

COST-727 Action: icing on structures

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Abstract

The COST-727 Action "Measuring and forecasting atmospheric icing on structures" was established in April 2004. The following general goal was then defined: 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.

Phase 1 of the action was dedicated to gathering available information for a comprehensive state-of-the-art report representing what the participants consider as a summary of today's available knowledge. The second Phase of the Action is dedicated to in-situ measurements of atmospheric icing with selected reference icing sensors at 6 stations operated in Europe and to the modeling of selected icing events with a new adaptation of the WRF model developed by Norway. The following deliverables are expected:

- *Scientific and technical publications on measurements and modeling of in-cloud icing*
- *Publications on verification of icing modeling*
- *Recommendations for WMO/CIMO AWS observations.*

The installation of the first 2 test stations has been performed in Switzerland (Guetsch, 2'300 m a.s.l., collocated with the highest wind turbine in Europe) and Finland (Luosto, 515 m a.s.l.). The other 4 stations are located in Sweden (Sveg), Germany (Zinnwald), United Kingdom (Deadwater Fell) and Czech Republic (Studnice).

First attempts of model simulations have been performed for icing events at the Guetsch, Deadwater Fell, and Zinnwald with very promising results. In particular, the collapse of a measurement tower located in the Swiss pre-Alps region could be simulated with a good accuracy.

Apart from meteorological measurements aspects, the COST-727 Action has promoted cooperation with the wind energy production sector (ice accretion on wind turbines) and the transport of electricity (power lines collapses). In particular, joint activities with the Conseil International des Grand Réseaux Electriques CIGRE has allowed to initiate a close collaboration with Iceland (simulation of wet snow accretion). Furthermore, the Final Workshop of the Action will be organized in collaboration with the 13th International Workshop on Atmospheric Icing on Structures IWAIS Conference in Andermatt, Switzerland, 8-11.9.2009.

Introduction

Icing¹ of structures is an important design parameter in many sectors, e.g. building industry, maritime and aviation activities, energy transport, tourism, meteorology, etc., and it has recently become a relevant issue also in activities related to wind energy production. Furthermore, human activities are increasingly extending to cold climate regions affected by icing problems.

¹ "Icing" is used to describe the process of ice or wet snow growth on a structure exposed to the atmosphere.

More specifically, icing effects – often combined with high wind speeds – can lead to security/safety problems in a society whose increasing complexity make it more and more sensitive to local disturbances. Here are some examples:

- For meteorological field measurements, it is obvious that ice accretion on operational meteorological instruments - in winter for lowland locations and all other the year for mountain or northern stations – can lead to erroneous information, with important potential consequences on climatic standards (structural design, water cycle, etc...) and forecasting, the latter being more and more relevant for modern activities.
- In the field of wind energy production, the accretion of ice on the wind turbine blades may cause a reduction of power due to disrupted aerodynamics [1] or lead to a complete loss of production due to the shut-down of the turbine [2]. Ice accretion may cause turbine overloads due to delayed stall or increase fatigue of turbine components due to rotor imbalance caused by the non-uniform ice formation on the blades [3]. Furthermore, ice throws from the blades when production is resumed represent a specific danger around the operating wind turbine with throws of impressive ice blocks tens of meters around [4].
- In the field of energy transport, icing of power lines can lead to dramatic accidents, even to the complete destruction of segments of power lines with important consequences on human activities (power cuts for whole regions) as occurred in 2005 in Germany.
- In the field of aviation, icing can significantly disturb the activities on airports (de-icing of airplanes, take-off and landing) as well as the normal flight operation of airplanes at all atmospheric levels.
- In the field of terrestrial transport, there is no need to describe further the effects of icing on traffic as this is well-known to all users, but there are also important - but less obvious - sensitive domains such as cable cars, railway switches, ski-lifts, etc... which are also sensitive to icing phenomena.
- In the field of telecommunication, ice accretion on transmission towers and/or telephone lines can lead to major disturbances of the mobile/fixed phone network. This may have dramatic consequences in a society which is increasingly addicted to this modern technology.



Pictures 1-3: Striking views of frozen meteorological instrument (top), wind turbine covered with ice (middle) and damaged power line (bottom).

Past activities

What has been done until now in order to attempt to develop remedies to attenuate the consequences of such events?

- For meteorological purposes, the effects of icing on measurements performed in harsh northern or mountainous environments has been investigated in national projects, (e.g. [5, 6]) and during two international comparisons: the first was organized under the WMO/CIMO label by France and Switzerland at the Mt Aigoual in France (Cévennes) in 1992-1993 for the inter-comparison of the

behavior of wind sensors under icing conditions [7]. A second inter-comparison was setup under the auspice of EUMETNET (SWS, Severe Weather Sensor I and II) with parallel measurements performed in Finland, France and Switzerland during one winter in order to study the response of sensors (wind, temperature and humidity, radiation) in harsh condition at different climatic locations in Europe [8,9].

- The increased use of wind power in many countries has required major changes to the basic network structures as the position of energy sources has changed. Often, these new sources are in hilly or mountainous regions which require power lines to deliver the power to an existing network. So their reliability and future stability relies on the continued development, refinement and application of the knowledge of line design and power production in severe climate areas.
- For wind energy purposes, several methods to prevent icing are in (test) operation and have been shown to work effectively [10,11,12,13]. Botura and Fisher [14] and Battisti [15] have presented methods for deicing. The wind energy research community has addressed the issue of icing since the early 1990's. However, due to a focus on developing wind farms at lowlands and offshore, no commercial de- or anti-icing solutions currently exist for medium and severe icing conditions [16]. With all of the methods that do not operate continuously, there is a strong need for a reliable icing detector to activate the deicing system. Various sensors have been tested, but did not perform satisfactorily. Consequently, there are no proven sensors which fulfill the needs of icing detection on wind turbines [17,18].
- For power lines, CIGRE (Conseil International des Grands Réseaux Electriques) has produced a major Technical Brochure by SCB2 WG16 on Guidelines for Meteorological Icing Models, Statistical Methods and Topographical Effects [19]. In order to maintain power supplies in a changing climatic world, it is vital to be able to determine the wind/ice loads on new and existing overhead lines over their expected lifetime. This requires high resolution, validated models and reliable functioning icing instruments. CIGRE is also upgrading older standards (such as IEC60826) on weather loading for structures. An extensive collection of reviews on the subject of power line icing has been published recently [20].

The COST-727 Action

Based on those past experiences, the COST-727 Action was launched in 2004 with the following objectives: to develop the understanding of icing (in-cloud icing, wet snow accretion, freezing rain) events and their distribution over Europe as well as to improve the potential to observe, monitor and forecast these various kinds of icing.

Due to diverse processes depending on geographic or climatic conditions, it is difficult to standardize the effects of ice accretion on structures. Therefore local (regional, national) experiments have to be performed, based on the only existing International Standards ISO 12494 [21]. Detailed information about icing frequency, intensity etc. has to be collected at different levels:

- i. Collect existing data from different regions,
- ii. Perform in-situ measurements of icing over periods of many years,
- iii. Perform icing modeling/simulation based on accurate meteorological data.

As icing measurements are practically never performed on Automatic Weather Stations, the first method relies mainly on operational activities in different fields such as telecommunication, power transmission, road and airport safety, wind turbine operation, etc... The third level should presently still be dealt with by R&D projects in Universities or within International projects (e.g. this COST-727 Action). Meteorological Services are more specifically fitted for the second level which implies operational activities upon a long period of time: in the future, standard instruments must be operated in the areas representative of the selected site (either for meteorological purposes or for industrial expertise) following established procedures and measurements should be taken for a sufficient long period to build a reliable basis for extreme value analysis. The time period could last a few years to several decades, depending on the conditions. However, shorter series may be of valuable help and can be connected to longer records of standard meteorological data, either statistically or (better) physically, in combination with theoretical icing models.

In order to fulfill these challenges, the COST-727 Action was organized in working groups dealing separately with these goals. On one side, intensive measurements were performed at two stations in Finland and Switzerland in order to select appropriate ice sensors on the market and to collaborate with the manufacturers to upgrade these sensors when necessary. On the modeling level, efforts were made to apply the ISO Standard formula to existing measurement dataset already existing in Europe. Finally icing mapping



Pictures 4-5: Views of the Luosto (Finland) measurement platform (left) and of the Guetsch (Switzerland) test site (right).

and forecasting were analyzed in view of the experiences gathered by the participants from Finland, Czech Republic and Bulgaria— countries with available long series of reliable icing observations. The procedure of ice mapping is based either on existing data of icing observations or on some simple icing models whose input parameters could be derived from the standard synoptic observations. Currently there are several national icing maps which are being developed:

- Icing occurrence for the Czech Republic, Bulgaria and Rumania
- Freezing rains for Finland and Austria
- Wet snow occurrence and wet snow loads for Germany.

An analysis of the frequency of rime icing on wind turbines based on simulated regional climate model data has also been made for Northern Europe. However, due to the not sufficient database of icing observations and manpower, still no icing map based on uniform procedure for the whole Europe is available. In fact, as forecasts have been rarely verified, it may still take a few or more years before the results of such work can be relied upon.

All these efforts have been concatenated in a State of the Art Report which was published early 2007 [22].

Fortunately, major improvements could be achieved in the middle of year 2007:

On the hardware level, two icing sensors were selected for further measurements: the first is based on the principle of frequency changes due to the accretion of ice on a vibrating finger, yielding a yes/no answer (Goodrich 0871LH1). The second sensor reproduces very nearly the definition set in the ISO 12494 standard: a 50 cm long, freely rotating cylinder (diameter 3 cm) is automatically weighted measuring the total amount of ice accreted and the accretion rate (Combitech IceMonitor Mk I). However, experiences gathered during the winter 2007-2008 showed that the present design concept of freely rotating cylinder was not fully adequate since in conditions of high levels of accretion ice tends to creep up on the body of the instrument and finally restrict or even stop the rod's free movement. Therefore, in connection with the manufacturer, a new prototype was designed (Mk II) with forced rotation and hanging cylinder: prototypes of this new sensor should be available for the winter 2008-2009. Additional ice detectors can be tested at each site and the results compared with those obtained by the reference instruments.

Furthermore, the available automatic ice sensors have still to be improved and extended. In particular, there are two parameters which should be locally monitored for input to the models: the liquid water content (LWC) and the droplet size distribution (DSD, for in-cloud icing in particular). For the time being, this information has still to be manually set when running the model – an obvious drawback. This means also that important improvements of the algorithms used in the WRF have to be performed in order to obtain more accurate modeling/forecasting of icing events, for in-cloud icing as well as wet snow accretion and freezing rain.

In parallel, four existing measurement sites located in Sweden, Germany, United Kingdom and Czech Republic were fitted with the Combitech instrument for the winter 2007-2008, and will be installing the Goodrich sensors in time for the 2008-2009 winter, so that 6 “icing” stations altogether will be operational in Europe (in fact, another 2 stations will be setup in Switzerland, in the pre-Alps and Jura regions).

The Weather Research and Forecasting (WRF) model is a well known modern mesoscale, non-hydrostatic numerical weather prediction model designed for mesoscale and high resolution forecasts mainly by NCAR, NOAA and NCEP (USA). By upgrading the WRF with advanced cloud microphysics and with the standard icing formula, excellent simulations could be achieved for icing events measured at the Guetsch station in Switzerland and at the Deadwater Fell station in UK during the winter 2007-2008. As a first operational application, the origin of an accident which happened in Switzerland in November 2007 could be related with WRF simulations to a major ice accretion event combined with high wind speeds on a measurements mast in the pre-Alps.

All test sites have accumulated icing data – with all other relevant meteorological measurements – which have been compiled within a unique European dataset: each station has delivered data for at least three icing events during the last winter, which will be used for simulation purposes and improvement of the updated WRF model. Subsequent simulations will be performed during the coming winter.

Conclusion

All COST Actions depend on the goodwill and support of the single participants to reach successfully the goals defined in the original Memorandum of Understanding. The mere fact that six stations could be outfitted and operated in six different countries in Europe with identical icing sensors already represents in itself a major success. It is therefore important that these activities will be continued in the future under a new international umbrella – European or world-wide – as there are still important improvements to be achieved.

The Final Workshop of the COST-727 Action will be organized in collaboration with the 13th International Workshop on Atmospheric Icing on Structures IWAIS Conference in Andermatt, Switzerland, 8-11.9.2009.

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