will be described in detail in this letter) Mr. Sagrillo—without any evidence to support his claims—concludes with additional false, misleading and unsupported comments. Mr. Sagrillo attempts to dismiss the issue of wind turbine ice throw altogether and states: ***"Since it's essentially a non-existent problem****, there have been few studies of the ice throw scenario with wind farms..."*

3. In its October 11, 2000 CUP Application, FPL Energy alluded to the April 1998 article without either submitting it or directly referencing it.[2] Plan Commissioner Cheryl Vogt expressly referenced this information at the January 17, 2002 Addison Plan Commission meeting. She stated: *"If I could just read something quickly, tab 13.7 in the appendix, it says,* ***'The risk of being struck by ice thrown from a turbine is diminishingly small at distances greater than approximately 250 meters.'*** *That works out to 820 feet, and that's in their own application."*[3] The information referenced by Plan Commissioner Vogt also appears in the Abstract of Dr. Henry Seifert, et al.'s April 1998 paper. (Exhibit A, p. 113)

4. The work that gave rise to the April 1998 paper was undertaken *"in order to produce an* ***<u>authoritative set of guidelines</u>****" "for dealing with potential dangers arising from ice thrown off of turbines."* The paper noted that ***"there are currently [in 1998] no guidelines for dealing with potential dangers arising from ice thrown off wind turbines."*** (Exhibit A, at p. 113)

5. As noted in the April 1998 paper—the risk is ***<u>not</u>*** theoretical, and the safety guidelines were urgently needed: *"Indeed, the potential risk has recently attracted significant publicity in Germany, where a number of significant incidents have been reported in the past year, indicating an urgent need for suitable safety guidelines."* (Exhibit A, at p. 114)[4]

6. The April 1998 paper expressly describes the risk of wind turbine ice throw as follows: *"Under certain meteorological conditions, it is possible for ice accretion to occur on wind turbine rotors. The accretion process is no different to that experienced by many exposed structures although heavier accretion has been observed on wind turbine rotors.* ***<u>Fragments of ice will drop or be cast from the rotor when this ice melts or is shaken off the rotor</u>. In theory, these fragments may present a risk to the safety of the public or operational staff."*** (Exhibit A, at p. 119)

7. The April 1998 paper expressly states that ***"Developers and owners of wind turbines have a duty to ensure the safety of the general public and their***

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[2] October 11, 2000 FPL Energy Conditional Use Permit Application, Appendix 13.7.

[3] Transcript of January 17, 2002 Addison Plan Commission meeting at p. 173. See also my letter to you dated July 28, 2003 at pp. 4 – 5.

[4] Furthermore, it appears likely that catastrophic wind energy incidents are under-reported. For example, wind enthusiast, Paul Gipe, reported the following in the Autumn 2001 edition of WindStats: *"**As turbines become larger, the consequences of such catastrophic failures as throwing a blade raises the stakes for the public at large**. At the European Wind Energy Conference in Nice in 1999, the halls were a buzz with the news that several megawatt turbines had 'lost' a blade in Germany.* ***<u>The manufacturers of the turbines were understandably uncomfortable even acknowledging that the events actually happened</u>****."* See http://www.wind-works.org/articles/BreathLife.html

own staff." (Exhibit A, at p. 113) It sets out an "Allowable Risk of Ice Impacts on the Ground" and concludes: *"The level of risk which is acceptable should be determined. This is subject to case specific factors such as ease of access,* ***however a suitable level may be 10^{-6} strikes/m^2/year which is the typical probability of lightning strike in the UK."*** (Exhibit A, at p. 120)

8. The April 1998 paper then presents *Figure 3* which outlines the required safety distances for a number of different risk levels. (Exhibit A, at p. 120) At the authors' recommended 10^{-6} (one (1) ice throw event per million square meters per year) the required safety distance is **400 meters (1,312 feet)** in heavy icing conditions (5 to 25 days per year) and **350 meters (1,148 feet)** in moderate icing conditions (1 to 5 days per year)—for a **50 meter** diameter wind turbine. The paper expressly states that ***"the allowable risk should be scaled pro rata under different assumptions"*** (Exhibit A, at p. 120) such as larger or smaller wind turbines.

Based on the foregoing ***"authoritative ice throw guidelines"*** and expressly recommended level of acceptable risk, it is clear that the Applicant's proposed project ***does not*** comply with these guidelines based on the following undisputed facts:

a) The Midwest is recognized for its harsh winter weather conditions—which has historically been a deterrent to wind energy development.[5] The Applicant has not presented data or information regarding Wisconsin (or West Bend/Addison or the site's) average icing days[6]—however it would appear that Wisconsin experiences icing conditions on more than 5 days per year. As such, it appears reasonable that Wisconsin would be considered a "Heavy Icing" area (as defined in the April 1998 paper).[7]

b) Therefore, based on *Figure 3* (Exhibit A, p. 120) and given the Applicant's proposed ***82 meter*** rotor diameter wind turbine (and pro rata scaling), and the recommended risk level of 10^{-6} (one (1) ice throw event per million square meters per year) in Heavy Icing conditions, ***the required minimum safety setback is 656 meters (2,152 feet)***.

c) The Applicant's site plan reflects a proposed turbine location and setbacks that are significantly less than what is required pursuant to the wind industry's own ***"authoritative ice throw guidelines."*** For example, 600 feet from the

[5] Lacroix, Antoine and Dr. James F. Manwell. *"Wind Energy: Cold Weather Issues."* June 2000, p. 3.
[6] Apparently a tool for estimating the number of icing days and icing intensity at a given site is still not available. See April 2003 *"State-of-the-art of wind energy in cold climates"* by T. Laasko, et al., p. 25. http://www.vtt.fi/virtual/arcticwind/reports/state_of_the_art.pdf
[7] For background, see: Lacroix, Antoine and Dr. James F. Manwell. *"Wind Energy: Cold Weather Issues."* June 2000, p. 3, 8, 10.

> Ritger homestead, 430 feet from the west property line, 635 feet from the south property line and 690 feet from Mile Road, and just 100 feet from the boundary of the Addison Wind Energy LLC's leased property—*are just a fraction of the 2,152 feet required under the guidelines.*

In addition, it should be noted that Section 3.2 of Dr. Seifert, et al.'s April 1998 paper describes in some detail the ***"Method for ice throw trajectory prediction."*** (Exhibit A, at p. 118) For example, the paper expressly states that the authors have modeled the effect on the trajectory of *"**any radial sliding velocity developed by the fragment prior to release (<u>the 'slingshot' effect</u>).**"* (Exhibit A, at p. 118) As you will recall, the public submitted numerous questions during the testimony of Mr. Ainsworth of Foth & Van Dyke that were directed at ascertaining how, if at all, Foth & Van Dyke considered the "slingshot' effect in preparing its blade and ice throw calculations. ***For reasons that were not explained and that remain somewhat unclear, Foth & Van Dyke ignored the 'slingshot' effect.***[8]

In summary, the safety issues are clear. The safety setbacks embodied in the Applicant's proposed site plan do not comply with the wind industry's own "authoritative set of guidelines," and Foth & Van Dyke is not a wind energy expert, and its ice throw and blade throw calculations do not appear to conform to the principles set out in the wind industry's own "authoritative ice throw guidelines" and therefore should not be relied upon, and wind developers and wind turbine owners—and the Town of Addison—have a duty to preserve and protect the safety of the general public, and the safety issues and risks of the Applicant's proposed site plan are known, significant and unacceptable. On this basis alone, ***Addison Wind Energy LLC's CUP application must be rejected.***

B. WIND TURBINE ICE SENSOR RELIABILITY

As you know, during the Plan Commission's discussion of the Addison Wind Energy LLC CUP application, Ann Schmidt has repeatedly requested information regarding the reliability of the ice sensors that the Applicant has proposed in its attempt to mitigate the risk of wind turbine ice throw. Again, neither the Applicant nor any of the witnesses that the Applicant called to testify—*including both Foth & Van Dyke and NEG Micon*—have answered the question or provided the information and data that Mrs. Schmidt specifically requested, notwithstanding the fact that this information is and has been readily available to those in the wind industry.

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[8] It should be noted that Foth & Van Dyke's Mr. Ainsworth testified before the Addison Plan Commission. He testified that he had no prior experience with wind turbines. It remains unclear whether and to what extent, if at all, that either Mr. Ainsworth and/or others at Foth & Van Dyke made use of the wind industry's research information, data and papers relating to the risk and calculation of ice throw and blade throw.

Wind industry research establishes that: icing is a significant safety issue, wind turbine anti-icing or de-icing systems have not proven reliable over many years, icing of meteorological sensors is a significant source of error in measurements, recent research demonstrates that icing sensors are not reliable, on-going research is directed at producing definitions and specifications for the measurement of icing and for ice sensors—which apparently don't yet exist, and the potential consequences of wind turbine icing are significant.

1. **<u>Background of "Severe Weather Sensor" Research</u>**: Research in the area of "Severe Weather Sensors" ("SWS") apparently began in 1997-1998 with *"a first project conducted by FMI-SMI [Finnish Meteorological Institute and Swedish Meteorological Institute] in 1997-1998 to review the need for meteorological measurements in icing conditions and the available sensors."*[9] EUMETNET—The Network of European Meteorological Services[10]—began another SWS Programme in July 2000 to define field test procedures for sensors in icing conditions and to test a numbers of sensors at three sites in Finland, France and Switzerland.[11]

2. **<u>Wind Turbine Icing is a Significant Safety Issue:</u>** The April 2003 paper by Dr. Henry Seifert of Deutsches Windenergie-Institut in Germany, titled *"Technical Requirements for Rotor Blades Operating in Cold Climate,"* reiterates the significant safety issues associated with operating wind turbines in cold climates. This paper was presented in April 2003 at BOREAS VI and is attached as **<u>Exhibit B</u>**. It states:

    > *The safety of the wind turbine as well as the vicinity at the site will be also affected by icing or in general by cold climate operation. Ice fragments thrown away or even large ice pieces falling down from the rotor can harm persons or animals or damage objects. The structural integrity of the turbine itself can be affected by heavy unbalance due to unsymmetrical icing, by resonances caused by changed natural frequencies of components exceeding the designed fatigue loads. Low air density can*

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[9] http://www.eumetnet.eu.org/

[10] EUMETNET is a network grouping of 18 European National Meteorological Services. EUMETNET members are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. EUMETNET provides a framework to organise co-operative programmes between the Members in the various fields of basic meteorological activities such as observing systems, data processing, basic forecasting products, research and development, training. Through EUMETNET Programmes, the Members intend to develop their collective capability to serve environment management and climate monitoring and to bring to all European users the best available quality of meteorological information. They will use EUMETNET to make more efficient the management of their collective resources. See http://www.eumetnet.eu.org/

[11] http://www.eumetnet.eu.org/

increase the loads and maximum power output. If the turbine does not automatically react, windings or transformers may burn, gearboxes can be overloaded and damaged. (Exhibit B, at p. 2)

3. **Wind Turbine Anti-Icing and De-Icing Systems Have Not Proven Reliable Over Many Years:** The Abstract of Dr. Seifert's April 2003 paper (Exhibit B) establishes that reliable wind turbine anti-icing and de-icing systems do not exist.

   > *The increasing size of wind turbines up to the multi-Megawatt turbines and the increasing numbers of turbines being installed at inland sites even in complex terrain in mountainous areas require special equipment of the rotor blades.* ***However, a commercial serial-produced anti-icing or de-icing system has not yet been proved reliable over many years. Just the opposite is the case.*** *There have been reports about damages in prototype [blade] heating systems, and some manufacturers change to special coatings of the blade's surface instead of heating systems. Where are the problems in integrating heating systems into the highly flexible large blades? What methods are used today and which possible solutions can be taken instead?* (Exhibit B, Abstract at p. 1)

4. **Icing of Meteorological Sensors is a Significant Source of Error in Measurements:** Germany's National Meteorological Service, Deutscher Wetterdienst,[12] described the EUMETNET work and has expressly stated that icing is *"a significant error source for measurements"* and that *"many of these sensors do not fulfill the WMO [World Meteorological Organization] requirements for availability and accuracy under icing conditions."*[13]

   > ***Icing of meteorological sensors is a significant error source for measurements done within the network of national meteorological observation stations****, but also at many other meteorological stations operated by research institutes and companies. The request to understand the possible errors due to icing present at historical meteorological data and to be able to have ice-free sensors available is growing.*
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   > *EUMETNET, therefore, started a project to study icing effect on meteorological gauges and to produce specifications for ice-free sensors. Three test stations are established in Finland (Luosto), France (Mont Aigoual) and Switzerland (Mont Säntis) to experience a cold icing environment which sets different requirements for meteorological sensors. Today there are several types of so-called ice-free sensors - especially wind sensors - on the market.* ***However, many of these sensors do not***

[12] http://www.dwd.de/en/wir/allgemeines/allgemeines.htm
[13] http://www.dwd.de/EUMETNET/test_reports11.htm

> ***fulfill the WMO [World Meteorological Organization (A United Nations Specialized Agency)] requirements for availability and accuracy under icing conditions***. [14]

5. **Recent Research Demonstrates that Icing Sensors are Unreliable:** Dr. Henry Seifert's April 2003 paper (Exhibit B) demonstrates unequivocally that icing sensors on wind turbines are unreliable. For example, the paper presents information from different ice sensors and states: *"Recent [ice sensor] measurements at the Tauernwindpark [Austria]. . .compared with parallel observations and measurements of heated and unheated anemometers created some doubts about the trustworthiness of the sensors."* The Dr. Seifert's Conclusions and Recommendations include the following:

> *Until today there are no standard solutions available on the market to keep the rotor blades ice-free or at least solutions for reliable ice detection as an information for the turbines' supervisory system. Consequently, today's rotor blades should be designed for the operation with ice accretion if the turbine is situated at sites with the risk of icing. The changed aerodynamic loads as described in [6] as well as the changed mass loads shall then be taken into account in the load assumptions.* ***Provided that a reliable ice detector is available****, the turbine can safely be set to standstill if icing events occur and put in operation again after automatical sensing of ice-free conditions.* ***However, practical experience at the Tauernwind [Austria] showed that all sensing systems tested reported different "ice information."*** *A rather good instrument for detecting ice at the rotor blades seems to be a web-cam in the hub, as shown in Figure 15, where the pressure side of an iced rotor blade can be seen. As an ice detector the camera via the internet cannot be used efficiently, as it requires a manned campaign and good visibility also at night. . .* (Exhibit B, at p. 12)
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> *Reliable prediction of energy production and the fatigue loads on the turbine's components at inland sites can only be done* ***if ice detectors deliver exact information about icing****.* ***Also the control system of the turbines has to rely on sound information on icing situations in order to shut the turbine down or react in another way to prevent the surrounding or the turbine itself from harm and damage. The reliable detection of ice is an indispensable requirement for the operation of wind turbines in cold climates. These ice detectors and ice free wind sensors need standardized conditions according to which they can be***

[14] http://www.dwd.de/EUMETNET/test_reports11.htm

> ***designed and calibrated. These standard conditions are not available yet and have to be defined.*** (Exhibit B, at p. 13)
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> *In order to fit the turbine economically to the site reliable information about possible icing is necessary. An adequate instrumentation is therefore of fundamental importance.* (Exhibit B, p. 13)

6. **Ongoing Research is Directed at Producing Definitions and Specifications for the Measurement of Icing and for Ice Sensors—Which Apparently Do Not Yet Exist:** In 2003, a group of 11 European countries (Austria, Finland, France, The Czech Republic, Germany, Italy, Norway, Spain, Sweden, Switzerland, and United Kingdom) organized under the European Cooperation in the Field of Scientific and Technical Research's ("COST") "Concerted Research Action" designated as *"COST 727 – Measuring and Forecasting Atmospheric Icing on Structures."*[15] The project is a **5-year** project and has an estimated cost Euro 3.5 million (2003 prices) (**or approximately $4.3 million**[16]). *COST 727* (attached as **Exhibit C**) again noted that reliable ice sensors do not exist—and apparently definitions and specifications for ice sensors need to be produced. *COST 727* stated:

> *At the EU level, in-cloud icing and cold climate problems with respect to wind turbines and meteorological observations have been studied within the "Icing of Wind Turbines" and "Wind Energy production in Cold Climates [WECO]" projects, as well as within the current "New Icetools" project (ref: www.fmi.fi/research).* ***In these projects however, icing as a phenomenon, parameterisation of icing or development of proper icing sensors were not really addressed.*** *The impact of icing upon meteorological sensors was studied within the EUMETNET Severe Weather Sensors (the SWS II)- project.* ***Common to all these projects is a lack of proper observation of icing, icing rate and duration of icing, and low participation of persons/institutes with dedicated interest in the icing phenomenon***. (Exhibit C, at pp. 2 to 3)
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> ***The EUMETNET SWS II project proved that at present reliable equipment to measure atmospheric icing (freezing rain and in-cloud icing) do not exist***. *There are currently a few sensors available to detect icing, but there is a need to improve them, to inform manufacturers about requirements for icing measurements as well as occurrence and*

[15] 2003 *"Memorandum of Understanding for the Implementation of a European Concerted Research Action Designated as COST 727 – 'Measuring and Forecasting Atmospheric Icing on Structures,"* and Technical Annex to Cost 727. See http://cost.cordis.lu/src/doc/727_MoU_TA_3rd.doc

[16] Euro to US$ exchange rate of Euro 1 = US$1.23810; See http://www.x-rates.com/calculator.html

> *distribution of icing intensity. A very important result would be to produce verifications of representativity of sensors under typical icing conditions. There is also a need to include WMO's (World Meteorological Organisation) measurement requirements for icing measurements and acknowledge them in the Guide to Meteorological Instruments and Methods of Observation.* ***It is important to produce definitions and specifications for measurement of icing and for ice sensors. This information is also required e.g. for safety standards of wind turbines***. (Exhibit C, at p. 4)

7. **The Potential Consequences of Wind Turbine Icing Are Significant:** The International Energy Agency (IEA) commenced R&D Wind Annex XIX – *Wind Energy in Cold Climates,* in late-2001 which was organized to run 3 years.[17] The IEA collaboration was organized to address the fact that, *"at present quite little information on statistics on operation of wind turbines under icing conditions is available."* (Exhibit F, at p. 61) T. Laasko, et al.'s ***April 2003*** IEA publication *"State-of-the-art of wind energy in cold climates"* highlights the magnitude of icing-induced measurement errors and the potential consequences—which include catastrophic failure of the wind turbine:

> ***Up until this point not much attention has been paid to icing of the wind gauges in the wind energy sector even though anemometers and vanes are very sensitive to icing. This is surprising given the importance of wind speed measurement in siting and system control. Tests have repeatedly shown that a small amount of ice reduces measured wind speed significantly and large ice accretions may stop the anemometer entirely****. For example,* ***a small amount of rime ice*** *on the cups and shaft of an anemometer* ***may lead to underestimation in wind speed of about 30% at wind speed of 10 m/s. The level of underestimation depends entirely on severity of icing conditions. This decrease is more insidious as, without other monitoring equipment, there is no way to determine if a given anemometer is reading an accurate wind measurement. This may lead to an underestimation of the wind speed or the failure of a turbine to shut down in a high wind event****.* [18]

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[17] Lacroix, Antione. *"IEA Co-operation on Wind Turbines in Cold Climates and Icing Conditions."* The Yukon International Wind Conference, May 27, 2003. http://www.yec.yk.ca/wind/presentations/May%2027/Project%20Development%20&%20Success%20Stories%20II/IEA.Annex.XIX.Presentation.May.27.Lacroix.pdf

[18] Laasko, T., et al. International Energy Agency (IEA) R&D Wind Programme, Annex XIX – Wind Energy in Cold Climates. *"State-of-the-art of wind energy in cold climates."* April 2003, pp. 16 - 17. http://www.vtt.fi/virtual/arcticwind/reports/state_of_the_art.pdf The April 2003 Report is regarded as produced *"the state of the art for technology and policy on cold weather wind turbine systems."* One of the Annex XIX objectives is to *"Establish and present guidelines for applying wind energy in cold climates."* http://www.ieawind.org/summary_page_xix.html The cooperating countries in IEA's Annex XIX are:

In summary, the wind industry's own research demonstrates that wind turbine ice sensors are not reliable—and apparently, definitions and specifications for measurement of icing and for ice sensors, and standardized conditions for ice sensor design and calibration do not yet exist. Therefore, the Applicant's proposal to install an ice sensor is not a reasonable, adequate or acceptable means to address the inherent safety risks associated with locating the proposed wind turbine in close proximity to residents, homes, public roadways, and private property. In short, the proposed site is simply not suitable for the proposed wind turbine.

C. WIND TURBINE ICING SAFETY ISSUES

The word "icing" is used to describe the process of ice or snow growth on a structure exposed to the atmosphere. The potential for icing of structures is an important design parameter and is a relevant issue in activities related to wind energy production, ***"where the icing of blades and control wind gauges significantly reduces the power production and causes a severe environmental safety problem."*** (Exhibit C, at p. 2)[19]

There can be no dispute that wind turbine operation in cold climates and wind turbine icing presents a fundamental and significant public safety issue. As noted in **Exhibit D,** a 2001 paper by Dr. Bengt Tammelin of the Finnish Meteorological Institute (FMI) and Dr. Henry Seifert of Deutsches Windenergie-Institut GmbH (Germany) titled *"Large Wind Turbines Go Into Cold Climate Regions"* and presented at EWEC 2001 – Copenhagen [European Wind Energy Conference] on July 2 - 6, 2001: *"Icing of rotor blades or other wind turbine components lead to decreased production as a result of ice accretion or* ***safety demands****;* ***the rotor blades are not allowed to move if there is any danger of ice throw****."* (Exhibit D, at p. 1)

Wind turbines operating in cold climates presents an inherent, significant and recognized public safety risk—and the scope of the risk is much broader than the Applicant has suggested.

1. **The Risk of Ice Throw is Just One of Five *Safety* Risks Associated with Icing:** Dr. Bengt Tammelin's July 2001 paper (Exhibit D, at p. 1) notes that icing of wind turbines affects Wind Turbine Design, ***Safety*** and Economics of wind energy plants. In terms of ***Safety***, the following 5 points were noted:

    - **Ice throw** (ice fragments can harm persons and animals and damage property)

Canada, Finland, Norway, Sweden, Switzerland and USA (NREL). http://www.pwtcommunications.com/ieaexco/ExCo52/ApIAnxXIXrpt.pdf

[19] 2003 *"Memorandum of Understanding for the Implementation of a European Concerted Research Action Designated as COST 727 – 'Measuring and Forecasting Atmospheric Icing on Structures,"* and Technical Annex to Cost 727, at p. 2. See http://cost.cordis.lu/src/doc/727_MoU_TA_3rd.doc

- **Unbalance** (heavy unbalance due to unsymmetrical icing can affect the structural integrity of the wind turbine itself)
- **Resonance** (resonances caused by changed natural frequencies of components exceeding the designed fatigue loads can affect the structural integrity of the wind turbine itself)
- **Over power** (Low air density can increase the loads and maximum power output such that the power production ***exceeds*** the design maximum. If the turbine does not automatically react, windings or transformers may burn, gearboxes can be overloaded and damaged)
- **Fatigue** (the long-term effect of icing especially on blade fatigue)

2. **Wind Turbine Icing Can Cause Turbine Vibration and Structural Failure:** The nature of the safety risk was reported in T. Laasko et al.'s April 2003 article, *"State-of-the-art of wind energy in cold climates:" "large ice accretions may cause turbine vibration and structural failure. Ice pieces are also hazardous when they shed off the turbine blades with high velocity."*[20]

3. **Wind Turbine Icing Problems Are Recognized by U.S. Wind Energy Experts:** These issues are also discussed at length in the June 2000 White Paper – *"Wind Energy – Cold Weather Issues"* by Antoine Lacroix and Dr. James F. Manwell of the University of Massachusetts at Amherst – Renewable Energy Research Laboratory. (attached as **Exhibit E)**

4. **Reported Wind Turbine Safety Issues:** As noted previously, *wind turbine safety issues are **not** theoretical*. For example, the Archives & Collections Society (a not-for-profit foundation) in Ontario, Canada has reported some of the known wind turbine safety incidents:

   The rotor of a Vestas V80 turbine weighs 77,175 lbs., or a little over 35 tonnes, with a blade tip speed of 300 kph. The rotor blades sweep a surface area the size of a football field.

   When they have broken off they have planed up to 400 metres (9 Dec 1993, Cemmaes, Wales). At Tarifa, Spain, blades broke off on two occasions in Nov. 1995 - the first in gusty, high winds, the second in only light wind (Report, Windpower Monthly, Dec. 1995).

   In an article written in January 1996 Professor Otfried Wolfrum, professor of applied geodesy at Darmstadt University [Germany], wrote of a significant number of blade failures in Germany, detailing four particularly severe ones

[20] Laasko, T., et al. International Energy Agency (IEA) R&D Wind Programme, Annex XIX – Wind Energy in Cold Climates. *"State-of-the-art of wind energy in cold climates."* April 2003, p. 22.

> ***where fragments of blade weighing up to half a tonne were thrown up to 280 m.***
>
> ***The civic authorities in Palm Springs, USA, as early as the late 1980s made developers move turbines to a distance of half a mile from the highway for safety reasons****.*
>
> *Apart from the danger of blades becoming detached or disintegrating, there is a risk that lumps of ice can form, and then be thrown significant distances when the wind rises and the blades begin to move. Professor Wolfrum [Darmstadt University – Germany] wrote on this subject: '****Some ice layers 150mm thick have been detected and their mass has been as high as 20 - 23 kg/m' [Proceedings BOREAS II, Helsinki, 1994, p. 219]. He demonstrated that these fragments could travel up to 550 m and land with impact speeds of 170 mph. This has led to 'Falling Ice' warning notices at some wind turbine sites****.*
>
> ***In April 2000, three UK wind farms were reported as being closed for safety reasons, apparently because of metal fatigue in the turbine towers****. The sites in question are at Cold Northcott in Cornwall and Cemmaes and Llangwyryfon in Wales [38].*
>
> *The Countryside Agency has called for turbines to be sited away from bridleways - a distance of three times the height of the turbines normally and four times the height of the turbines near National Trails (height to blade tip) -* ***because noise and flicker can startle horses and endanger their riders and because of risk from thrown ice****. The British Horse Society has expressed similar concerns.*[21]

D. ADEQUACY & SAFETY OF CURRENT WIND TURBINE DESIGNS

The wind energy technical research papers raise serious and on-going questions about the adequacy and safety of current wind turbine designs. The problems are clearly articulated: there are no structural safety design standards for wind turbines operating in icing conditions, there is little knowledge of precisely how the turbine is loaded under icing conditions, verification of design loads is *"urgently needed,"* the wind turbine and component industry and operators are "poorly aware" about the occurrence and frequency of icing and lack knowledge about safety problems—especially iced blade safety problems, there is very little knowledge and data regarding the appropriate application of theoretical ice and snow load formulas—which may lead to significant error in wind turbine design loads used in many countries.

[21] See Archives & Collections Society website at: http://www.aandc.org/research/wind_pec_present.html

1. **The Rapid Increase in Wind Turbine Size Raises Serious Questions About the Adequacy and Safety of New Wind Turbine Designs:** Dr. Bengt Tammelin's July 2001 paper, *"Large Wind Turbines Go Into Cold Climate Regions,"* (Exhibit D) notes that the issues associated with wind turbine icing have increased as the size of the wind turbines have increased significantly. For example, 600 kW windmills were common in the mid-1990s. A few years later by about the year 2000, 1.5 MW machines were common. The July 2001 paper highlights the fact that *important information is still missing, including verification of design loads*—notwithstanding the fact that approximately 400 very large windmills (500 MW) have been designed, manufactured and are in operation in cold climates.[22] The July 2001 paper also notes that ice sensors located on the nacelle (similar to what the Applicant in this case has proposed) may not accurately predict icing at the outer part of the blades.

> *Figure 8 shows the development of sizes of commercially produced wind turbines within the last years in Germany, a tendency which can also be observed in other countries.* ***The growing size is also accompanied by growing rotor tip heights, <u>increasing the probability to scratch low clouds in wintertime</u> and thus, the possibility for icing even in flat terrain****. It might happen, that the ice sensors at the nacelle are not affected, but the outer part of the blades. Corresponding adaptation of the control system might avoid these effects. However, to increase and improve the exploitation of wind energy at cold climate regions in various parts of Europe* ***well documented demonstrations and full scale verifications of results achieved are still missing. <u>Monitoring the operation and loads of the large wind turbines is urgently needed in order to verify the design loads</u>, <u>not only concerning icing but also for wind farm and complex terrain operation</u>***. (Exhibit D, at pp. 3 – 4)

2. **The Wind Turbine Load Assumptions in "Many Countries" May Have Significant Error:** The 2003 COST "Concerted Research Action" (Exhibit C) Research & Development scope of work highlights the magnitude of the potential error and the extent to which the large wind turbines operating in cold climates are really ***"guinea pig" R&D experiments:***

> *A lot of theoretical work on ice and snow accretion on structures is available. However,* ***<u>there is very little knowledge and data about the parameters needed to use the produced formulas in the most proper way</u>****. There is also a lack of data on occurrence of atmospheric icing. It is obvious from preliminary data available from various parts of Europe that atmospheric icing occurs during a much wider range of temperature and*

---

[22] http://www.yec.yk.ca/wind/presentations/May%2027/Project%20Development%20&%20Success%20Stories%20II/IEA.Annex.XIX.Presentation.May.27.Lacroix.pdf (See map at p. 3.)

> *humidity than usually expected.* ***Thus, for instance, predictions of loads provided in many countries may lead to 1-2 decade errors at present***. (Exhibit C, at p. 6)

3. **The Fact is That the Wind Turbine and Component Industry and Operators are "Poorly Aware" About the Occurrence and Frequency of Icing and Lack Knowledge About Safety Problems Caused by Icing Especially Iced Blade Safety Problems:** Dr. Bengt Tammelin's (Finnish Meteorological Institute) August 21, 2002 article by titled: *"NEW ICETOOLS: Experimental Wind Energy Data from Cold Climate Sites in Europe,"* (attached as **Exhibit F)** supports this conclusion:

> *However, it seems that wind turbine and component industry, and operators are poorly aware about occurrence and frequency of icing periods in various parts of Europe, not only in far North but also in most southern parts. There also seems to be a* **lack in knowledge** *of technical solutions already available, experiences in operation of different types of turbines under icing conditions,* ***and also about safety problems caused especially through iced blades***. (Exhibit F, at p. 57)
>
> .
>
> .
>
> ***Several wind turbines have already been installed at ice affected cold climate sites with very poor information on climatic conditions and needs for specially designed turbines****, which has led to unsatisfactory and uneconomical wind power production.* ***Some sites also produce safety problems for the public***. (Exhibit F, at p. 57)

4. **There Are Apparently No Structural Safety Design Standards for Wind Turbines Operating in Cold Climates:** Shockingly, there are apparently ***no structural safety design standards at all for wind turbines operating in icing conditions***. In fact, based on Jonas Wolff's (VTT Energy – the leading wind energy research institute in Finland) paper titled: *"Icing in Standards"* (attached as **Exhibit G)** and presented at BOREAS V in December 2000, ***it is left up to the project developer and turbine buyer to determine the load conditions and whether the windmill is adequate for the site conditions***:

> *The current standard for structural safety issues presents wind turbine safety classes and load cases to be calculated. The standard defines operating conditions as 'normal' for temperatures down to -10°C and 'extreme' down to -20°C. Clearly, temperatures get lower in northern Europe and mountainous areas, not to mention more remote regions at high latitudes or elevations. The standard also introduces a set of wind*

> *turbine classes according to mean (or reference) wind speeds and turbulence levels.* ***All extraordinary sites, including offshore and icing conditions, belong to the special class S, in which load cases have to be agreed upon between the customer and the manufacturer. Thus the project developer and turbine buyer have to ensure that the product is adequate for the site conditions****. Further [the standard] presents partial safety factors and material factors to be used in the load and fatigue calculations.* ***As there still is little knowledge of precisely [how] the turbine is loaded under icing conditions the partial safety factors should probably be higher due to uncertainty. Some special load cases for icing conditions should be developed.*** *There should be a variety to the amount, distribution properties of accreted ice as some principal load imbalance cases.* (Exhibit G, at p. 2)

5. **Wind Turbine Certification for Cold Climate Operation Requires Reliable Procedures for Predicting Ice Load—Which at Present, Apparently Don't Exist:** Dr. Bengt Tammelin's August 2002 article (Exhibit F) raises serious questions regarding the design of current turbines and their suitability for cold climate operation. For example:

> ***Certifying wind turbines for cold and mountainous regions require reliable procedures for the prediction of ice amount during standstill and operation.*** *International design standards take icing load cases into consideration in different ways. The IEC-61400-1 ed2 Wind Turbine Generator Systems – Part 1 Safety Requirements recommends to take ice loads into account* ***but a special load case is not given****.* ***However, investigations concerning icing of wind turbines during operation at different places in Europe showed that heavy ice loads are not negligible****.* (Exhibit F, at pp. 61 – 62)

The August 2002 article concludes by stating:

> ***Icing of structures like wind turbines, wind sensors, power lines etc. is much more common in Europe than typically expected e.g. by wind power people****. Icing is not only a problem for the far north, but also for inland/mountainous sites in Germany, UK, Spain, Italy, Austria, and also in most of the new EU candidate states.* (Exhibit F, at p. 62)

* * *

In summary, the foregoing information clearly demonstrates both the inherent and significant public health & safety risk presented by wind turbines operating in cold climates, and the uncertainty in assessing and evaluating the risk. The risk of ice throw cannot be addressed by the Applicant's ice sensor proposal—because numerous studies establish that such sensors are unreliable, and definitions and specifications for ice sensors are still under development.

The risk is further compounded by the fact that there are apparently no structural safety design standards for wind turbines operating in icing conditions, little knowledge of precise turbine loading in icing conditions, and little awareness of the occurrence and frequency of icing and the safety problems caused by iced blades. The foregoing information also provides further rationale for conventional wind energy siting guidelines published by the National Wind Coordinating Committee (NWCC) (and others) that require that wind turbines only be sited in remote areas far from population centers and with limited human visitation. The Town of Addison is not such a place.

With this important information now before the Addison Plan Commission, the myriad risks and uncertainty presented by the Applicant's proposal and the proposed site plan are simply unacceptable. The Addison Wind Energy LLC CUP must be rejected.

In closing, I must say that it is shocking that none of the foregoing information was presented by the current Applicant or its witnesses (or by FPL Energy and its cadre of consultants in the previous matter). The lack of candor is stunning. It is unclear why Foth & Van Dyke's—the purportedly independent engineer—"literature review" did not turn up these publications. However, in view of the information presented in this letter, Foth & Van Dyke's failure (or refusal) to identify the scope of its alleged "literature review" and certify its blade throw and ice throw calculations (which I requested in writing on July 25, 2003 and again on December 7, 2003 in letters to Mr. Steigenberger) is indeed telling.

The Public deserves more. The Addison Plan Commission should demand more.

If you have questions or need additional information, don't hesitate to call me at 629-5375 or 414-732-5618. My fax number is 262-629-4190.

Sincerely,

Catharine M. Lawton

Cc: Donna Schneider – By Hand Delivery to Town Hall
Ellen Wolf – By Hand Delivery to Town Hall
Bob Bingen – By Hand Delivery to Town Hall
Addison Plan Commissioners – By U.S. Mail
Dennis M. Steigenberger, P.E., Foth & Van Dyke – By Facsimile (920) 497-8516

BOREAS IV 31 March - 2 April 1998, Hetta, Finland

ASSESSMENT OF SAFETY RISKS ARISING FROM WIND TURBINE ICING

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ABSTRACT

Developers and owners of wind turbines have a duty to ensure the safety of the general public and their own staff. However, there are currently no guidelines for dealing with potential dangers arising from ice thrown off wind turbines. This puts developers, owners, planning authorities and insurers in a difficult position. To rectify this situation, the work presented here has commenced in order to produce an authoritative set of guidelines. Initial work has resulted in the development of a risk assessment methodology which has been used to demonstrate that the risk of being struck by ice thrown from a turbine is diminishingly small at distances greater than approximately 250 m from the turbine in a climate where moderate icing occurs.

1 INTRODUCTION

The work presented here is being undertaken as part of a project entitled "Wind Energy in Cold Climates (WECO)" part-funded under contract JOR3-CT95-0014 of the Non-Nuclear Energy Programme managed by the European Commission, DGXII, and by the UK Department of Trade and Industry. This project is being co-ordinated by the Finnish Meteorological Institute with DEWI (D), Garrad Hassan (UK), Risø (DK) and VTT (FI) as contractors. The project also involves associate contractors and subcontractors from many other European countries. The WECO project has three central objectives:

- To refine current assessments of the European wind energy resource through development of ice maps for the constituent countries.

- To identify methods for the improvement of the performance of wind turbines and anemometry technology in ice-prone climates and to quantify the cost implications of these methods.
- To produce safety guidelines for wind developments in ice-prone areas.

The work presented here addresses the last of these and has been motivated by an absence of authoritative reference material on the subject when it is raised as a concern by planning authorities and neighbours to proposed wind turbine developments. The findings of this research have been previously published [1,2] and this paper aims to summarise and update those previous publications. The lack of previous work by others on the subject may reflect the fact that there has been no reported injury from ice thrown from wind turbines, despite the installation of more than 6000 MW of wind energy world-wide. In addition, relatively few turbines have been installed in climates where icing is a serious problem. That situation is rapidly changing as extensive development of the wind resource in many Northern European countries has now commenced. Indeed, the potential risk has recently attracted significant publicity in Germany, where a number of significant incidents have been reported in the past year, indicating an urgent need for suitable safety guidelines.

2. THE PHENOMENON OF ROTOR BLADE ICING

Under icing conditions, all exposed parts of the wind turbine are liable to ice build-up. However, it has been observed that a moving turbine rotor is liable to accrete significantly heavier quantities of ice than stationary components for reasons which are explained below. Furthermore, the rotor blade ice has the potential to be cast some distance from the turbine if it breaks off a rotating blade. It is these aspects which set rotor blade icing apart from icing of stationary turbine components or indeed any stationary structure, and make it worthy of research.

There are several mechanisms of ice accretion on structures. The most important of these, for wind turbines, is rime icing which occurs when the structure is at a sub-zero temperature and is subject to incident flow with significant velocity and liquid water content. The precise deposition mechanism is the subject of ongoing experimental and theoretical research. However, the authors have a substantial body of field observations which has played an important role in the work reported here.

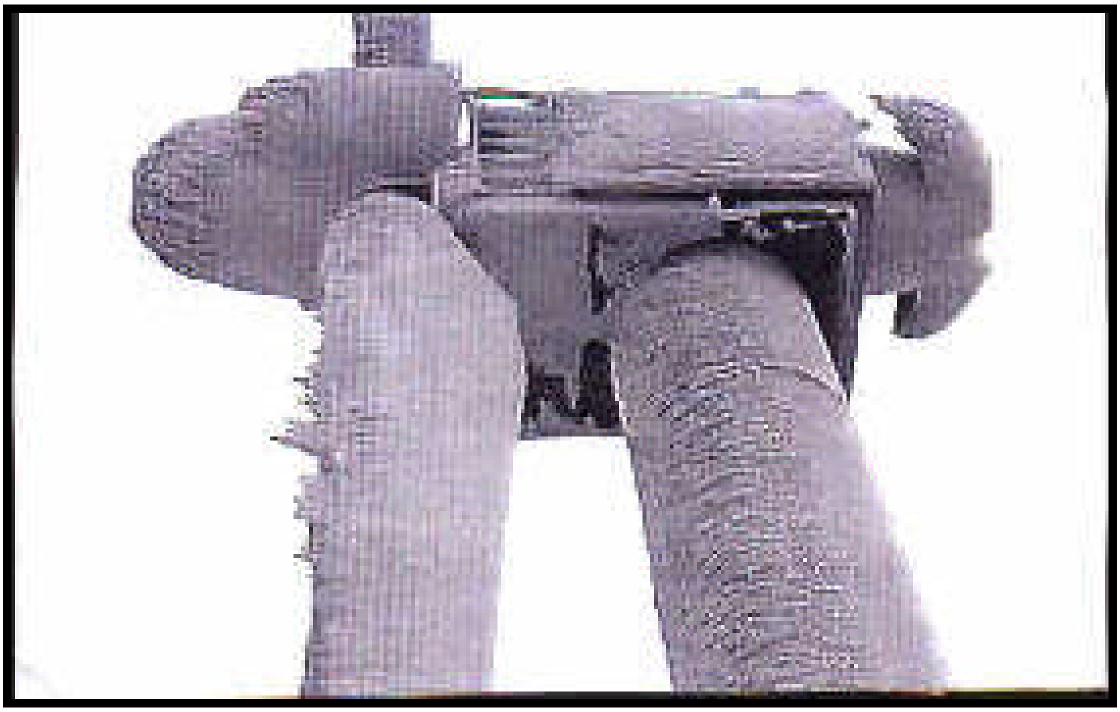

Figure 1 Heavy ice accretion on a 300 kW wind turbine rotor

A typical example of heavy rime icing on a wind turbine rotor is shown in Figure 1. It can clearly be seen that the heaviest ice build-up is at the tip of the blade but what is surprising is the amount of accretion with a chordwise thickness of up to about 0.5m. The build-up at the root of the blade is much less severe compared to nearby stationary structures.

The rime build-up is quite hard but it is also less brittle than might expected and remains attached to the rotor under significant flexure of the blades. Field observations indicate that most ice shedding occurs as temperatures rise and the ice thaws from the rotor. A typical scenario is that ice builds up on the rotor and on the wind speed and direction sensors which are mounted on the nacelle. Sensor malfunction causes automatic turbine shutdown. In this situation, most turbines will restart only when the ice has thawed and fallen from the stationary turbine which the operator then resets. However it is common practice for the operator to accelerate the process by thawing the sensors and restarting the turbine with ice still on the rotor. This circumstance has been observed to lead to heavy shedding of ice.

As regards the size of ice fragments shed from rotor blades, their mass and the distance which they are cast, there is very limited objective and subjective information. The only objective source of information is that collected in the recently completed EU Joule project "Icing of wind turbines", also funded by DGXII. As part of this work, carried out by DEWI and FMI, a questionnaire was circulated to a large number of turbine operators as described by Seifert [3]. The questionnaire asked for information on the occurrence of icing including mass and location of any observed ice debris flung off the rotor. The distribution of this questionnaire has continued as part of the WECO project.

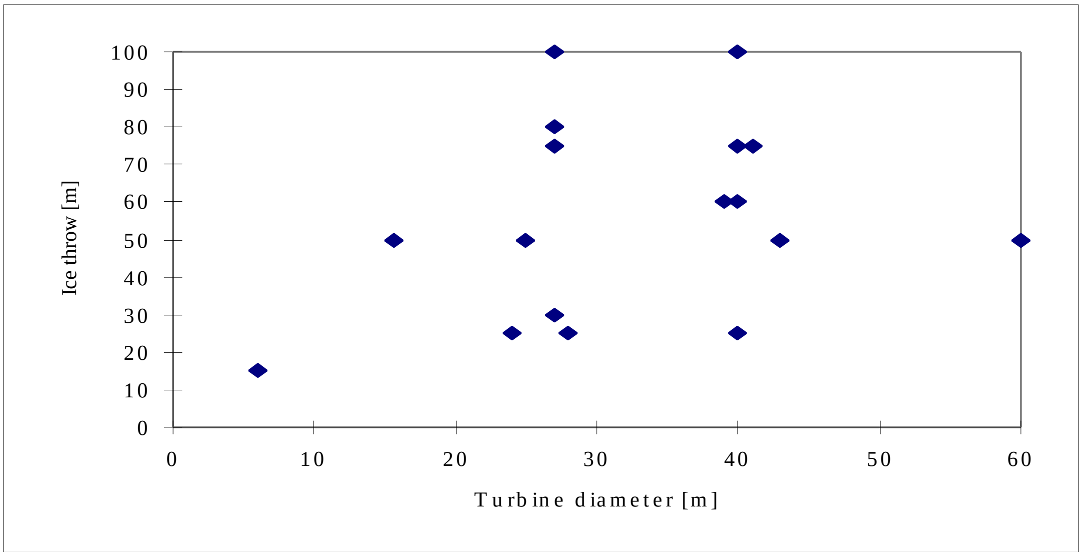

Figure 2 Ice throw data collected by icing questionnaire

Figure 2 summarises the data collected so far, as supplied by DEWI [4]. The data presented in Figure 2 show that most fragments which were found on the ground were estimated to be in the range 0.1 to 1 kg mass and were found 15 to 100 m from the turbines. Of course these figures must be taken as very approximate, and it is not possible to know how well the ground was searched especially at larger distances from the turbines.

In addition to this objective information, anecdotal evidence suggests that the tendency is for ice fragments to be dropped off, rather than thrown off, the rotor. Also, it tends to be shed off the tips in preference to other parts of the blade and large pieces of debris tend to fragment in flight. There is significant evidence that rime ice continues to form when the turbine is operating and is not shaken off by blade flexing, even though this may be the case for other types of ice formation. Also, rime ice formation appears to occur with remarkable symmetry on all turbine blades with the result that no imbalance occurs and the turbine continues to operate.

3. MODELLING OF ICE THROW

3.1 Aspects to be modelled

The risk of a person being hit by a fragment of ice thrown from an operational wind turbine depends on the following factors:

- The probability of the turbine having ice build-up on the blades
- The likelihood of ice fragments becoming detached from the blade, which is undoubtedly a function of radial position on the blade and on blade azimuth. It may also depend on the speed of rotation of the blades, as well as on blade pitch, blade profile and flexibility.
- The point where the detached ice fragment lands, which also depends on the radial position and azimuth at the time of becoming detached, and on the rotor speed and wind speed. The speed of the fragment at the end of its trajectory is also of interest, and this depends on the same factors.
- The probability of the person being in an area of risk and any safety precautions taken.

3.2 Method for ice throw trajectory prediction

While little is known about the probability of ice fragments becoming detached from various parts of the blade, it is relatively easy to calculate the distance travelled and the final velocity of the fragment once it has become detached, assuming that it does not break up in flight. A method for doing this has been developed as part of WECO and has been previously described by the authors [1,2]. This model has been further developed and now includes modelling of the effect on the trajectory, of:

- Blade azimuth at the instant when the fragment is released
- Radial location of the fragment on the blade at the instant of release
- Any radial sliding velocity developed by the fragment prior to release (the ‘slingshot’ effect)
- Turbine dimensions and rotor speed
- Gravity
- Fragment dimensions
- Aerodynamic drag
- Aerodynamic lift
- Mean downstream wind speed

3.3 Calculating the risk at a given distance

In practice the ice fragments shed from a turbine will follow a whole range of trajectories depending of the mass and shape of each fragment, the wind speed and direction, the point on the rotor at which the ice is released, etc. As previously described [1,2], Monte-Carlo simulation is used to generate a large number of possible trajectories and the probability of each one, so as to arrive at an assessment of the risk of ice fragments landing in any particular square metre of ground area.

4. GUIDANCE IN RISK ASSESSMENT

It is possible that guidelines for use by developers and planning authorities should take the following format:

A. Public safety and turbine icing - background information.

i. Under certain meteorological conditions, it is possible for ice accretion to occur on wind turbine rotors. The accretion process is no different to that experienced by many exposed structures although heavier accretion has been observed on wind turbine rotors.

ii. Fragments of ice will drop or be cast from the rotor when this ice melts or is shaken off the rotor. In theory, these fragments may present a risk to the safety of the public or operational staff. This risk can be assessed and mitigated by steps given below.

iii. When more than a few metres from the turbine, the risk of ice landing at a specific location is found to reduce quite quickly with the distance of the location from the turbine. It is also found that ice falls predominantly downwind of the rotor plane.

iv. Fragments of ice have been observed to have masses in the range of less than 1 kg.

v. As operational staff work more regularly and in closer proximity to the turbines, they can be exposed to more risk than members of the public.

B. Assessment of risk

It is proposed that the risk assessment should be undertaken in three stages:

i. Occurrence of icing conditions

An estimate should be made of the time (number of days per year) during which icing conditions occur at the turbine site:

- **“**Heavy icing” - more than 5 days, less than 25 days icing per year.
- “Moderate icing” - more than 1 day, less than 5 days icing per year.
- “Light icing” - less than 1 day icing per year.
- “No icing” - no appropriate icing conditions occur.

The method for this estimation is the subject of another aspect of the WECO project [5]. To state the obvious, if the site falls within the “No icing” category, it can be assumed that no risk exists and no further assessment is required.

ii. Allowable risk of ice impacts on ground.

The level of risk which is acceptable should be determined. This is subject to case-specific factors such as ease of access, however a suitable level may be 10^{-6} strikes/m^2/year which is the typical probability of lightning strike in the UK [6].

iii. Determine safety distance.

Use data presented in Figure 3 to determine the safety distance for the chosen level of allowable risk. Clearly the smaller the level of risk which is to be tolerated, the greater the safety distance which must be allowed.

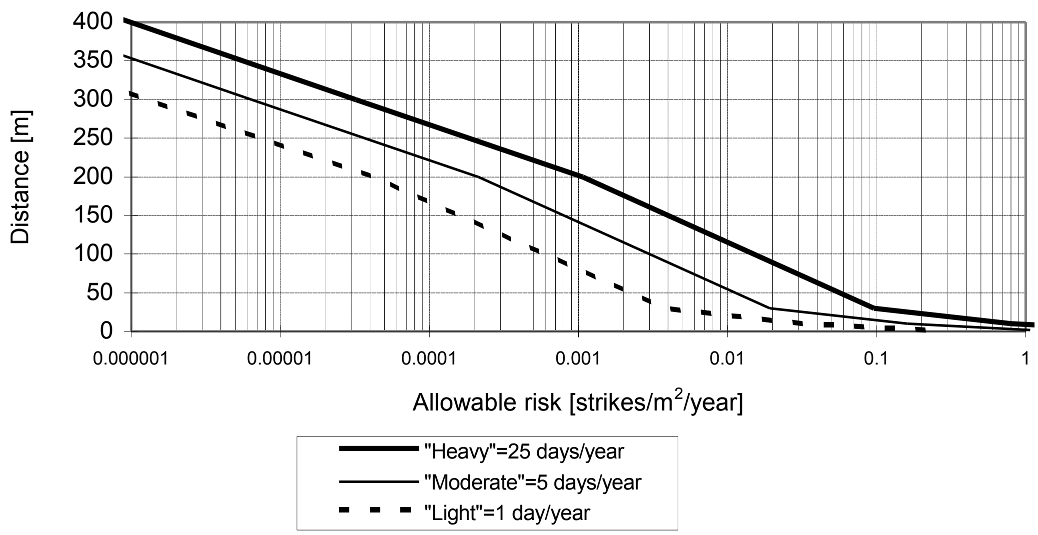

Figure 3 Safety distance for different icing levels (50m rotor)

Figure 3 is based on a rate of ice accretion averaging 75 kg/day during icing conditions, a figure which has been estimated for a 3-bladed turbine of 50m diameter. The allowable risk should be scaled *pro rata* under different assumptions.

5. MITIGATION OF RISK

In a situation where a significant risk to the public or operational staff is believed to exist, the following measures are suggested:

i. Curtailing operation of turbines during periods of ice accretion.

ii. Implementing special turbine features which prevent ice accretion or operation during periods of ice accretion.

iii. Re-siting of the turbines to remove them from areas of risk.

iv. The use of warning signs alerting anyone in the area of risk.

v. Operational staff should be aware of the conditions likely to lead to ice accretion on the turbine, of the risk of ice falling from the rotor and of the areas of risk.

6. ACKNOWLEDGEMENTS

This work was carried out with financial support from the European Community under the Non-Nuclear Energy Programme, contract no. JOR3-CT95-0014, and from the UK Department of Trade and Industry.

7. REFERENCES

[1] E.A. Bossanyi and C.A. Morgan, ‘Wind turbine icing - it’s implications for public safety’, 1996 European Union Wind Energy Conference, H.S. Stephens & Associates.

[2] C.A. Morgan and E.A. Bossanyi, ‘Wind turbine icing and public safety - a quantifiable risk?’, Wind Energy Production in Cold Climates, Bengt Tammelin Kristiina Säntti, 1996.

[3] H.Seifert, "Glacial period for rotor blades", DEWI Magazine No. 8, February 1996.

[4] Private communication from H.Seifert, DEWI to E.Bossanyi, Garrad Hassan 20 February 1996.

[5] Tammelin and Santii, Estimation of rime accretion at high altitudes - preliminary results, Wind Energy Production in Cold Climates, Bengt Tammelin Kristiina Säntti, 1996.

[6] J.F.MacQueen et al, "Risks associated with wind-turbine blade failures", IEE Proceedings Vol. 130 Pt. A No. 9, December 1983.

TECHNICAL REQUIREMENTS FOR ROTOR BLADES OPERATING IN COLD CLIMATE

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ABSTRACT: The increasing size of wind turbines up to multi-Megawatt turbines and the increasing numbers of turbines being installed at inland sites even in complex terrain in mountainous areas require special equipment of the rotor blades. However, a commercial serial-produced anti-icing or de-icing system has not yet been proved reliable over many years. Just the opposite is the case. There have been reports about damages in prototype heating systems, and some manufacturers change to special coatings of the blade's surface instead of heating systems. Where are the problems in integrating heating systems into the highly flexible large blades? Which methods are used today and which possible solutions can be taken instead? Starting with the various shapes of leading edge icing, trailing edge icing and blade surface icing, special strategies of operation for different control systems such as pitch, stall and active stall controlled turbines are discussed. Recommendation is given how to optimise the operation strategies of the supervisory systems of the various types using blade heating or not. Also the affect of icing on the rotor blades properties like its natural frequencies and on the blade fatigue and ultimate loads are discussed. Guidance is given which ice fragments at which rotor blade size have to be taken into account for ice throw calculations.

1. Introduction

Wind turbines are increasingly erected at inland sites as the coastal areas are already used for wind energy and the offshore projects are still under development for the next years. Furthermore, today's serial produced turbines easily reach lower clouds at winter time even close to the sea coasts. How future large offshore plants will be affected by icing events is not clear at the moment, as the necessary information and meteorological measurements at various offshore sites are not yet available.

Inland sites and especially sites in mountainous and northern regions as well as large turbines will be affected by ice during standstill and operation [1]. The first large wind farms such as the Tauernwindfarm in Austria have been commissioned and first operation results are now available (www.tauernwind.com [2]). Prototypes of wind turbines up to the Megawatt scale have been equipped with blade heating systems with special sensors and other features in order to fit the turbines to cold climate sites. However, no standard cold climate serial produced wind turbines are available on today's market. This paper summarises and discusses technical solutions and gives guidance on the systems which can be used for the various cold climate conditions.

2. Cold climate site effects on the design of a wind turbine

Cold climate sites will affect the design of a wind turbine in different ways: Ice and rime as well as high air density at low temperatures will cause severe effects on the aerodynamics and thus, on the loads and the power output of the turbine. Temperature effects and especially high masses of ice on the structure can change the natural frequencies of wind turbine components and change the dynamic behaviour of the whole turbine. Also, the control system can be affected. The stall of the rotor may occur earlier or later due to changed airfoil shape, the electrical or hydraulic pitch control can change their settings. Frozen or iced control instruments give faulty information to the supervisory system of the turbine. Extreme low temperatures will require special materials. For example normal steel will become brittle at those temperatures.

The safety of the wind turbine as well as the vicinity at the site will be also affected by icing or in general by cold climate operation. Ice fragments thrown away or even large ice pieces falling down from the rotor can harm persons or animals or damage objects. The structural integrity of the turbine itself can be affected by heavy unbalance due to unsymmetrical icing, by resonances caused by changed natural frequencies of components exceeding the designed fatigue loads. Low air density can increase the loads and maximum power output. If the turbine does not automatically react, windings or transformers may burn, gearboxes can be overloaded and damaged.

Also the overall economy of wind energy projects will be affected by cold climate operation, especially at ice endangered sites. The site prognosis has to include type and duration of icing events, the frequency distribution of the temperature has to be known in correlation to the wind situation in order to predict the energy production as well as down times due to icing. Possibly, a special class of cold climate turbine has to be defined, as the standard IEC classes 1 to 4 will not apply at those sites. This may require special equipment of the turbines such as heating elements for the blades, heating of gear boxes and electronic boards, use of special steel for extreme low temperatures, heated wind vanes and anemometers or special ice sensors. Special requirements for maintenance and repair at cold climate sites should be taken into account even during the planning phase and during the calculation of the economics of the project. Access to the site during the cold period may be very difficult or costly. The access to the site may be impossible if the roads are iced or full of snow for longer periods. In these conditions the erection, maintenance or repair of the turbine will be not possible or will produce long standstill periods without power production.

Measurements with heated anemometers seem to be erroneous and measurements with unheated sensors seem to underpredict the extreme wind speeds which may occur in the high mountains mostly in combination with icing events as been seen in the measurements at the Tauernwindfarm [2]. In the ice map for Europe [1] areas have been catalogued according to the number of icing days such as no icing, rare icing and frequent icing. However, this can only be a first step for a more precise assessment of cold climate identification.

Even the national or regional legislation could affect a wind farm project as building permission can require certain distances to roads and objects for safety reasons due to ice throw.

3. Definition of cold climate sites

How can icing at a specific site be detected? The standard weather observation by the meteorological services does not deliver all information to enable a reliable prediction of icing events in quality and quantity as documented in [1] for many sites in Europe. Additionally, to the wind, air pressure, air temperature, and humidity, which are the standard quantities to be observed at the weather stations, the height of the clouds and the liquid water content should be known. As this is not be done at the stations, other indicators have to be found to get an idea about icing event at the prognosis sites.

Ice detection by observation

One of the possibilities to detect ice is the observation of already installed wind turbines, power lines, trees or high antenna towers in the neighbourhood of the planned site. Ice fragments found on the ground close to wind turbines as shown in **Figure 1** and **Figure 2** after icing events, reports from utilities about frequent damages of power lines due to icing, forestry experts reporting of damages due to rime ice will be useful indicators for the quality and frequency of icing events. Reason for these icing events can be undercooled fog occuring during wind speeds suitable for energy production. Also, low clouds will cause so-called in-cloud icing at large wind turbines, the top rotor position of which can easily reach the clouds where the undercooled water will cause ice accretion at the leading edge.

Figure 1 Typical ice indicators: From the left, iced power lines, lightning conductor, grass on the ground, rime ice fragment from a rotor blade found on the ground.

Figure 2 Typical ice fragments taken from rotor blades or found on the ground. From the left: Glace ice origin from the rotor of a MW turbine, glace and rime ice from a 500 kW turbine.

During the operation a properly installed digital camera storing hourly pictures which can be also downloaded via the internet proved to be a quite reliable instrumentation to detect icing events as shown in the Tauernwind project (www.tauernwind.com [2]).

Ice detection by sensors

However, ice detection by observation needs manned campaigns and is thus extremely expensive, especially a continuous observation also at night. Ice sensors seem to be a solution for an automatic and reliable ice detection. This can be performed either by special ice sensors directly or by recording of standard instruments indirectly. For the first choice commercially available instruments can be used and first tests are reported in [1]. Recent measurements at the Tauernwindpark (left side and top of right side of Figure 3) compared with parallel observations and measurements of heated and unheated anemometers created some doubts about the trustworthiness of the sensors.

Figure 3 Direct and indirect ice sensors

First long term measurements with two types of anemometers - a heated and an unheated one - at the Tauernwindpark showed ambiguous results during icing events or snow fall at very low temperatures as described in [3] and shown in Figure 4. The example shows a measurement of the wind speed at hub height at the Tauernwindpark in Austria by using a heated (including cups) and a non-heated anemometer. The meteorological situation could be identified by recording the temperature and pictures from the site with a webcam (time series in 20 minute intervals). The left picture shows an icing event where the heated anemometer shows higher wind speeds than the unheated, which is expected. On the next day the temperature dropped to several degrees below zero and heavy snow fall started, combined with wind speeds up to

15 m/s. On the heated anemometer the snow melts on the hot cups and the water is transported by centrifugal forces to the outer part of the cups. The “forced convection” caused by the low temperature and the high wind speed let the melted snow immediately “re-freeze” on the outer radius. The resulting higher inertia and drag causes lower rotational speed of the anemometer and therefore faulty wind speed indication. On the other hand, the unheated anemometer remains cold. The snow hitting the cups does not melt and is reflected at the cups’ surface and thrown off by the centrifugal forces. Thus, no big effect on the wind speed measurement is recognised which is seen in the right side of Figure 4 where the unheated anemometer shows much higher wind speed compared to the heated one. In the middle of the Figure it can be seen that without icing or precipitation the two anemometers record the same wind speed. Consequently, ice detection by using a heated and a non-heated anemometer should be used cautiously as an indicator for icing events.

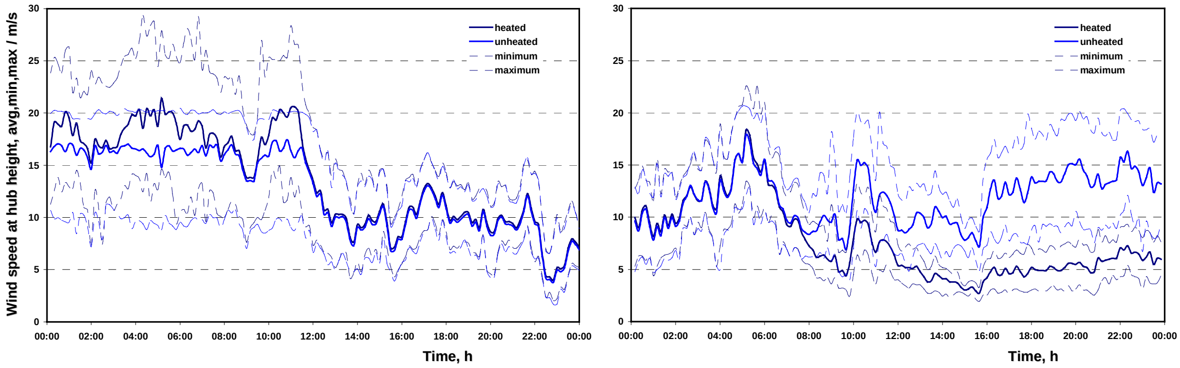

Figure 4 Example for a two days wind speed measurement at Tauernwind. 10 - minute averages, minima and maxima of the heated and non-heated hub height anemometers.

Ice detection by aerodynamic noise

Another detection of even small amounts of ice accretion can be the increase of aerodynamic noise from the rotor blades. Figure 5 shows a measurement during the beginning of slight icing at the leading edge and the resulting increase of noise as well as the shift of the frequency to higher levels (small graph).

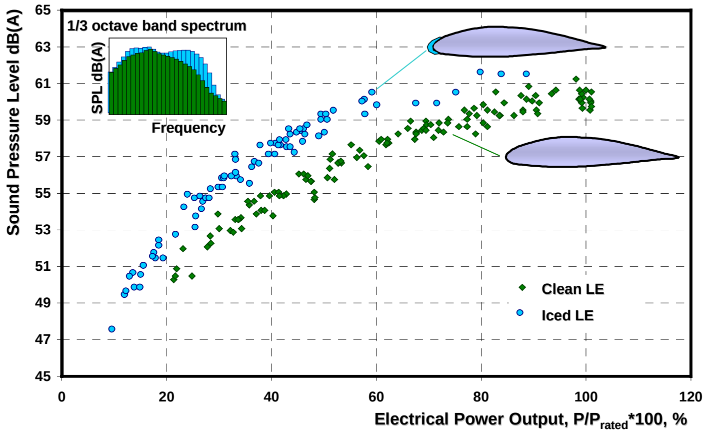

Figure 5 Acoustic noise measurement: Sound pressure level versus the normalised power output during beginning of slight icing conditions (LE = leading edge).

The disturbed aerodynamics result in fully turbulent boundary layer from the leading edge on and thus produces a higher noise and frequency level which can be heard clearly.

Ice detection by detection of damages such as break down of meteorological masts or power lines due to buckling and possibly resonances of the structures caused by the high additional masses should be an exception, but can be an additional indicator at sites, where heavy icing is not expected.

4. Strategies

Various strategies of operating a wind turbine at ice endangered sites can be selected. The first parameter is the expected duration of icing. It is obvious that at sites where icing events are unlikely, no strategy is necessary. At sites where ice events will occur rarely, such as some days in a year, it is recommended to detect the icing events either by using ice free anemometers and vanes combined with temperature measurements and power curve observation, or to install one ice sensor per farm. During the icing events the turbine can either operate, idle or be stopped, depending on the situation at the site (close to roads or objects). It has to be defined under which circumstances the turbine may restart after icing events, automatically or only after a visual inspection.

At sites with a high probability of icing - e.g. several weeks per year - an active or passive de - icing or anti - icing system for the rotor blades is recommended. At many sites in northern Europe the wind speeds during the icing season are relatively high so that long down times due to iced rotor blades will cause high losses of production.

Types of rotor blade icing

Figure 6 Typically iced rotor blades, here examples at MW turbines. The leading edge contour is marked by the white line.

During the rotation of the rotor blades in icing weather conditions the leading edge of the rotor blade collects more and more ice around the stagnation point of the airfoils. Due to the increasing air velocity along the radius, the ice accretion builds up more at the outer part of the blade with an approximately linear increase which is depicted in **Figure 6**. In principle, two types of icing during operation can occur, clear ice and rime ice. The right sketch in **Figure 7** shows the situation of a cross section of a rotor blade during operation with ice accretion at the leading edge. The cross section area increases as the “chord length” of the airfoil grows. Aerodynamic forces act on the ice fragment and - if too large - breaks it off. New ice builts up and the leading edge will look like a saw blade after some time.

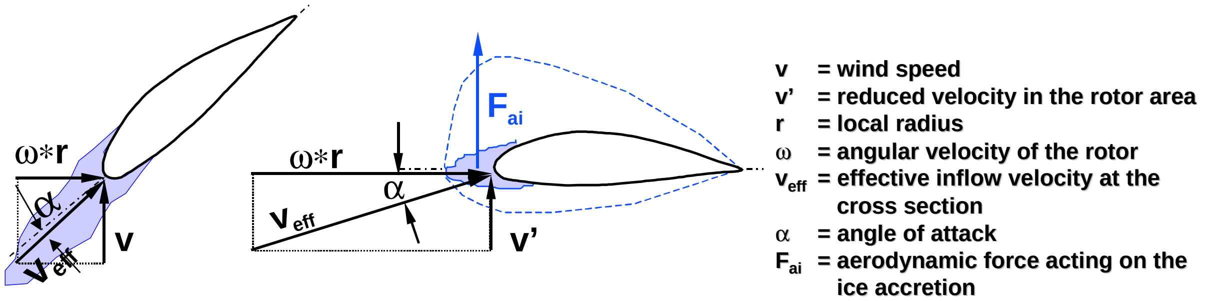

Figure 7 Icing at leading edge at different modes of operation. Left side idling, right side power production.

The left side of the Figure **7** shows the situation at low wind speed when the turbine is idling. Here the aerodynamic forces on the ice fragment are very small and no centrifugal forces will act on it as the rotor speed is close to zero. The shear forces between the ice and the blade’s surface are small and the ice can build up to a large amount at the leading edge as shown in Figure 8 where the ice piled up during idling. The middle of the Figure shows the three rotor blades of the same pitch controlled turbine during operation. The ice at the leading edge has been thrown off close to the tip unsymmetrically resulting in an aerodynamic and mass imbalance.

Figure 8 Leading edge ice accretion during idling (left side), unsymmetrical icing at a 3-bladed rotor during operation (middle) and saw blade-like ice accretion (right side).

5. Removing ice from the rotor blade

Two types of systems to prevent wings from icing are known in the field of aviation. **De-icing** systems and **anti-icing** systems, where the first one actively removes the ice from the wing and the second one prevents the wing from icing. Also in the wind energy these two concepts have been tested at prototypes and small serial production lines.

As anti-icing systems so-called **passive systems** are used for example in painting the rotor blades black. The advantage is that at daylight the blade heats up and the ice melts earlier than with white painted blades. However, in summertime the temperature of the blade's surface may affect the material properties of the glassfibre reinforced plastics (GRP), which is sensitive to high temperatures.

Also special coatings which shall reduce the shear forces between the ice and the blade's surface are put to the test as at one of the Tauernwind turbines. Tests of different coatings have been performed in the Kanagawa climatic wind tunnel and reported at the BOREAS 6 conference [4]. The advantages of coating the whole surface of a rotor blade are relatively low costs, no special lightning protection is required, the blades are easy to maintain and the whole surface is protected. Furthermore, these types of coating may reduce the sensitiveness against dirt and bugs during the warm periods, improving the aerodynamic performance of the rotor. Disadvantages are the ice throw during operation. It is expected that the ice fragments will break off regularly and will be thrown away from the rotor. At heavy icing conditions and low wind speeds due to low shear forces during idling, there will be also large ice accretion at the leading edge. Also unsymmetrical ice accretion can be possible, leading to unbalance.

Figure 9 demonstrates the situation at a pitch controlled turbine during idling (left side) and operation (right side). It is assumed that in case of a small ice accretion at the leading edge the shear forces are relatively small and thus the ice will break off only if the aerodynamic and centrifugal forces on the fragment are strong enough.

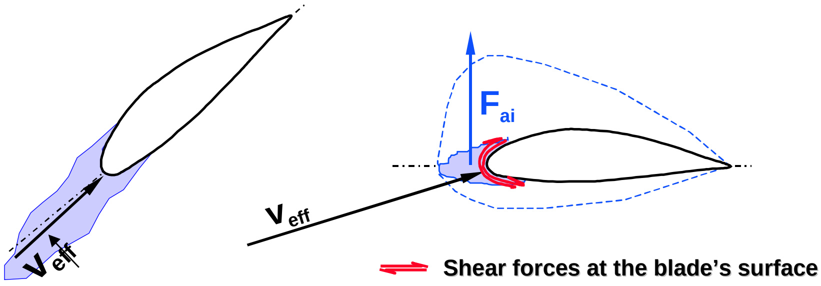

Figure 9 Shear forces between ice accretion and blade's surface during idling and operation (right side).

The EU demonstration project Tauernwindfarm will show how much special anti-adhesive coatings will increase the power production or decrease the loads.

There are also two principles to be discussed for the active systems: A **de-icing system**, which removes collected ice during operation or idling and an **anti-icing system** which avoids the accretion of ice on the rotor blades during operation or idling.

Small airplanes often use **mechanical de-icing** systems by means of so called inflatable rubber boots on the leading edge of the wing and control surfaces. However, for wind turbine rotor blades with their high centrifugal loads at the outer radii a pneumatic system will inflate itself or has to be divided in short sections. Furthermore, it will disturb the aerodynamics and cause more noise. During the 20 years of service life of a wind turbine under harsh climatical conditions the rubber boots will require intensive maintenance which may not be economical.

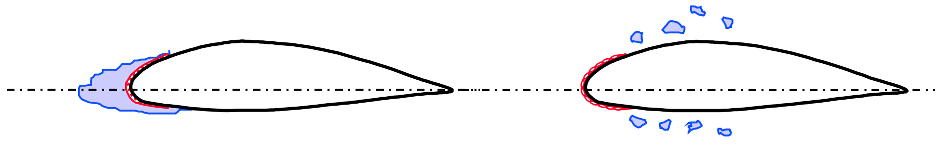

Figure 10 Principle sketch of mechanical de-icing by “rubber boots”.

In the past, active heating of the blade or parts of it have been tested or are under operation. Typical technical solutions are electrically heated foils at the leading edge (heating wires or carbon fibres) or blowing warm air into the rotor blade at standstill.

Heating the rotor blade interior with warm air needs special tubes to pipe the hot air. The advantages are that the leading edge surface and thus the blade’s aerodynamics is not affected. There is also no negative effect on the lightning protection system. At standstill the complete surface can be de-iced. On the other hand, GRP material is a good insulator. During high wind speeds or during rotation of the rotor at low temperatures the forced convection will require very high heating power. If this heating system is used at standstill at low wind speeds after icing events the high energy prices without production have to be paid by the operator.

During operation - for pitch controlled turbines also at idling and standstill - it is sufficient to heat the area around the stagnation point of the airfoil only. In practice, heating elements at the blade’s leading edge are mounted. The use of heating foils at the blade’s leading edge surface as shown in Figure 11 has proved to be an effective anti-icing method during operation as reported in [1]. Also the heating power balance recommends this type of anti-icing system as experienced in Northern Finland [1]. Without any heating systems at these types of sites, the turbine would be full of ice over a long period, just at the time when the good winds are blowing.

Figure 11 Wind turbine suited for icing conditions: Heating elements at the leading edge.

Heating foils can be applied at most of the rotor blades even after manufacturing them. However, the blade' s surface at the leading edge, where the air flow is most sensitive, is disturbed. Depending on the attachment of the foils, the aerodynamic performance of the airfoil might change during the un-iced conditions.

With stall and active stall controlled turbines at standstill, e.g. during icing conditions combined with low wind speeds, the trailing edge might head towards the wind and thus collect the ice. Leading edge heating elements will not help de-icing this blade as Figure 12 demonstrates. The right side shows the rotor blade of a stall controlled turbine yawed out of the wind during a period of in-cloud icing on the top of a mountain in southern Germany.

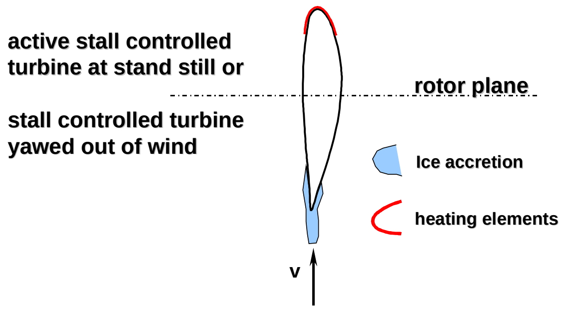

Figure 12 Stall-controlled wind turbine in icing conditions at standstill: Possible configuration if only the leading edge is heated. Observation of trailing edge icing (right side) of a stall-controlled turbine at stand still.

The left side of Figure 13 shows a stall controlled turbine at standstill catching an icing period at low wind speeds with the rotor headed towards the prevailing wind direction. Even with heating elements at the leading edge an ice-free start with increasing wind speed will hardly be possible.

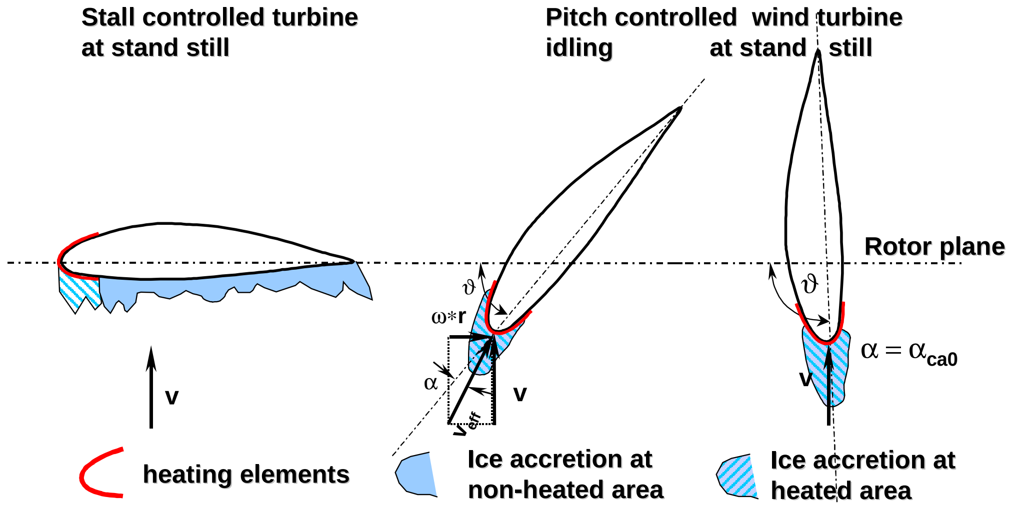

Figure 13 Stall- and pitch-controlled wind turbine with heating elements at the leading edge during icing conditions at standstill and idling.

The right side of the Figure shows the same situation for a pitch-controlled turbine in standstill or idling position. The activation of the heating system will de-ice the leading edge and enables the rotor to start energy production.

However, during operation heating power in the range of about 2 percent of the turbine's rated power is needed to keep the leading edge free of ice [5]. If the heating is switched on during standstill or idling, higher prices for the energy needed have to be paid. Furthermore, the electrical heating elements - metal or carbon fibre made - can attract lightning strokes at an exposed position at the surface of the blade. Also the airfoil contour must be kept free from waviness to avoid unnecessary disturbances of the laminar flow around the leading edge during ice free conditions.

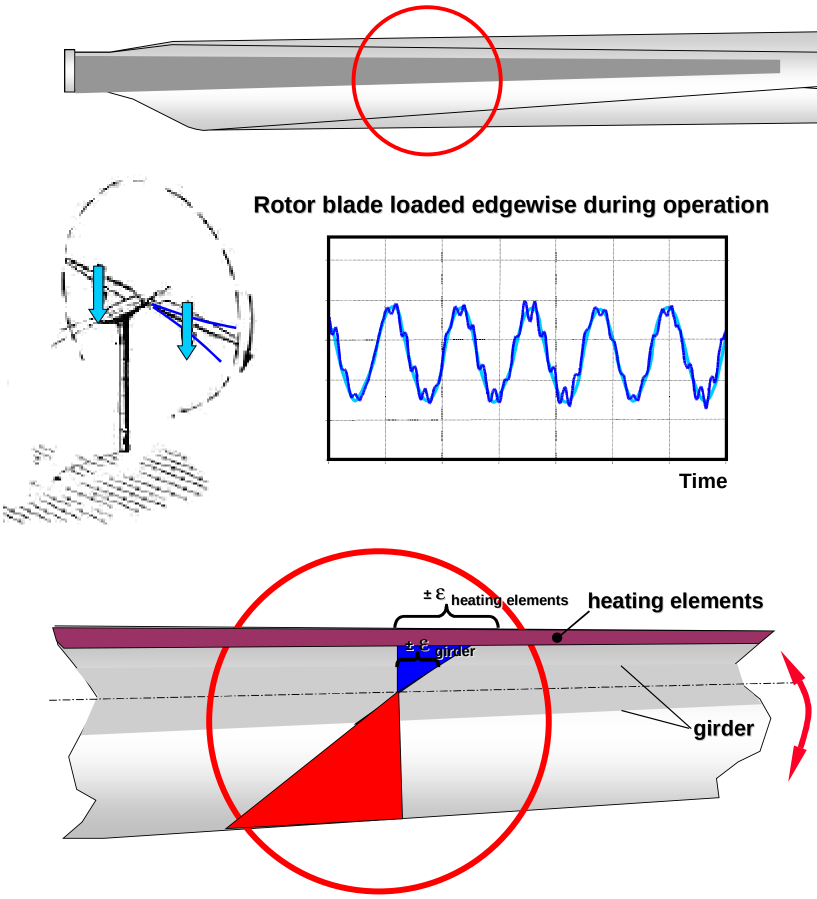

Figure 14 Loading on leading edge heating elements during operation.

The position of the heating elements at the leading edge involves additional problems. The rotor rotation in the gravity field causes typical high deterministic loads on the blade's structure as shown in the top of Figure 14. Aerodynamic driving forces and superposed so-called edgewise vibrations - caused by low damping of the natural frequency in this direction - are added to the gravity loads. Consequently, high strains in the GRP-load carrying girder as shown in Figure 14 will cause even higher strain in the wires or fibres, respectively, of the heating elements. This will be especially true if the heating elements are carbon fibre made. Their Young's modulus is much higher compared to glass fibres of today's rotor blade structures. In other words the "heating fibres" take over the loads. Special technical solutions are required in order to avoid these effects and to avoid cracks in the heating elements.

Conclusions and recommendations

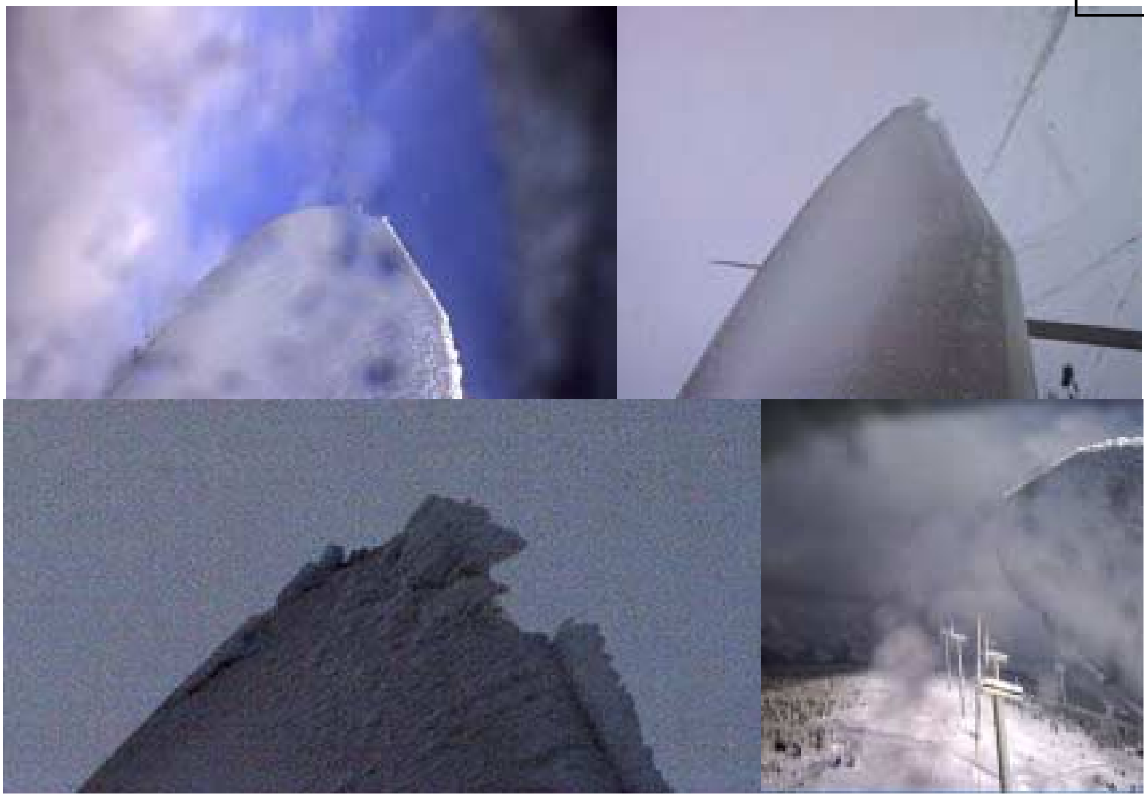

Figure 15 Pictures taken by WEB camera from the hub of one of the Tauernwind turbines

Until today there are no standard solutions available on the market to keep the rotor blades ice-free or at least solutions for reliable ice detection as an information for the turbines' supervisory system. Consequently, today's rotor blades should be designed for the operation with ice accretion if the turbine is situated at sites with the risk of icing. The changed aerodynamic loads as described in [6] as well as the changed mass loads shall then be taken into account in the load assumptions. Provided that a reliable ice detector is available, the turbine can safely be set to standstill if icing events occur and put in operation again after automatical sensing of ice-free conditions. However, practical experience at the Tauernwind showed that all sensing systems tested reported different "ice information". A rather good instrument for detecting ice at the rotor blades seems to be a web-cam in the hub, as shown in Figure 15, where the pressure side of an iced rotor blade can be seen. As an ice detector the camera via the internet cannot be used efficiently, as it requires a manned campaign and good visibility also at night. For checking the blades' surface in order to compare ice detection with other instruments or to check for ice accretion before a manned restart of the turbine after icing events, the web cam seems to be an appropriate means at the moment.

Some types of de-icing and anti-icing systems described above have been tested on prototypes or small serial production lines or are still under development. Thus, only little experience with anti-icing and de-icing systems is available compared to the large number of turbines being erected world wide. The size of the turbines is still growing and reaches easily 150 to 200 m with the blade in the upright position. These rotor blades can scratch low clouds and may collect ice even at coastal or offshore sites. But also the market for inland turbines, especially those with large towers, increases and requires standard solutions for operation during icing conditions.

What has to be done? The principles of operation of wind turbines under icing conditions have been compiled in the EU-funded WECO project (Wind Energy Production in COld climate [1]). However, since finishing the research work, much more wind turbines of bigger size have been installed. Documentation of icing and its effect on the power production as well as on the ultimate and fatigue loads of the structures have to be carried out at certain research and demonstration projects on a pre-competitive basis in order to improve the theoretical background. This knowledge has to be used to improve the national and international Standards concerning cold climate operation.

As icing is a common external condition for the aviation, the wind energy can take profit from the experience and adopt it to their special needs.

Reliable prediction of energy production and the fatigue loads on the turbine's components at inland sites can only be done if ice detectors deliver exact information about icing. Also the control system of the turbines has to rely on sound information on icing situations in order to shut the turbine down or react in another way to prevent the surrounding or the turbine itself from harm and damage. The reliable detection of ice is an indispensable requirement for the operation of wind turbines in cold climates. These ice detectors and ice free wind sensors need standardised conditions according to which they can be designed and calibrated. These standard conditions are not available yet and have to be defined.

In order to fit the turbine economically to the site reliable information about possible icing is necessary. An adequate instrumentation is therefore of fundamental importance.

REFERENCES

[1] Bengt Tammelin, Massimo Cavaliere, Hannele Holtinnen, Colin Morgan, Henry Seifert, Kristiina Säntti; Wind Energy in Cold Climate, Final Report WECO (JOR3-CT95-0014), ISBN 951-679-518-6, Finnish Meteorological Institute, Helsinki, Finland, February 2000.

[2] Trautmannsdorff, J.; Tauernwindpark Oberzeiring 19,25 MW - highest wind farm in the world: Erection and operational experience from winter 2002/2003. Paper presented at BOREAS VI, 9 to 11 April 2003, Pyhä, Finland

[3] Seifert, H.; Westerhellweg, A.; Kröning, J.; Risk analysis of ice throw from wind turbines; BOREAS VI, 9 to 11 April 2003, Pyhä, Finland

[4] Kimura, S.; The effect of anti-icing paint on the adhesion force of ice accreted on a wind turbine blade; BOREAS VI, 9 to 11 April 2003, Pyhä, Finland

[5] Bengt Tammelin, Henry Seifert; Large wind turbines go into cold climate regions; paper presented at EWEC 2001 European Wind Energy Conference, Copenhagen, Denmark, 02.-06.07.2001

[6] Seifert, Henry; Richert, Frank: A recipe to estimate aerodynamics and loads on iced rotor blades: Paper presented at Boreas IV Conferenz in Enontekiö, Finland, 31.03. to 02.04.1998.

EXHIBIT C
1

SOURCE: cost.cordis.lu/src/doc/727_MoU_TA_3rd.doc
European Cooperation in the Field of Science and Technical Research

Memorandum of Understanding
for the implementation of a European Concerted Research Action
designated as

COST 727
"Measuring and forecasting atmospheric icing on structures"

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of the document COST 400/01, "Rules and Procedures for Implementing" COST Actions, the contents of which the Signatories are fully aware of.

2. The main objective of the Action is to develop the understanding of icing (especially in-cloud icing) and freezing rain events in the atmospheric boundary layer and their distribution over Europe as well as to improve the potential to observe, monitor and forecast them.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at Euro 3.5 million in 2003 prices.

4. The Memorandum of Understanding will take effect on being signed by at least five Signatories.

5. The Memorandum of Understanding will remain in force for a period of five years, calculated from the date of first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter 6 of the document referred in Point 1 above.

Technical Annex

COST 727

Measuring and forecasting atmospheric icing on structures

A. BACKGROUND

The word icing is used to describe the process of ice or snow growth on a structure exposed to the atmosphere.

The potential for icing of structures is an important design parameter in the sectors of, e.g., building industry (TV towers and ski lifts), energy distribution, maritime activities, aviation conditions on the ground and meteorological observations. It has also recently become a relevant issue in activities related to wind energy production, where the icing of blades and control wind gauges significantly reduces the power production and causes a severe environmental safety problem. Furthermore, as human activities are increasingly extending to cold climate regions affected by icing problems, there is also a need to increase robust meteorological measurements under cold climate conditions.

Freezing rain may be a significant factor at some sites. Freezing rain is a meteorological parameter which is routinely observed as occurrences by national meteorological networks. In recent years there has also been considerable research effort by electricity companies in the study of ice and wet-snow accretion on overhead transmission lines. This research has also involved the participation of several European research centres and institutes.

In many cases the most severe form of icing is in-cloud icing. It occurs when super-cooled cloud droplets collide with cold surface. As the intensity of ice accretion is strongly related to wind speed, it is a severe problem especially at elevated sites such as high towers and structures built in mountains or upon hills.

There are some theories available on in-cloud ice accretion upon structures, but so far there are not enough statistics or measurements available to be able to predict icing and impacts of ice accretion or to assess the geographical distribution of ice accretion intensity. Very sophisticated icing models based on spectrum of particle size, mass of particles and their thermodynamic state, and description of the airflow are available. However, there is little information on input parameters required for the modelling of ice accretion as well as under which exact atmospheric conditions in-cloud icing occurs.

At the same time relevant economic sectors have a growing need to start to produce (meteorological) forecasts on icing, ice accretion and duration of icing for various end-users based on a sound scientific parameterisation of relevant processes. Typically, so far, icing expectance is simply forecasted when the temperature is below 0°C and relative humidity over 95%, or when the target structure is within a cloud.

At the EU level, in-cloud icing and cold climate problems with respect to wind turbines and meteorological observations have been studied within the "Icing of Wind Turbines" and

"Wind Energy production in Cold Climates" projects, as well as within the current "New Icetools" project (ref: www.fmi.fi/research). In these projects however, icing as a phenomenon, parameterisation of icing or development of proper icing sensors were not really addressed. The impact of icing upon meteorological sensors was studied within the "EUMETNET[1] Severe Weather Sensors (the SWS II)- project. Common to all these projects is a lack of proper observation of icing, icing rate and duration of icing, and low participation of persons/institutes with dedicated interest in the icing phenomenon.

According to preliminary statistics produced within EU wind energy projects, severe icing occurs over large regions in Europe from Northern Spain and the Italian Apennines to hills in northern UK, in the Alps and the Nordic countries. Unfortunately, these frequency distribution estimates are based on very simple parameterisation of icing (cloud, $T<0°C$, wind speed >0 m/s), and do not give actual climatological distribution of icing over Europe nor can they be used for, e.g., specification of ice prevention systems (e.g. blade heating systems for wind turbines) or for the ISO standard for atmospheric icing (ISO/CD 12494).

The preliminary icing map (icing from supercooled cloud droplets) over Europe produced within the EU/WECO project (Wind Energy production in COld climate) is based on synoptic measurements on temperature, wind and clouds from 100 weather stations. The estimate on intensity of ice accretion is based on empirical data from measurements with an FMI[2] ice cylinder. The cloud data include only synoptic values of the cloud height and the cloud amount. It gives a rough estimation about possible in-cloud icing events at different altitudes, but it cannot be used for icing climatology over Europe. However, this work can be significantly improved by adopting new information produced by this COST Action and by also taking meteorological data from upper air sounding stations and other synoptic stations. There are also large differences in in-cloud icing due to topography; the isolated hills or hilly terrain typical in northern UK or Finland are usually affected only with the lowest clouds, whereas in the Alps middle clouds also affect icing while climatological conditions change from valley to valley.

Structures for which icing is a significant hazard include lattice towers (TV and communication towers, high voltage power line towers), airplanes on the ground and wind turbines. When severely iced, these objects become large bodies for which the droplet collision efficiency is very small. For such small values of the collision efficiency, the aerodynamic theory that describes it fails, and the theoretical model results become excessively sensitive to the input parameters (droplet size, wind speed). Therefore, empirical methods need to be developed in order to estimate ice loads for lattice towers and other large bodies. Data from full-scale measurements of ice loads on towers (Ylläs, Finland; Akkanalke, Sweden) need to be analysed in order to verify and validate the models.

Another important problem area related to in-cloud icing is the dependence of ice load on the elevation above ground level. This problem severely hampers estimation, and thus the design of tall structures, such as TV-towers and large wind turbines. Efforts to model the height dependence of ice loads need to be done by both theoretical and empirical modelling, as well as to be supported by direct measurements.

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[1] EUMETNET is a grouping of 18 European meteorological services (www.eumetnet.eu.org)
[2] FMI = Finnish Meteorological Institute

The EUMETNET SWS II project proved that at present reliable equipment to measure atmospheric icing (freezing rain and in-cloud icing) do not exist. There are currently a few sensors available to detect icing, but there is a need to improve them, to inform manufacturers about requirements for icing measurements as well as occurrence and distribution of icing intensity. A very important result would be to produce verifications of representativity of sensors under typical icing conditions. There is also a need to include WMO's (World Meteorological Organisation) measurement requirements for icing measurements and acknowledge them in the Guide to Meteorological Instruments and Methods of Observation. It is important to produce definitions and specifications for measurement of icing and for ice sensors. This information is also required e.g. for safety standards of wind turbines.

Forecast of rime accretion and freezing rain is needed by many sectors of activities and responsible bodies. However, at present icing forecasts are not produced by national meteorological services (NMS). Therefore, there is a need to design a forecast scheme based on available parameters.

The required research is multidisciplinary and has wide applications for various sectors of activity in various regions of Europe. Therefore, this COST Action is very appropriate in terms of addressing the mentioned issues, since it will draw together the scattered national activities in the field. It is also obvious that this COST-Action will act as a stimulator to some EU research projects and also to some national R&D projects. This Action will not directly address upper air icing of aircraft and splash water icing of ships as applications. However, these issues will also benefit from the better understanding of the physics and climatology of icing developed in this Action.

B. OBJECTIVES AND BENEFITS

The main objective of the Action is to develop the understanding of icing (especially in-cloud icing) and freezing rain events in the atmospheric boundary layer and their distribution over Europe as well as to improve the potential to observe, monitor and forecast them.

The means by which this objective will be achieved include:

- To undertake scientific research of the processes relevant for atmospheric icing of structures and instruments
- To support the development of icing climatologies and occurrence thresholds for validation purposes and to establish its relationship with boundary layer icing forecasting
- To regularly assess the requirements from the operators and planners of TV/towers, power lines, wind turbines and meteorological services
- To develop methods that are suitable for operational implementation taking into account users' needs
- To produce detailed documentation on the various methods and models, their quality and applicability
- To recommend measurement requirements and to introduce specifications for ice detectors
- To disseminate existing expertise and the results of the Action to a wide range of users and scientists.

- To provide preliminary estimates on potential icing conditions under a changing climate (ref. IPCC reports, NEFP Climate & Energy project[3])
- To enhance a more active and sustained co-operation in research & development in the field, and to foster exchange of knowledge, of data and methods between participants across Europe.

Achieving the above means will lead to the following direct benefits:

- Increased scientific understanding of processes and conditions leading to icing
- Increased knowledge of the requirements for various applications (energy transport, tourism, wind power production etc.)
- Pre-normative data for certification bodies to improve safety and probabilistically optimised economical design of structures
- Statistical data on prevailing icing conditions and occurrence,
- Basis for planning future needs on the issue of icing; measurements, parameterisation, prediction and forecasting
- Basis for development of better devices or methods to prevent icing of structure and instruments,
- Effective advanced models and methods for processing observational data and forecasting ground icing occurrence
- More synergetic co-operation between European countries in the development of forecasting methods of atmospheric icing and for the exchange of forecasting tools
- Better estimate of measurements bias under icing conditions
- Wider distribution of knowledge about risks of icing among various sectors of activity and economy
- Strengthening of the European scientific community devoted to icing and related investigations.

Consequential benefits will arise from the operational implementation of the results of this Action:

- Planning aids for energy networks, manufacturers and maintainers of wind energy turbines, tourism, and meteorological forecasters
- Reduction of costs due to interruption of communication or energy supply, material damage and traffic congestion
- Possibility to develop new observation systems and devices based on the recommendations for standard measurement equipment
- Improved safety in traffic following from ability to assess and predict airfield and road slipperiness.

[3] A Nordic project “Impact of the Climate Change on Renewable Energy Sources and their role in the Nordic Energy System” partially funded by the Nordic Energy Research; http://www.os.is/ce/

C. SCIENTIFIC PROGRAMME

The main focus is in-cloud icing. The Action is divided into two phases:

C1. Preparatory Phase

The goal will be to gather and assess existing methods to:
- produce statistics on icing events and duration of icing at any site desired
- predict ice loads on structures
- forecast icing or rime accretion (time, duration, intensity of icing)
- measure icing and available data
- model ice accretion upon structures.

The regulations concerning environmental safety on falling ice from towers, wind turbines and other structures will also be assessed. Additionally, these inventories and assessments will be used to plan measurement campaigns.

This will be achieved by sending a questionnaire to study the needs for predictions, forecasting and measurements of icing within industry, aviation, civil engineering, meteorology and other applications. Based on this inventory of needs and the scientific and technological state-of-the-art, the scientific programme of the Action will be planned by the Action's participants.

Deliverables:
- Reports on the state-of-the-art
- Inventory of users' needs based on analyses
- Establishment of web sites for the Action
- Working plan for the Second Phase of the Action

C2. Research and Development Phase

A lot of theoretical work on ice and snow accretion on structures is available. However, there is very little knowledge and data about the parameters needed to use the produced formulas in the most proper way. There is also a lack of data on occurrence of atmospheric icing. It is obvious from preliminary data available from various parts of Europe that atmospheric icing occurs during a much wider range of temperature and humidity than usually expected. Thus, for instance, predictions of loads provided in many countries may lead to 1-2 decade errors at present.

Forecast of rime accretion and freezing rain is needed by many sectors of activities and responsible bodies. In principle the icing forecast can be a part of a Limited Area Weather Forecast Model System (e.g.. HIRLAM). On the other hand, experimental data and observations are needed to verify the accuracy of the forecasting models. Possibilities for more accurate forecasting systems will be assessed and tested in the framework of the more general weather forecast systems.
Obtaining sufficiently accurate input data for icing models is a significant problem that needs to be solved. The cloud droplet size distribution and liquid water content are not routinely

measured and the anemometers supposed to provide correct wind data are often iced up. High temporal resolution determination of the air temperature is critical in the ice disappearance phase of the modelling effort. Proper measurement and extrapolation of these input parameters to often remote sites of interest is extremely difficult. Consequently the future usefulness of theoretical icing modelling will essentially depend on the progress made in this area. Making the measurements by the rotating multi-cylinder automatic could be attempted, which would enable the validation of the icing theories in the field (e.g. at the existing test sites at Deadwater, U.K., Olos, Finland and at the EUMETNET SWS sites).

The empirical data on icing obtained within the EUMETNET SWS II project, actually studying ice-free sensors in harsh conditions at three sites (Mont Aigoual/France, Mont Säntis/Switzerland, and Luosto fell/Finland) during the winter 2001/02, will be used and applied in this Action.

Several new wind energy plants located at high latitude and high altitude sites in Europe will also provide some empirical data that will be used for this COST Action. Also some TV masts in various countries are capable of measuring total ice loads on the mast. Such data are available at several broadcasting companies and research centres. The available data can also increase the knowledge on the frequency of super-cooled clouds in various parts of Europe.

This phase would yield:
- research activities on in-cloud icing
- measurement activities on atmospheric icing
- modelling of icing processes
- improved forecasting systems
- verification of existing icing sensors
- mapping of icing occurrences and potentials in Europe

Deliverables:

- Scientific and technical publications on measurements and predictions of in-cloud icing
- Publications on verification of icing forecasts
- European icing map
- Recommendations for WMO observations and further work.

D. ORGANISATION

The Management Committee (MC) will implement the Technical Annex of this Memorandum of Understanding (MoU) by developing a work programme that will take into account the expertise and the interest of the participating institutions and results from some earlier works connected to this topic.

According to the above scientific programme, it is envisaged that the basic activity will be carried out within 3 Working Groups (WG) representing three clear lines of activity:

(1) Development of the scientific understanding of icing processes, their occurrence and their forecast (including verifications), and modelling of ice loads (ice accretion and melting; duration of ice load).
(2) Icing observations, measurements, field campaigns at different climatic regions and under different types of icing conditions, verification of sensors and development of ice detectors (sensors).
(3) Establishment of frequency distribution maps of icing potential in Europe based on the new knowledge of WG 1 and existing climatological data. This would also necessitate use of GIS-methodologies (a cooperation with COST-719 is to be established).

WG1: ICING MODELLING

WG1's activities will be to:

a) create an inventory about the knowledge base on icing (physics, models,…)
b) identify and summarise the gap in knowledge in order to be able to produce more accurate on-site predictions of icing (number of icing days, distribution on rates of icing, melting processes, etc.)
c) set up improved models and forecast schemes on the basis of available data
d) give recommendations on how to implement icing forecast schemes into the product chain of other forecast products on the basis of the given forecasted data stream.

WG2: MEASUREMENTS AND DATA COLLECTION ON ICING

Measurements over a specific period of time on ice accretion and testing of icing sensors will be based on existing test sites in the far north (Luosto/Finland), Alpine region (Switzerland) and in southern Europe (Mnt Aigoual/France). Additional experimental data from other ongoing activities will be used for this Action.

WG2's activities will be to:

a) create an inventory and collect available experimental data on icing as well as ancillary data
b) review and assess existing ice detectors and their performance
c) review and assess existing verification data from different sources
d) contribute to the set up of icing measurements at different locations in Europe and to the development of existing test sites
e) set up a data quality control scheme for measured icing data
f) establish a basic data set for icing modelling and verification
g) provide recommendations to set up a long-term icing measuring network and data base (to be submitted to WMO)
h) establish an icing monitoring core group for collecting and maintaining data on icing during and especially after the course of the Action
i) develop the scientific and technical bases of specifications of ice detectors
j) set up recommendations for testing/approving ice detectors and ice/free sensors.

WG3: MAPPING AND FORECASTING OF ATMOSPHERIC ICING

WG3's activities will be to:

a) harmonise the pre-processing methods using relevant meteorological and ancillary input data
b) map icing in Europe on the basis of the data obtained from the previous item as well as other measured and modelled data
c) establish a European Icing Atlas (in cooperation with COST 719)
d) assess the possible influence of climate variability and climate change on icing effects (together with WG1)
e) produce climatological data on icing using data from numerical forecast models.
f) adapt the recommendations of WG1 on icing forecast to study feasibility of implementation and usability of such a forecast scheme
g) set up and run a test implementation in one or more of the participants' NMS
h) final recommendation on icing forecast for NMSs and WMO

Based on experience from Phase 1 of the Action it will be decided whether activities dealing with icing forecast will need a subgroup within WG3.

Each WG will appoint a chairperson. The COST Technical Committee for meteorology will appoint a TC-Raporteur for the Action from its members.

The MC will meet twice a year, preferably in conjunction with the WG-meetings. The MC-Chair and Vice-Chair together with the WG-Chairs will form a Steering Group. Its main responsibility should be to link and integrate the activities of the WGs in such a way that the information, the needs and the results of each WG will also serve as input for the other WGs. A partner should be responsible for the database of collected data and its updating. The collected database should be available after the end of the Action to all interested scientists.

It is foreseen that the participants of this Action will come from national meteorological services (NMS), research institutes, universities and industry. The Action will also provide possibilities for the exchange of young researchers through the Short-Term Scientific Missions (STSM) scheme.

The Action will co-operate and make joint efforts with existing international groups in various fields of application, particularly the International Workshop on Atmospheric Icing of Structures (IWAIS), the CIGRE[4] Task Force on Atmospheric Icing , the IEA[5] Implementing Annex Wind Energy in Cold Climates (http://arcticwind.vtt.fi) and the EU research project on wind energy "New Icetools" (http://www.fmi.fi/research_meteorology/meteorology_7.html).

[4] CIGRE = International Council on Large Energy systems http://www.cigre.org/GB/indexie.htm
[5] IEA = International Enery Agency; http://www.iea.org/homechoi.htm

At the mid-term of the Action, an open workshop (30-60 persons from research institutes, manufacturers and industry) will be held to present the achieved results and to discuss the remaining work.

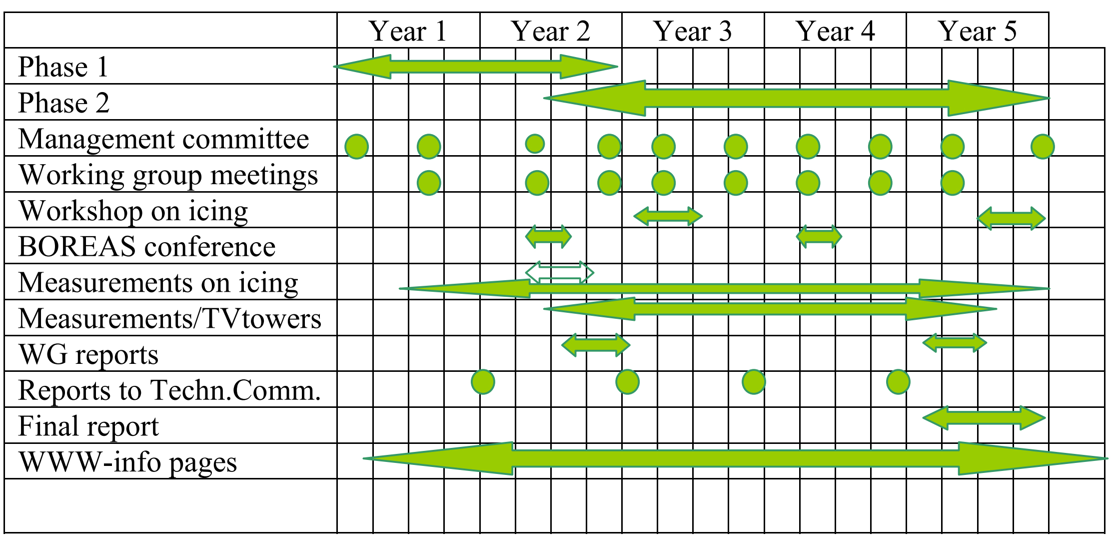
Close to the end of the Action a 3-day Final Workshop with wide participation of scientists and users from outside the Action will be held. This workshop will be organised as one session of a major conference on climatology or any other relevant topic.

The organisation and the timetable are shown in the diagram below.

E. TIMETABLE

The Action will have a total duration of 5 years. The research about atmospheric icing is multidisciplinary and has wide applications for various sectors of activity in various regions of Europe. The programme of the Action is planned for 5 years for the following reasons. First of all the community studying icing processes is very dispersed and in general splitting its time with other activity. Thus, in order to achieve capacity building and strengthening of the active core group, some time will be required at the beginning of the Action to promote its activity and will involve the bringing together a wide group of scientists from across Europe. The Action also plans to have two specific winter field expriments (see the graph) to account for variation in weather conditions and gather a wider set of data. The campaign should be planned beforehand and the resulting data should be analysed during the subsequent year. A duration of 5 years will therefore enable the relevant measurements to be performed together with proper analysis and interpretation of the results.

The scheduled plan is shown in the diagram below. In the diagram open arrows indicate a planning phase.



F. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: Austria, Finland, France, The Czech Republic, Germany, Italy, Norway, Spain, Sweden, Switzerland and United Kingdom.

On the basis of national estimates provided by the representatives of these countries, the economic dimension of the activities to be carried out under the Action has been estimated, in 2003 prices, at roughly Euro 3.5 million.

This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

G. DISSEMINATION PLAN

Information and results from this Action will be disseminated to the meteorological community and to manufacturers of meteorological sensors, to power industry (wind energy, power transmission,..) and to the building research community, regional planners, international certification and standardisation bodies, and to the scientific community working with cold climate and icing problems.

The methods to be used for dissemination of the Action and its results are:
- a public Website at the most early stage
- establishment of an e-mail network
- scientific publications in papers representing different areas of research and technology
- reports and articles for the general public
- specific technical reports for the various stake holders
- presentations at WMO seminars (e.g. CIMO[6])
- presentation in conferences, particularly International Workshop on Atmospheric Icing of Structures (IWAIS) and the Global Wind Energy Conference (organised by the European Wind Energy Association)
- international seminar arranged by this Action in co-operation with the BOREAS VII and VIII conferences (the main organiser is the Finnish Meteorological Institute)
- recommendation to WMO and NMSs with respect to icing measurements and ice-free sensor operation
- Final Report, also to be made available as a CD-ROM.

Additionally, good connections between some participants of this Action and the industry will be exploited to disseminate more effectively this information.

[6] CIMO = WMO Commission for Instruments and Methods of Observation

ADDITIONAL INFORMATION

History of the proposal:

The need for this Action comes directly from the society, industry, power industry, aviation, and from part of the meteorological community. A lack in knowledge of atmospheric icing and data on icing is the key issue for many applications. For some unknown reasons, research in atmospheric icing has not had a high priority within the national meteorological services or WMO.

During the last years, some of the initiators of this Action have been involved in several EU wind energy projects and EUMETNET projects on severe weather sensors where the impact of icing has been studied, but the icing process itself has remained a rather unknown factor. The Finnish Meteorological Institute has been the coordinator for many of these projects.

As a result from these projects and the increasing demand to produce better information on icing, a COST Action has been seen to be a proper way to improve the scientific network in order to inform the European community about icing, the impacts of icing and the possibilities to measure, predict and forecast icing.

The proposal has been under preparation for a while. During this time, the number of countries and institutes willing to participate in a COST Action on icing has increased significantly.

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Additionally this Action has been discussed with the members of the EUMETNET PB-OBS[7] in connection to the EUMETNET SWS II project on meteorological sensors, which has just been finalised.

[7] EUMETNET permanent working group on observations

REFERENCES

Graham Poots 1996. Ice and Snow Accretion on Structures. Research Studies Press Ltd. 338 p.

K. Finstad and L. Makkonen, 1992. Turbine Blade Icing Model. In the proceedings of the BOREAS, experts meeting on Wind power in icing conditions, 10-13 February 1992 hetta, Finland. P. 35- 49.

IEC 1998. Wind turbine generator systems - Part 12: Wind turbine power performance. International standard. IEC 61400-12.

Michel Leroy, Bengt Tammelin, Reijo Hyvönen, Jacques Rast, Marc Musa, 2002. Temperature and humidity measurements during icing conditions. In proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2002). Instruments and observing methods, report No 75, WMO/TD-No 1123.

Makkonen, L., Marjaniemi, M. and Peltola, E., 1998. Calculation of ice accretion on wind turbine blades. In proceedings of European wind energy conference, EWEC´97 (ed. R. Watson), Irish wind energy association, Dublin,. 615-618.

Marc Musa, Stephen Suter, Reijo Hyvönen, Michel Leroy, Jacques Rast, Bengt Tammelin; 2002. Measurement of temperature with wind sensors during severe weather conditions. In proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2002). Instruments and observing methods, report No 75, WMO/TD-No 1123.

Peltola, E.,Marjaniemi, M., Kaas, J. and Aarnio, E., 1998. Heating of wind turbine blades - design and operational experience. In proceedings of European wind energy conference, EWEC´97 (Ed. R. Watson), Irish wind energy association, Dublin. 619- 621.

Jacques Rast, Alain Heimo, Bengt Tammelin, Michel Leroy, 2002. Solar Radiation Measurements under Icing Conditions. In proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2002). Instruments and observing methods, report No 75, WMO/TD-No 1123. 5 p.

Tammelin, B, M. Cavaliere, H. Holttinen, C. Morgan, H. Seifert and K. Säntti, 2000. Wind energy production in cold climates (WECO). European Commission, Directorate-General for Research. Project Report. 41 p.

Tammelin, B et al.(Editors). Proceedings of the BOREAS (1992), BOREAS II (1994), BOREAS III (1996), BOREAS IV (1998), BOREAS V (2000) and BOREAS VI (2003) conferences on Wind power production in cold climates.

Tammelin, B., Heimo, A., Leroy, M., Rast, J. and Säntti, K., 2001. Meteorological measurements under icing conditions - EUMETNET SWS II project. Reports 2001:6. Finnish Meteorological Institute, Helsinki, 52 p.

Tammelin, B, Alain Heimo and Michel Leroy, 2002. Ice-free sensors - the EUMETNET SWS II project. In proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2002). Instruments and observing methods, report No 75, WMO/TD-No 1123.

Tammelin, B, Alain Heimo, Michel Leroy, Jacques Rast, Kristiina Säntti, Carole Bellevaux, Bruno Dal Cin, Marc Musa and Aulis Peltomaa: Improvements of severe weather measurements and sensors – EUMETNET SWS II Project. In Print

World Meteorological Organization (WMO), 1996. Guide to Meteorologfical Instruments and Methods of Observation. WMO-No 8, sixth edition. Secretariat of the World Meteorological Organization - Geneva - Switzerland.

http://orbit-net.nesdis.noaa.gov/arad/fpdt/icg.html (aircraft icing)

www.eumetnet.eu.org

http://www.dwd.de/EUMETNET/test_reports11.htm

EXHIBIT D - p. 1

Paper presented at the EWEC 2001, Copenhagen, 02.-06.07.2001

LARGE WIND TURBINES GO INTO COLD CLIMATE REGIONS

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ABSTRACT: Cold climate and severe icing problems have to be faced when erecting wind turbines at mountainous or hilly inland sites at regions like northern Spain, Apennines in Italy, Southern France, Alps, mountainous areas in Germany, Scotland, large regions in the eastern Europe and the Nordic countries. Similar conditions at sites with good wind conditions will be also found in other regions and at other continents. Low air temperature and especially icing conditions create new demands for the design of wind turbines and their components, and also to wind energy assessment. Theoretical models have been produced to calculate e.g. loads and power production under icing conditions, and blade heating systems and ice free sensors are now available. However, well documented demonstrations and verifications of results achieved are still missing. They are urgently needed to increase and improve the exploitation of wind energy at cold climate regions.
Keywords: Icing/Frost, Mountains/High Terrain, Safety

1 INTRODUCTION

Icing of rotor blades or other wind turbine components lead to decreased production as a result of ice accretion or safety demands; the rotor blades are not allowed to move if there is any danger of ice throw. At harsh sites annual power loss may grow up to 20-50 per cent. It has been estimated that about 20 per cent of the installed wind power within the European Union, which can be 8.000 MW by the year 2010, is going to be realised at sites were icing has to be taken into account in order to utilise the existing wind-energy potential [1].

Within the last years large wind turbines and wind power plants have been installed, or are planned to be installed, at sites with severe icing problems. At present some wind turbine manufactures provide turbines and components like wind sensors suitable for icing conditions. Partly, the icing problems have been taken into account when planning the power plants, partly not.

Table 1 summarizes the complexity of effects influencing the wind turbine design, its safety and its economics.

Icing of wind turbines affects

WT - Design	Safety	Economics
Aerodynamics Loads Dynamics Control system Instrumentation Material	Ice throw Unbalance Resonance Over power Fatigue	Energy production Site prognosis Wind measurem. Design life time Wind turbine equipment

Table 1 Cold climate operation affecting the design, safety and economics of wind energy plants.

Co-operative research projects mainly co-ordinated by DEWI [2] and FMI [3], partly supported by the European Commission, and the BOREAS conferences [4] made information on severe weather problems and their solutions available. An excerpt is listed below:

- Method for wind-energy assessment based on the so-called “European Wind Atlas” and the “icing map” data across Europe,
- Reduction of power output under different types of icing conditions,
- Aerodynamics and loads of iced blades,
- Methods to measure icing,
- Blade heating systems,
- Ice free wind sensors,
- Safety distances due to ice throw,
- Low temperature effects.

The Tauernwindpark, to be erected in the Austrian Alps in the year 2002 will use many of the results of the investigations and of the experience of the project partners.
An artists view of the project is shown in Figure 1.

Figure 1 Tauernwindpark in Austria: Planned 12x1,3 MW wind power plant at about 1800 m a.s.l.
(Computer animation by Energiewerkstatt, Austria).

2 PREDICTION OF POWER LOSSES

The prediction of wind energy potential at the site is often based on the so called Wind Atlas method. At large wind energy plants a very precise estimation of the wind regime and the knowledge of affects on the power production is vital. At cold climate conditions the wind resources are often underestimated, if using non ice free anemometers, or at mountainous sites often overestimated if using inappropriate ice-free anemometers [5]. In the last years ice free wind sensors have been made available by the industry, however, there is still a need for improvement and cost reduction. Ice free instruments are needed for both, for wind speed measurements and as control instruments for the turbines [6]. With the increasing costs for a single wind turbine (the average size of a turbine in Germany in the year 2000 was 1,1 MW) the prize of a proper wind sensor used for the wind turbines should not be discussed any more.

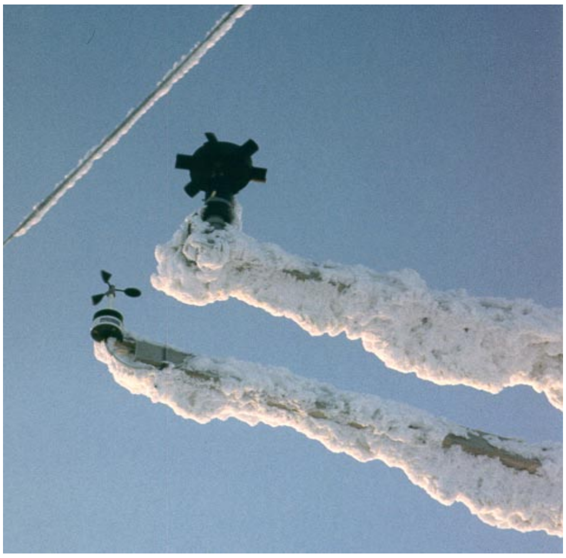

Figure 2 Testing of ice free wind sensors within the EUMETNET SWS project at one of the test sites [6]. (for further information see e.g.: www. eumetnet.eu.org)

The most severe form of icing for wind turbines at European sites is formed by in-cloud icing. The number of icing days and the prediction of ice accretion can be estimated from meteorological data. The effect on power production can then be calculated when knowing the aerodynamic characteristics of various iced airfoils. Then the principle procedure of predicting energy losses can be expressed as follows:

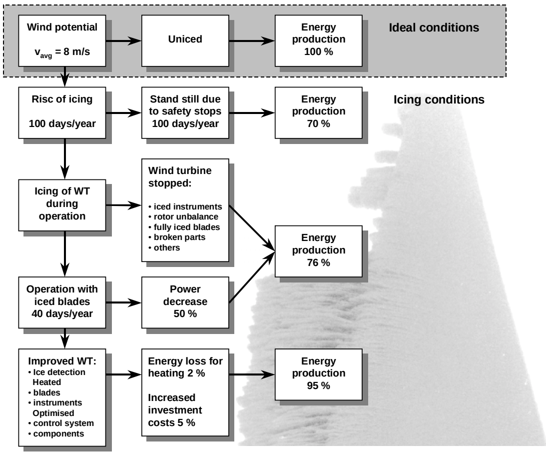

Figure 3 A schematic presentation of the procedure to calculate the power production at a planned site if the blades were partly clean and part of the year affected by various types and amounts of ice.

3 ROTOR BLADE ICING AND HEATING

At sites where icing frequently occurs heating of the blades is a suited method to keep the turbines running at high wind speeds without remarkable losses of energy and increases of loads. Additional experiences could be gained during the WECO project. In consequence, Kemijoki Oy's blade heating system could be improved and it was shown during the free field operation that – in spite of earlier concerns – it survived lightning strokes. Calculated and carefully distributed heating power (about 5 per cent of the turbine's rated power) was enough to keep the turbines well operated in arctic conditions of northern Finland. At the test site 450 kW wind turbines have been provided with plastic heating foils at the leading edges. The blade heating system is now used at new wind power plants in Finland and Sweden, and planned power plants in Austria, France, Germany and Switzerland, and other countries outside Europe will use these systems.

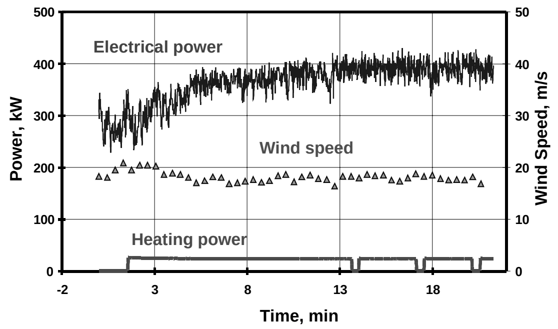

Figure 4 Power output at high wind and starting heating sequence.

Figure 4 – results from measurements taken in the northern Lapland - shows how the energy output increases after switching on the heating elements after the beginning of icing conditions. The balance between heating power demand and additionally produced power is obvious. Furthermore it is expected that with increasing ice accretion at the blades the turbine would produce less and less energy and more mechanical loads. However, it was also observed that icing starts during standstill or idling of the turbines at low wind speeds. Depending on the control system of the turbines different situations will occur. At low winds pitch controlled turbines mostly wait with pitch settings in such way that the slow idling rotor indicates the wind speed.

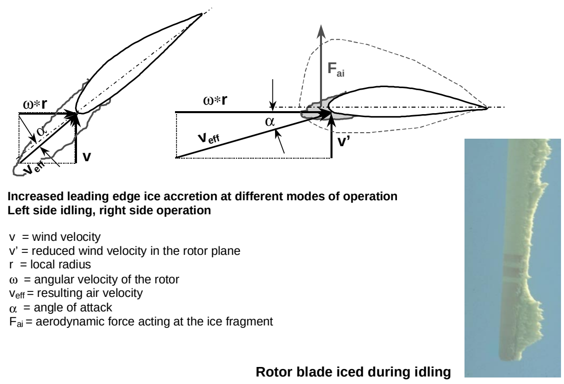

Figure 5 Icing during idling and operation

During icing conditions the leading edge collates more and more ice at the leading edge which will not be removed by centrifugal loads, as the rotational speed is rather low, nor are the aerodynamic forces high enough to break off the growing ice accretion from the leading edges. The situation is depicted in Figure 6 where the difference between an idling and operating rotor with the resulting leading edge ice accretion is shown.

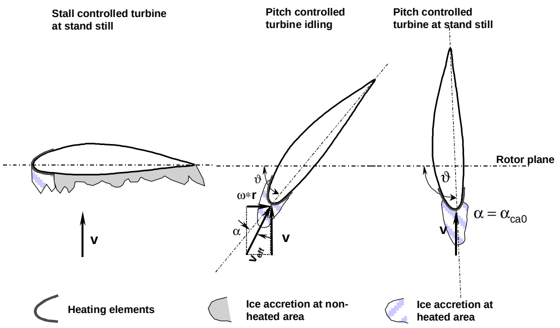

Figure 6 Icing at low wind speeds for different types of wind turbines

Heating elements are normally mounted around the blade's leading edge as can been seen in Figure 6. In standstill and idling conditions of a pitch controlled turbine activated heating elements will melt the ice and enable the turbine to start operation (rights side of Figure 6). Stall controlled turbines will collate the ice on the pressure side of the airfoil which is sketched in the left side of Figure 6. Consequently, the turbine will not start at moderate wind speeds. Also a slightly unbalanced rotor, due to icing will prevent rotation of the rotor.

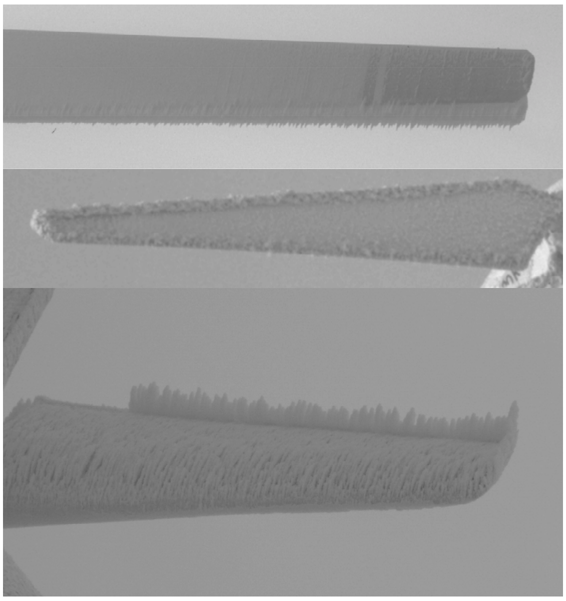

Figure 7 Typical leading edge ice accretion at an operating rotor blade (top), stall controlled rotor blade iced at low wind (middle) and iced trailing edge at a parked stall controlled turbine (bottom).

A typical leading edge icing which can be easily removed or prevented by the mentioned heating elements is shown in the top of Figure 7. The two other situations show different icing of stall controlled turbines during low wind conditions and parked turbines. It is obvious that these types of ice accretion cannot be removed by the heating elements nor will the rotor start rotating.

However, it is not recommended from the economical point of view to install heating systems on all wind turbines. If icing occurs only a few days to a week per year at the site, the turbine should be switched off at icing conditions or has to be designed to withstand the additional loads. Both is described more detailed in [3].

4 SAFETY

Especially when installing wind turbines close to human activities (buildings, skiing resorts, roads, ship routes etc.) a special attention to the possibility of ice throw has to be given. In the WECO project a distance of 1.5(hub height + rotor diameter) between the turbines and the nearest object has been recommended [3] if no special precaution is foreseen at ice endangered sites. It is important to be able to monitor the status of the rotor blades and to observe the cases when the blades are iced. The safety demands are that the rotor blades are not allowed to move if there is a danger of ice throw and there is a risk to harm people and animals.

5 SUMMARY

Large wind turbines have been installed at sites with cold climate and icing effects, and many new plants are under discussion. Icing conditions are much more common in various parts in Europe, especially at mountainous sites, than is usually taken into account by manufactures of wind turbines and wind sensors, or even operators. The installation of turbines for profitable wind energy production is possible even at sites with severe icing conditions. At present knowledge of ice-affected problems and how to solve them as well as needs for ice free wind turbines is available.

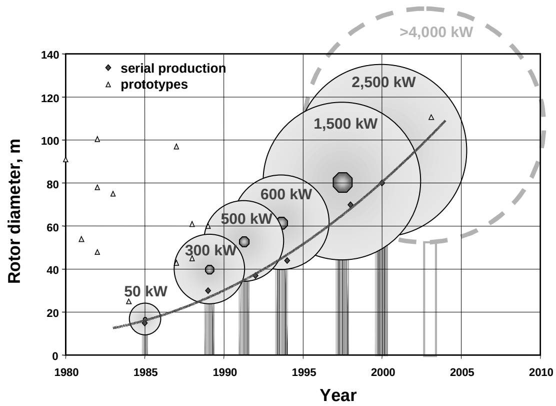

Figure 8 Development of sizes of wind turbines within the last years in Germany.

Figure 8 shows the development of sizes of commercially produced wind turbines within the last years in Germany, a tendency which can also be observed for other countries. The growing size is also accompanied by growing rotor tip heights, increasing the probability to scratch low clouds in wintertime and thus, the possibility for icing even in flat terrain. It might happen, that the ice sensors at the nacelle are not affected, but the outer part of the blades. Corresponding adaptation of the control system might avoid these effects.

However, to increase and improve the exploitation of wind energy at cold climate regions in various parts of Europe well documented demonstrations and full scale verifications of results achieved are still missing. Monitoring the operation and the loads of the large wind turbines is urgently needed in order to verify the design loads, not only concerning icing but also for wind farm and complex terrain operation.

6 REFERENCES

[1] B. Tammelin, H. Seifert and K. Diamantaras, 1999. BOREAS IV. In the proceedings of BOREAS IV (B. Tammelin et al., editors). P. 331-335. Finnish Meteorological Institute, Helsinki.

[2] H. Seifert and B. Tammelin, 1996. Icing of wind turbines. Final report: JOU2-CT93-0366. Deutsches Windenergie- Institut.

[3] B. Tammelin, M. Cavaliere, H. Holttinen, C. Morgan, H. Seifert and K. Säntti, 2000. Wind energy production in cold climate WECO. Meteorological publications No 41. Finnish Meteorological Institute, Helsinki. Project report, EUR 19398. European Commission, Community research.

[4] B, Tammelin et al., editors, 1992-2000, Conference proceedings of BOREAS, BOREAS II, BOREAS III, BOREAS IV, BOREAS V. Finnish Meteorological Institute, Helsinki.

[5] B.Tammelin, M. Cavaliere, S. Kimura, C. Morgan and A. Peltomaa, 1999. Ice free anemometers. In proceedings of BOREAS IV (B. Tammelin et al., editors). P. 239-252.

[6] B. Tammelin, J. Joss, M. Leroy and K. Säntti, 2001. Meteorological measurements under icing conditions – Eumetnet SWS II project. In the proceedings of BOREAS V. Finnish Meteorological Institute. In print.

EXHIBIT E

Wind Energy: Cold Weather Issues

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Renewable Energy Research Laboratory

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1. Introduction

As the environmental matters become more important and as the world is striving to find cleaner sources of energy, the portion of electricity that is wind generated is likely to increase substantially every year. However, harnessable winds are sometimes located where the climate is inclement for a substantial part of the year. Indeed, areas such as New England and the Mid-West have long been identified for their wind energy potential but partly because of harsh winter conditions, have not seen many wind farms being commissioned.

Until recently, most large-scale wind energy development took place in regions where cold weather was not a major concern, most notably California. More recently, wind energy development has begun to occur in colder regions. Thus, many developers and manufacturers are beginning to gain more cold weather operating experience. Much of that information is not publicly available and in any case, not all of the issues that have been encountered have been completely resolved. The wind farm developer is therefore confronted with a lack of information when planning wind farms in a cold weather environment.

This paper provides an overview of the issues affecting wind turbine operations in cold weather with a special emphasis given on atmospheric conditions prevailing in the Northeast United States. The first section describes previous and more recent wind energy projects in cold weather areas. In the second section, environmental elements most likely to impact on the operation of wind turbines in cold weather are introduced: low temperatures, icing and snow. It also presents various climatic situations and their specific behavior in cold weather. The third section suggests some solutions to problems identified in the previous section. In addition, this paper suggests ideas of further research on the operation of wind turbines in cold climate. It also identifies organizations interested by similar issues whose cooperation would be beneficial.

2. Previous Experience

The first wind turbine to be grid-connected in America was built more than fifty years ago in Vermont. It was located on Grandpa's Knob near Rutland and began feeding the grid for the first time in October 1941 (Putnam, 1948). It is interesting to note that early in the design process, the concern about cold weather, especially icing was very present. Indeed, the selection of Grandpa's Knob was based on the fact that a lower elevation mountain would represent a reduced risk of heavy ice accumulation. The designers wanted to eliminate any possibility of structural failure, which would have resulted in the end of the project. So the choice of Grandpa's Knob was made in spite of superior wind resources available on mountains with higher elevation. The next attempts at grid-connected wind turbines in New England were made during the 1980's in New Hampshire and Vermont at Crotched Mountain and Mt. Equinox respectively. It is fair to say that the difficult winter conditions are partly responsible for their short duration. Note, for example, the accumulation of ice on the turbine shown in figures 1 and 2. During these years, however, some experience was acquired in small wind energy conversion systems. This type of machinery was often installed to provide power for scientific camps, communication relays or meteorological stations in Antarctica and other desolated areas.

More recently, wind turbines have been installed in areas where cold weather conditions exist. In the Midwest, especially in Minnesota and Iowa, glaze ice and snow can be expected (AWEA, 2000). In Vermont, a wind farm has been built in a mountainous domain where rime ice is likely to occur. Europeans have installed wind farms in Scandinavia, the highlands of Germany, Austria and the Alps (Seifert and Tammelin, 1996). Conditions like rime and cold temperatures are likely to be found in these regions. A series of conferences were held in Finland to address these issues and other aspects of wind energy in cold weather such as resource assessment.

3. Cold Weather Issues

There are three general issues important to the operation of wind turbines in cold weather. These issues could be classified under three categories:

- the impact of low temperatures on the physical properties of materials
- the ice accretion on structures and surfaces
- the presence of snow in the vicinity of a wind turbine

Cold weather operation of wind turbines require that these issues be examined in the design or at least in the phase preceding the installation of the turbines in their working environment. Not doing so would mean prolonged period of inactivity required for safety purposes or because turbines inability to perform satisfactorily.

3.1 Low Temperatures

Low temperatures affect the different materials used in the fabrication of wind turbines, usually adversely. Structural elements such as steel and composite material all see their mechanical properties changed by low temperatures. Steel becomes more brittle; its energy absorbing capacity and deformation prior to failure are both reduced. Composite materials, due to unequal shrinkage of their fiber/matrix components, will be subjected to a residual stress. If this stress is sufficient, it can result in microcracking in the material. These microcracks reduce both the stiffness and the impermeability of the material, which can contribute to the deterioration process (Dutta and Hui, 1997).

Low temperatures can also damage the electrical equipment such as generators, yaw drive motors and transformers. When power is applied to these machines after they have been standing in the cold for a long period, the windings can suffer from a thermal shock and become damaged.

Gearboxes, hydraulic couplers and dampers suffer from long exposure to cold weather. As the temperature goes down, the viscosity of the lubricants and hydraulic fluids increases up to a point where at -40^{o} F, a chunk of heavy gear oil could be used to pound nails (Diemand, 1990). Damage to gears will occur in the very first seconds of operation where oil is very thick and cannot freely circulate. In addition, due to an increase in internal friction, the power transmission capacity of the gearbox is reduced when the oil viscosity has not reached an acceptable level.

Seals, cushions and other rubber parts loose flexibility at low temperatures. This may not necessarily result in part failure but can cause a general decline in performance. A typical rubber part can see its stiffness augmented by a factor of 8 at a temperature of -40^{o}F (Brugada, 1989). Brittleness also increases which changes impact resistance and makes the part prone to cracking (Brugada, 1989).

3.2 Icing

Icing represents the most important threat to the integrity of wind turbines in cold weather. Based on the duration of inoperative wind measuring equipment at one surveyed mountain in western Massachusetts, it was determined that icing weather can occur as much as 15% of the time between the months of December and March (Kirchhoff, 1999). Wind turbines must therefore be able to sustain at least limited icing without incurring damage preventing normal operation. Furthermore, it is advisable that power production be maintained in moderate icing for the following reasons:

- To minimize downtime period and benefit from the more favorable winter winds
- To keep the rotor turning and therefore limit the ice growth to leading edge part of the blade that is likely fitted with some ice protection equipment

The icing likely to form on wind turbine blades is of two kinds: glaze and rime. Glaze ice is the result of liquid precipitation striking surfaces at temperatures below the freezing point. Glaze is rather transparent, hard and attaches well to surfaces. It is the type of icing encountered during ice storms. New England and especially Massachusetts is an area of high occurrence for glaze storms as confirmed in Figure 3. A study covering a period of fifty years of glaze precipitation in the United States conducted by Tattelman and Gringorten supports this claim. They have established the probability of an ice storm of thickness greater or equal than 0.63 cm for the Pennsylvania, New York and New England regions during one year to be 0.88, i.e. almost once per year.

Rime ice occurs when surfaces below the freezing point are exposed to clouds or fog composed of supercooled water droplets. Its white and opaque appearance is caused by the presence of air bubbles trapped inside. Rime ice is of primary importance in high elevation locations such as hills or mountaintops. Figure 1 and 2 show how severely can a wind turbine be affected by rime ice.

Figure 1. Severe rime ice accretion on a US Windpower 56-100 turbine installed on Mt. Equinox Vt. Note the magnitude and extent of the ice coverage. (University of Illinois at Urbana-Champaign, Dept. of Aeronautical and Astronautical Eng.)

Figure 2. Same as Figure 1 showing a close-up view of the rotor and nacelle. (University of Illinois at Urbana-Champaign, Dept. of Aeronautical and Astronautical Eng)

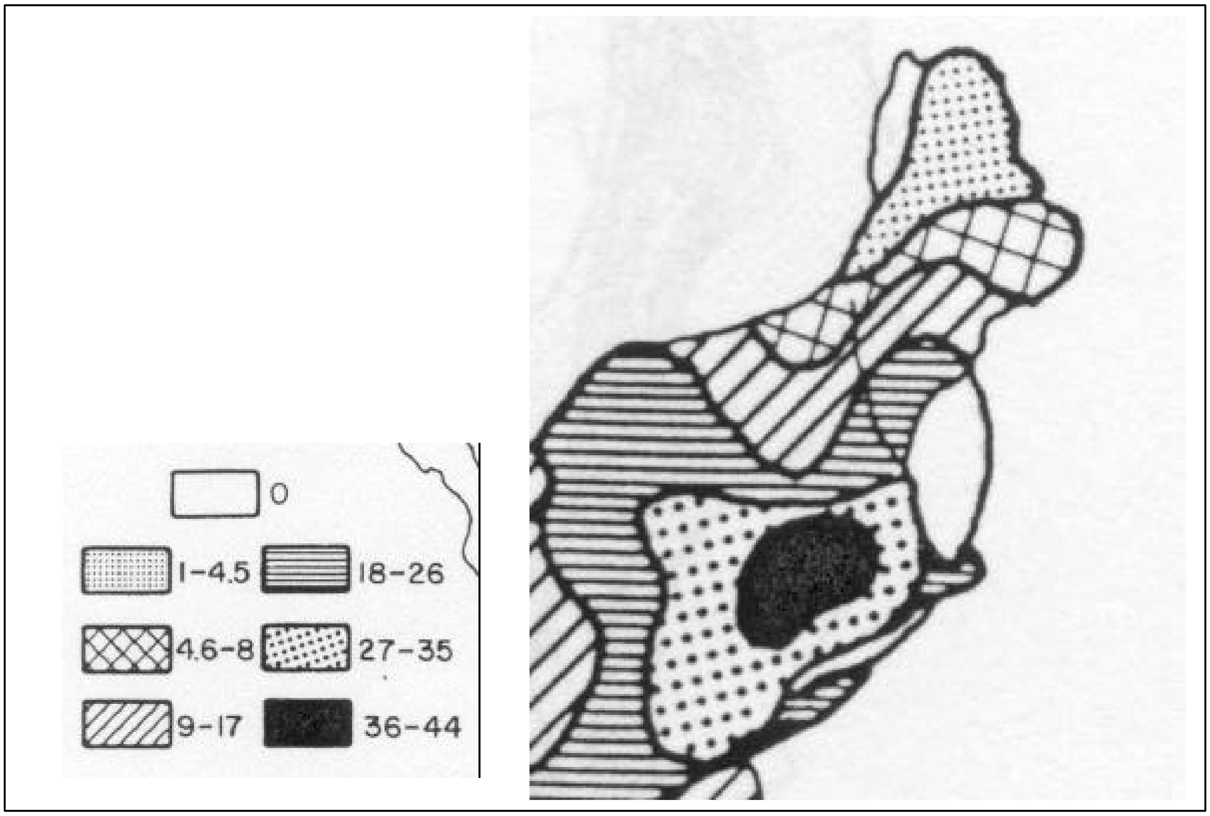

Figure 3. Total number of glaze storms, without regard to ice thickness, observed during the 9-year period of the Association of American Railroads study (undated) (Adapted from Bennett, 1959)

Ice collects on both the rotating and non-rotating surfaces. The most adverse effect of icing occurs on the rotor itself. Its consequences on the rotor are the following:

- Interfere with the deployment of speed limiting devices such as tip flaps or movable blade tip
- Increase the static load on the rotor
- Change the dynamic balance of the rotor, thereby accelerating fatigue
- Reduce the energy capture by altering the aerodynamic profile of the rotor
- Ice fragments can be propelled and represent a safety hazard for population and property in the vicinity of wind turbines. Larger chunk can also strike the rotor and damage it.

Ice also accumulates on fixed structures such as nacelles, towers and ladder, making periodic maintenance more difficult by preventing easy access to turbine components. It can interfere with the normal functioning of pitch control and orientation mechanisms. Finally, the presence of ice on structural elements increases both the static loading and the wind loading due to an augmentation in surface area.

3.3 Snow

Due to its very low specific gravity, snow is easily carried by wind. It can infiltrate almost any unprotected openings where an airflow can find its way. Wind turbine nacelles, i.e. the housings that contain the gearbox and the generator, are not necessarily airtight compartments. In fact, they incorporate many openings in order to provide a supply of fresh air for cooling purposes. Hence, snow can accumulate inside the nacelle and damage the equipment. This could prove very detrimental for the electrical machinery. On the other hand, snow could also obstruct these openings and prevent normal circulation of air. It is suggested to use deflectors or baffles in order to keep these openings free of obstruction.

3.4 Climatic Type

3.4.1 Polar Weather

Locations where wind turbines have supplied energy for many years are the remote sites of Arctic and Antarctica. Small units are used to power radio relay stations, expedition base and navigational aids. The abundant wind supply makes them ideal and very cost-effective sources of energy for these areas. The climatic conditions are more characterized by the extreme low temperatures than by precipitation of any kind. Therefore, the major meteorological concern associated with the polar weather is the severity of the low temperatures that generally degrades the stiffness and toughness properties of materials.

3.4.2 High Elevations

In the Northeastern U.S., the most suitable sites for wind turbines are frequently mountains or ridgetops. These also are areas where wind turbines are more susceptible to rime ice due to the relative proximity of low-level clouds. Bailey (1990) suggests that during cold weather at altitude about 2300 ft, rime ice can be expected approximately 10% of the time. This figure jumps to 20% for altitude above 3000 ft.

3.4.3 Lower Elevations

The type of meteorological hazard most likely to happen at lower elevations is glaze ice. Bailey (1990) suggests that glaze ice events are of short duration and light in intensity but the January of 1998 northeast ice storm proved otherwise. One could only observe the magnitude of the damages inflicted to trees and power lines. It could also suggest that the weather patterns are changing and become more dependent on global meteorological phenomena.

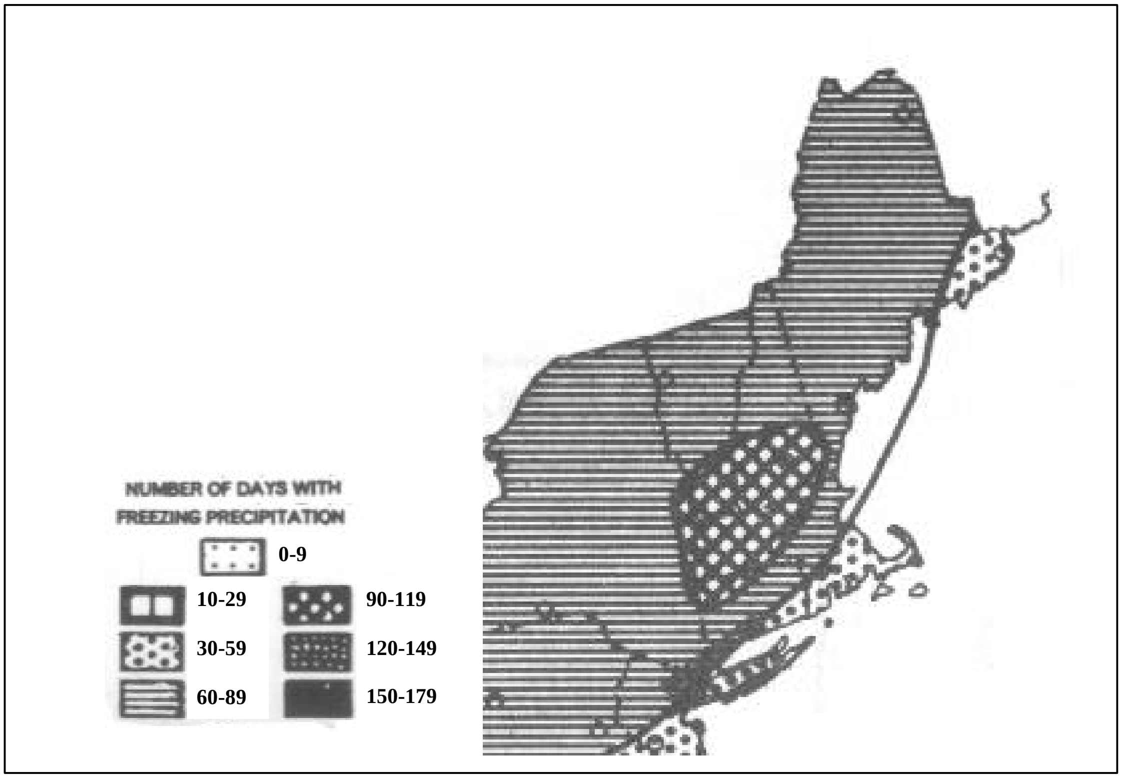

Figure 4. Total number of days with freezing rain or drizzle in the 10-year period from 1939 to 1948. Based on data from 95 Weather Bureau stations (Adapted from Bennett, 1959)

4. Proposed Solutions

Some solutions are already known for cold weather wind turbine operations. In fact, they are the same as any other cold weather engineering applications. This is especially true for materials and other elements whose low temperature behavior is well understood. For instance, the service conditions of a steel tower will determine the type alloy used in its fabrication. This is similar for lubricants; the application it will serve and the outside temperature will dictate the choice of a specific lubricant.

4.1 Low temperatures

Metals have found applications in low temperatures for many years now. For instance, it is well documented that alloys such as nickel and aluminum improve the strength of steel at low temperatures. Aluminum itself is also very suitable for these applications. Composite materials are fairly new and have not found low temperatures widespread applications. Dutta (1989) indicates that technologies that have done well in warmer climate sometimes behaved disastrously in low temperatures. His investigations of composite materials in low temperatures do not suggest a way to prevent unequal shrinkage and residual stress inside the fiber/matrix element. One way to prevent this would be to use fiber and matrix that exhibit similar thermal expansion coefficients.

Preventing thermal shocks on electrical machinery windings could be accomplished by locating heaters inside the nacelle. Prior to turbine activation, these heaters could be operated to provide quick warm up and allow windings to reach an operational temperature.

Heating elements, used as is or with a circulating oil pump, could be added to gearboxes in order to improve the viscosity of the lubricants. A lower viscosity lubricant could be used to facilitate the cold start but this could offer less protection when the normal operating temperature is reached. Another suggestion would be to slowly start the turbine drivetrain and do not apply full torque until a safe lubricant temperature is reached. This could prove to be very impractical considering normal wind turbine start up procedures, however.

Selection of appropriate rubber will insure that seals and other rubber parts retain their elasticity and prevent their brittleness at low temperatures. It is suggested to use special nitride rubber or fluorosilicone materials (Soundunsaari and Mikkonen, 1989).

4.2 Icing

Wind turbine icing has received a lot of attention in the recent years. As wind energy was developing in Scandinavia and in the highlands of Germany, icing was quickly identified as an area of uncertainty. Hence, research has been undertaken to identify and model the type of icing wind turbines would be subjected to. Efforts have also been done in the area of icing prevention technologies. They can be classified in two categories: active and passive.

Passive icing prevention methods rely on the physical properties of the blade surfaces to prevent ice accumulation. An example of passive icing prevention is the application of an anti-adhesive coating on the blade such as teflon. Another approach takes advantage of the heat absorbing capacity of dark colored surfaces and consists in the use of black coated blades. This technique was used on the eleven wind turbines that were erected in Searsburg VT in the summer of 1997.

Figure 5. Searsburg turbines use black blades to prevent ice accumulation. Note the layer of ice along the blade leading edge. (National Renewable Energy Laboratory)

Active de-icing methods have also been investigated. They come directly to us from the aeronautical industry. They consist of thermal, chemical and impulse de-icing. In thermal de-icing, electrical elements, similar to the one found on the rear window of a car, can be used to warm and melt the ice accumulation off the blades. Existing research in wind turbine active icing prevention has focused on thermal de-icing. Based on early work in Europe, Jasinski et al. (1998) indicate that thermal anti-icing requires an amount of heater power equal to at least 25% of the turbine maximum rated power. Recent work conducted in Europe indicates that the early estimate in anti-icing power requirement can be revised down. They now claim that the power requirement ranges between 6 to 12% of the output for 1000 to 220 kW turbines respectively.

In a comprehensive wind turbine icing prevention approach, sensors that could detect the build-up of ice on the rotor could be considered. Such devices already exist for the aeronautical industry. They consist of detection sensors and a control unit. The control unit processes signals received from the sensors and activates the ice removal mechanisms. A similar system could be adapted to work on wind turbines and insure automatic de-icing operations.

5. Recommendations

Wind turbines installed in New England should have demonstrated capabilities to operate and/or survive under cold weather conditions. This includes low temperatures, icing and snow. Studies to monitor the impact of these factors, especially icing, on the operations of wind turbines should be undertaken.

Representative of Massachusetts should participate in international activities regarding the identification and amelioration of cold weather related problems on wind turbine operations. Members of the Massachusetts energy community should establish working relations with groups and organizations already involved in cold weather issues. These include:
CRREL –The U.S. Army Cold Regions Research and Engineering Laboratory; Hanover, N.H.

Wind turbine operators
Green Mountain Power – The Vermont utility operates a 7.5 MW windfarm near Searsburg VT since 1997.

IREQ – Hydro-Québec Research Institute; Varennes, Québec

European nations that are involved in wind energy research:
JOULE III Wind Energy in Cold Climate (WECO) Project, co-funded by the European Commission – The BOREAS Conferences

VTT Energy - The leading institute in research on wind energy in Finland
FMI Energy – The Finnish Meteorological Institute
DEWI – Deutsches Windenergie-Institut

Additional research should be carried out on icing and its effects on wind turbine operations. The following subjects could be of interest:

- The long term effect of icing, especially on blade fatigue

- Is the blade more prone to collect ice when at rest or when running, the answer could be different whether glaze or rime ice is involved
- The ice collection pattern, is it similar to aircraft icing or is it more random in shape?
- What part of the blade is more prone to icing, the root or the tip?
- What is the energy loss associated with icing?

So far, the research in icing seems to have focused on rime ice. This is due maybe because this is a better understood phenomena and also this is the sort of icing occurring where icing on wind turbine is a concern and where research has begun on this subject. Available weather data suggest that this is not necessarily the type of icing most likely to occur in the lower elevations of New England. Therefore, documenting glaze ice on how it forms, its occurrences throughout New England and its impact on the utilities among others, is something that seems valuable to undertake.

An investigative effort could be done in the area of ice monitoring. For instance, the anemometer stations could also be fitted with icing detectors to evaluate the duration of each icing episode and the total number of hours during a season. Although there are different types of ice detectors available, their general operating principle is the same: they sense a change in properties resulting from an accumulation of ice. Some work by detecting the frequency variation in a sonic or vibratory wave while others monitor the capacitance between metal strips. The Rosemount ice detector uses the frequency shift principle (Ryerson, 1988). Researchers from CRREL have used it to study the ice growth on the summit of two New England mountains.

6. Conclusion

The most favorable areas for the production of wind energy are often located where the climatic conditions are severe and unpredictable. In order to improve the performance of wind turbine in this environment, some issues need to be examined carefully.

The issue of low temperatures can be addressed by making sure that the turbine is designed appropriately. The technology is available and has been used for other applications of engineering in cold weather. A problem like icing deserves further investigation. Work in the areas of ice detection, prevention and removal could significantly improve the dependability of wind turbines in cold weather.

Other groups in North America & Europe operate wind turbines in conditions similar to New England. Some have accomplished work in areas that are compatible with our objectives. Cooperation with these organizations is suggested. This would contribute to improve our level of expertise and inform us of the evolution of the technology.

7. Reference

American Wind Energy Association - *AWEA* (2000) Wind Energy Projects Throughout the United States. Data from the website: http://www.awea.org/projects/index.html

Bailey, B.H. (1990) "The Potential for Icing of Wind Turbines in the Northeastern U.S.". Windpower 1990: 286-291

Bennett, I. (1959) Glaze: Its Meteorology and Climatology, Geographical Distribution and Economic Effects. Quartermaster Research and Engineering Center, Environmental Protection Research Division, Technical Report EP-105.

Brugada, R. (1989) "Performance of Thermoplastic Elastomers (TPEs) at Subzero Temperatures". Proceedings of the Subzero Engineering Conference 1989: 67-73

Diemand, D.(1990) Lubricant at Low Temperatures. CREEL Technical Digest TD 90-01, Cold Regions Research & Engineering Laboratory, Hanover, New Hampshire.

Dutta, P.K. and D. Hui (1997) "Effects of Cold Regions Environment on Structural Composites". Proceedings of the International Conference on Advanced Technology in Experimental Mechanics, Japan Society of Mechanical Engineers.

Jasinski, W.J., S.C. Noe, M.S. Selig and M.B. Bragg (1998) "Wind Turbine Performance Under Icing Conditions". Journal of Solar Energy Engineering 120: 60-65

Kirchhoff, R.H. and F. Simons (1999) "Icing, Freezing and Thawing of Wind Anemometry". Proceedings of the 1999 European Wind Energy Conference: 1021-1024

Putnam, P.C. (1948) Power from the Wind. New York: Van Nostrand Reihnold Company, 225 pp.

Ryerson, C. (1988) "Atmospheric Icing Climatologies of Two New England Mountains". Journal of Applied Meteorology 27 (11): 1261-1281

Seifert, H. and B. Tammelin (1996) "Icing of Wind Turbines in Europe". Proceedings of Boreas III Conference 1996: 43-51

Tattelman, P. and I.I. Gringorten (1973) Estimated Glaze Ice and Wind Loads at the Earth's Surface for the Contiguous United States. Air Force Cambridge Research Laboratories Report AFCRL-TR-73-0646.

NEW ICETOOLS - Experimental Wind Energy Data from Cold Climate Sites in Europe

B. Tammelin, Finnish Meteorological Institute (FI)

1. Introduction

There is a growing interest in EU to build wind power plants at inland sites and especially within mountainous regions, and also in the far north. Typical for such sites are not only low air temperature but also icing of blades and other components. These climate conditions make new requirements to design of wind turbines and their components, and also to wind power assessment and wind measurements, and to economical optimisation.

From the previous EU projects and some national projects there are quite a lot of theoretical and even some experimental data on wind turbines operating under such climatic and weather conditions. There have also been some improvements in producing ice-free wind sensors for wind energy assessment and operation of turbines, blade heating systems and codes to estimate loads and power production under icing conditions. However, it seems that wind turbine and component industry, and operators are poorly aware about occurrence and frequency of icing periods in various parts of Europe, not only in far North but also in most southern parts. There also seems to be a lack in knowledge of technical solutions already available, experiences in operation of different types of turbines under icing conditions, and also about safety problems caused especially through iced blades.

Fig. 1: A photomontage of 13 MW Tauernwindpark in Austria with Vestas wind turbines to be erected in 2002.

Within this project the aim is to collect systematically data from different types of wind power plants operated in different parts of Europe under different types of icing climate. Data will also be used to verify the codes available and improve the tools to predict loads, power production, heating demand on blades and other components.

2. The Project

2.1 Objectives and General Setting

The overall objectives of the project are to develop and improve the tools suitable for manufacturers, operators, developers and consultants to exploit wind energy utilisation in hostile terrain and ice-endangered sites (mountainous southern and Central Europe, arctic hills and valleys, Alps, northern European coast and off-shore).

Several wind turbines have already been installed at ice affected cold climate sites with very poor information on climatic conditions and needs for specially designed turbines, which has led to unsatisfactory and uneconomical wind power production. Some sites also produce safety problems for the public.

There is a rapidly increasing interest in deploying wind energy under these harsh conditions not only within Europe but also elsewhere because the wind resource is extremely good. Icing, however, reduces the production yield and lowers the availability. Thus the economics of the project is worse than for normal

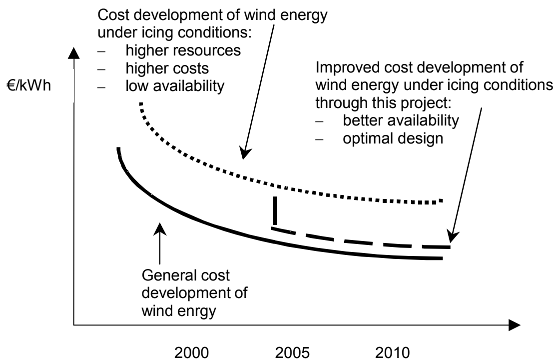

Fig. 2: Cost development of wind energy at lowland and icing sites. Due to the presented project some barriers hampering cold climate wind deployment will be overcome. As the reliability and availability of adapted technology can be verified and an optimal site-dependent design can be used, the net economics will respond to that of lowland applications.

lowland applications. Although adapted technology is developed, the anticipated high extra costs and the low confidence in ice-preventing technology hamper development. By this project, the net economics (expressed in € /kWh) of icing wind energy applications is expected to close the gap to that of normal lowland applications as described in the following figure. The results of the project will also improve the exploitation of inland sites with a more moderate wind resource.

2.2 Organisation

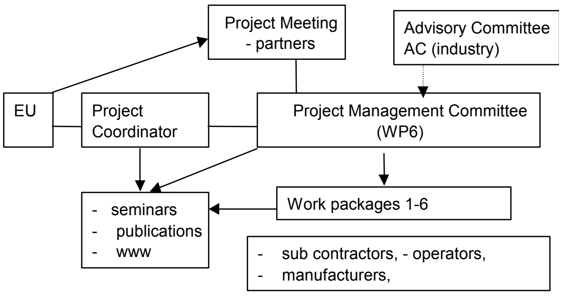

Fig. 3: New Icetools project management.

To achieve the overall objective the project is divided in six work packages. The work packages and their objectives are described in the 2.3.

The consortium includes 6 partners from Austria, Germany, Sweden and Finland. The general setting of the project is shown in Fig. 3. The project is coordinated by Finnish Meteorological Institute (FMI). An advisory committee having members from the industry and certifying bodies (DEWI and TÜV) is formed to guide the work of the project management committee.

In this way the project constitutes a co-ordinated effort to collate operational experiences from several wind energy installations under harsh climatic conditions with direct link to the industry and certifying bodies.

2.3 Work Programme

The project is divided into six work packages as shown in Table 1.

Work package No	Work package title
1	Icing
2	On-site icing and loss of production
3	Modelling ice loads
4	Prevention of icing effects
5	Questionnaire and market analyses
6	Management and information dissemination

In WP 1, coordinated by Finnish Meteorological Institute, the objective is to improve the knowledge on icing by

- collecting data of on-site measurements of icing
- verifying existing methods to estimate icing with observation performed at the WT and other sites in various parts of Europe
- studying the effect of solar radiation and temperature on duration of ice accumulation
- studying the meteorological / climatological conditions for icing
- studying the possibilities of icing forecast on the basis of regular meteorological products.

WP 2 is coordinated by ISET. The objectives are

- to study duration of ice accumulation on blades versus weather parameters using monitoring data produced in WP1
- to study the existing empirical data on icing events by analysing frequency, duration, failures, costs, energy loss, site characteristics at wind power plants
- to study the behaviour and requirements of nacelle-ice-free-anemometers
- to perform on-site intensive observation campaigns to verify the shape and amount of ice accumulated on the blades to verify:
- existing codes used to describe the ice on the blades to produce e.g. the Cl, Cd coefficients and to optimise the blade heating systems
- observed power curves to predicted power curves for stall and pitch controlled turbines
- to improve the PROP code for practical predictions of power curves and losses in power production, but also taking into account possible overproduction due to clear ice on the blades to improve the tool/method to predict power losses due to icing in various types of icing conditions upon stall and pitch controlled turbines
- ice accretion during idling upon blades of pitch and stall regulated turbines
- to calculate the effect and economics of blade heating systems, of stand stills due to safety problems and of potential anemometer problems on power production at several sites in Europe
- to study high air density versus high wind speed statistics in Europe
- to study the statistics between temperature, wind speed and solar radiation

In WP 3 VTT together with FOI aim to present and verify simple structural safety load cases for wind turbines operating under arctic conditions

WP 4, coordinated by VTT, deals the various methods to prevent the effects of icing. The objectives are
- to improve observation tools for icing events.
- to collate operational experience of wind turbines with blade heating in different types of icing climate.
- To collate information on blade heating influence, on lightning susceptibility, blade materials and aerodynamics.
- to study the durability and reliability of adapted technology

In WP 5 the aim is
- to collect feedback from the operators concerning their experience on icing events, cold climate problems and ice throw etc. For this a questionnaire will be sent to operators, manufacturers etc. to collect data from the winter 2002/2003.
- to produce a market study in wind potential at cold climate sites in EU including also the new candidate states

This work package is led by Enairgy.

The management as well as the information dissemination of the project is made in WP 6, coordinated by FMI.

2.4 Data Used in the Project

Much of the work is relying on past and ongoing measurement campaigns at several sites located in Austria, Germany, Sweden and Finland. Most of the data acquisition systems, which will be used in the project are already installed at operating power plants and thus this is a cost effective way to carry out joint measurement campaigns with comparable procedures and with common objectives.

<u>Olostunturi, Finland</u>

Olos is one of the most Northern wind farms in the world and it is operating in N 67.55 E 23.48 h=500 a.s.l. in Finland. In winter icing is severe and an ice prevention system in wind turbine blades is compulsory. The Olos wind farm consists of five Bonus Mk IV 600 kW wind turbines. All turbines are equipped with an ice prevention system called JE-System.

A separate measurement 40 m high mast locates 115 m from the nearest wind turbines. In addition to normal meteorological measurements, blade heating power and icing are measured. Ice free measurement instruments are in use. Video monitoring for ice detector has been installed during the spring 2002.

Pori, Finland

The wind farm consists of 8 wind turbines of 1 MW nominal power supplied by the Danish manufacturer Bonus Energy A/S. The wind farm was installed in 1999 in Pori, western coast of Finland (N 61.3°, E 21.2°).

For wind and icing measurements an 85 m high mast was erected at the Pori wind farm in the autumn of 1999 during the follow-up project. A high mast is needed to reach the highest tip position of the Bonus 1 MW wind turbine. Also effective power from turbine 1, blade heating power and icing information from the turbines are recorded.

Luosto, Finland

The FMI test station is located in northern Finland. Site locates 515 m a.s.l. Measurement platform is instrumented extensively including several ice-free anemometers, temperature and humidity sensors, and solar radiation measurement equipment (Fig. 4). Also measurements of icing are done using Labko and Roremount ice detectors, Vaisala present weather sensor and two video monitoring systems.

Fig. 4: EUMETNET wind sensor test at Luosto fell in Finland. Different sonic and cup anemometers under icing conditions [4].

Oberzeiring, Austria

Partially demonstration wind farm will be erected during the summer 2002. Farm consists of 12 Vestas 1.3 MW wind turbines. The site is located at 1835 m a.s.l. Severe weather conditions prevail during winter months. Meteorological mast for wind and icing measurements will be erected on the site. (Fig 1)

Plankogel, Styria-Austria

Site consists of one 750 kW NEG Micon wind turbine and measurement mast and is located at 1450 m a.s.l. Measurements of wind speed and direction, humidity, temperature, pressure, radiation, visibility and icing will be made near the wind turbine. During winter months intensive measurements of icing on the wind turbine will be made.

Suorva, Sweden

Site consists of one 600 kW Bonus wind turbine and meteorological mast. Site is surrounded by mountains and therefore does not fulfil the recommendations of IEC standards.

The data will be used for verification of operation and failures of different types of turbines and different design of components. To get more operational data questionnaires will be sent especially to power plants operated under icing conditions in mountains in Spain, Italy, UK, Switzerland and many Eastern European Countries.

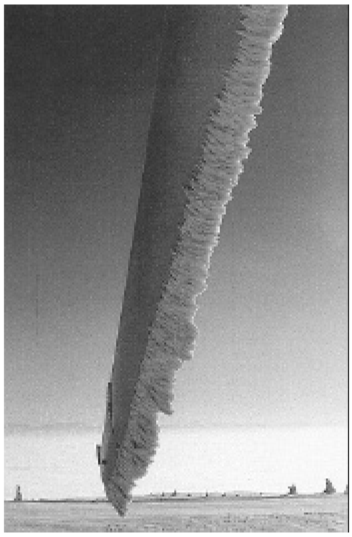

Fig. 5: Iced wind turbine blades in Germany.

Production and failure statistics

The production and failure statistics of wind turbines in Germany and Finland are used in the project to get an overview of the effect of icing on the wind turbines. These databases enable the comparison between meteorological observations and data with the practical experience from operators of wind turbines. This is made to explain the discrepancy and difference of reported experience and consequences of icing between observations from close-by wind turbines.

3. Experience and Data from Other Projects

3.1 WECO-project

Many aspects of the NEW ICETOOLS-project were dealt with in the EU-sponsored WECO-project.

Ice throw from blades may be a safety problem especially when turbines are close to roads, buildings or other human activities. In the WECO project the distances of ice pieces thrown by a rotating turbine were estimated based on theoretical calculations and field observations [2]

The present icing map for Europe was produced within the WECO project using meteorological data from over 100 observation stations. The new icing map under NEW ICETOOLS will include more stations, new methodology and latest experience achieved e.g. in the EUMETNET SWS project.

Icing of blades typically strongly reduces the power production of turbines. Up to now quite few monitored data on power reduction versus the amount and the shape of ice exist. However, according to examples of ice observed upon blades a calculation method to predict power losses due to icing was produced in the WECO project [2]. In the NEW ICETOOLS project it is hoped to get experimental data on this issue to verify and improve the modelling of power losses for different types of large wind turbines.

3.2 EUMETNET SWS-II-project

Wind sensors are required for wind energy assessment, verification of models [6], power curve analyses and operation of wind turbines. Even slight icing of anemometers will strongly reduce the measured wind speed [3]. Icing of wind sensors is much more frequent and usual in Europe than generally expected.

Unfortunately quite a few ice-free sensors are available today. And unfortunately very few of the ice-free sensors available are accurate and reliable enough to be used for proper wind energy business. However, a couple of ice-free and non-ice-free wind sensors may be used during operation to control icing of wind turbines.

Fig. 6: EUMETNET wind sensor test at Mont Aigoual in France. Degréane DEOLIA96 sensors are currently used in the Météo-France network. This model has shaft heating. Cups on the left and the vane on the right [4].

Concerning wind power business there is a need to specify ice-free anemometers to be used for different purposes mentioned above. Therefore results from ongoing projects like EUMETNET SWS II [4] are required.

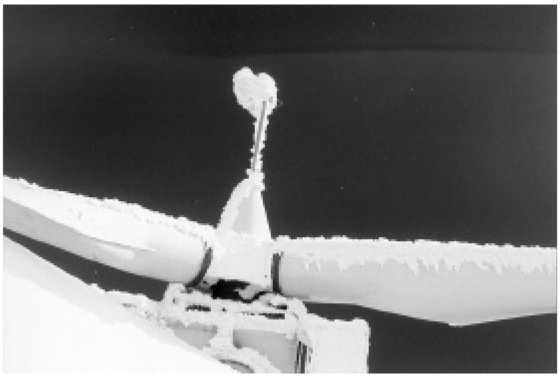

Fig. 7: Iced blades and control anemometer in Switzerland.

3.3 IEA Collaboration

At present quite little information on statistics on operation of wind turbines under icing conditions is available. New optional operators of turbines at possible icing sites also would like to have some information of experience achieved from existing sites like e.g. that from Sweden [7].

This kind of data is collected and produced also under the framework of IEA R&D Wind in the Annex XIX Wind energy in cold climates. The annex is a co-operation between Finland, Sweden Denmark, Norway, Switzerland, Canada and USA [7].

3.4 Standardization and Certification

Certifying wind turbines for cold and mountainous regions require reliable procedures for the prediction of ice amount during standstill and operation. International design standards take icing load cases into consideration in different ways. The IEC-61400-1 ed2 Wind Turbine Generator Systems - Part 1 Safety Requirements recommends to take ice loads into account but a special load case is not given. However, investigations concerning icing of wind turbines during operation at different places in Europe showed that heavy ice loads are not negligible. Thus, based on these experiences a proposal for simplified load assumptions for design codes has been worked out in [1]. However, the distribution forming the highest ice mass is the linear distribution. A method taking this distribution into account for load calculations is described below. The maximum depth of ice amount at the tip is thereby dependent on the blade's chord length. Measurements and observations for different sized wind turbines are known and were used as a basis for the approximations [2].

4 Dissemination of Information

Information on the NEW ICETOOLS project will be found e.g. on www-pages www.fmi.fi. It is also most likely that BOREAS VI "conference", the traditional meeting to discuss icing problems since 1992, will take place in Finnish Lapland (www.pyha.fi) at early April 2003.

5. Summary

Icing of structures like wind turbines, wind sensors, power lines etc. is much more common in Europe than typically expected e.g. by wind power people. Icing is not only a problem for the far north, but also for inland/mountainous sites in Germany, UK, Spain, Italy, Austria, and also in most of the new EU candidate states.

In this paper the new project, which will study the operation of wind turbines under icing conditions and make verification on various models on ice/rime accretion upon blades, on loads due to icing etc. compared to effects observed on wind turbines has been shortly described. The project focuses on production of a new icing map for Europe. The duration of the project is 1 Jan 2002 - 31 Dec 2004.

The project highly appreciates your co-operation concerning our questionnaire sent out later this year to collect data on operation of wind turbines under icing conditions.

Also any other information concerning icing events and operation of wind turbines under icing conditions is welcome. Please send your information to:
FMI Energy, Finnish Meteorological Institute, Vuorikatu 24, 00100 Helsinki, Finland.

6. Acknowledgements

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7. References

[1] Seifert, H. and Tammelin, B., 1996. Icing of wind turbines. Final report: JOU2-CT93-0366. DEWI.

[2] Tammelin, B., Cavaliere, M., Holttinen, H., Morgan, C., Seifert, H. and Säntti. K., 2000. Wind energy production in cold climate. Meteorological publications No 41. Finnish Meteorological Institute. pp. 41.

[3] Kimura, S., Tammelin, B., Peltomaa, A. and Tsuboi, K., 2000. Icing effect on a cup anemometer. Meteorological publications No 44. Finnish Meteorological Institute. pp. 41.

[4] Tammelin, B., Heimo, A., Leroy, M., Rast, J. and Säntti, K., 2001. Meteorological measurements under icing conditions - EUMETNET SWS II project. Reports 2001:6 . Finnish Meteorological Institute. pp. 52.

[5] Tammelin, B., Bergström, H., Botta, G., Douvikas, D., Rathman, O., Strack, M. and Hyvönen, R., 2001. Verification of wind energy prediction produced by Wasp and some mesoscale models in European mountains. In proceedings of European Wind Energy Conference 2001.

[6] Schönborg, A. and Blomgren, L., 2001. Two year´s experience of three different turbines on the same site - Rodovålen- in the very middle of Sweden. In the proceedings of BOREAS V conference. CD-rom. Finnish Meteorological Institute.

[7] H. Holttinen, G. Ronsten, L. Tallhaug, P. Lundsager, R. Horbaty, I. Baring-Gould, A. Lacroix, E. Peltola, T. Laakso, The State-of-the-art of wind turbines in icing and cold climates, presented at 2002 Global Wind Power Conference, 2-5 April 2002, Paris, France.

[8] Tammelin, B. and Säntti, K., (Ed.), 2001. Wind power production in cold climate - BOREAS V. Finnish Meteorological Institute.