Masoud Farzaneh
(Ed.)

Atmospheric Icing of Power Networks

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Editor

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Foreword

Atmospheric ice takes a wide range of forms, usually quite beautiful and harmless. But it may, on occasion, pose severe risks to the security of many types of man-made structures, including power networks and transportation systems. As ice or sticky snow accumulates on network equipment and structures, it adds weight which, if combined with wind, can upset the precarious balance of these systems, sometimes leading to partial or total collapse. Other factors can also come into play; for example, ice or wet snow formation along insulators can eventually bridge the shed spacing, which can cause flashovers and, consequently, power outages. Serious damage and even loss of life can result from severe ice storms, as has been noted in the recent past, and efforts to mitigate their effects are on-going. This brings us to the purpose of this book.

First of all, let us mention that, despite the existence of many technical reports and papers in specialized journals and conference proceedings, none are assembled as a comprehensive study of the atmospheric icing phenomenon, and the results are not sufficiently distilled to support power line design. With its clear and tight focus, this book aims to fill that gap in the field of atmospheric icing. Furthermore, standards-based, deterministic approaches to overhead line design are currently used in the field, while international standards are striving to incorporate probabilistic design methods. Design experts need to understand where the probability distributions come from and know how to apply them.

Consequently, a team of internationally acclaimed experts in various aspects of atmospheric icing was invited to produce a compendium of their respective expertise. This compilation gives a detailed account of the fundamentals of atmospheric icing and it moves through a survey of the state of the art in design, modelling, prevention, and more, all in a richly illustrated format. In essence, we wanted to arrange the book in a logical sequence, from the meteorological aspect, moving on through various subjects, and finally leading to design. Accordingly, Chapter 1, *Modern Meteorology and Atmospheric Icing*, looks at how meteorology can help engineers and designers to better plan power-line routes or situate wind-turbine parks, through better understanding of weather patterns in a given region. In the next chapter, *Statistical Analysis of Icing Event Data for Transmission Line Design Purposes*, the authors describe how data from ice storms is gathered by monitoring systems and is used to establish design parameters for lines crossing regions where severe icing events occur. The third chapter, *Numerical Modelling of Icing on Power Network Equipment*, discusses how numerical icing models have become such essential tools in the field, as they use observations and measurements to produce simulations of extreme events that may be beyond our empirical experience. This is followed by *Wet Snow Accretion on Overhead Lines*, which deals with the physics of snow, particularly wet snow accretion on power line conductors, both in the wind tunnel and under natural conditions, in terms of overload hazards. Chapter 5, *Effects of Ice and Snow on the Dynamics of Transmission Line Conductors*, deals with the reliability and lifespan of iced conductors under such stresses as galloping, or wind-induced oscillations and aeolian vibrations, the mechanisms involved, and prevention methods. This is followed by a review of mitigation methods in *Anti-icing and De-icing Techniques for Overhead Lines,* which describes the various methods used by utilities, or under development, to combat ice accretion, by either removing already accreted ice or preventing it from sticking to surfaces. Then, *Effects of Ice and Snow on the Electrical Performance of Power Network Insulators* is a detailed look at the electrical performance of line and station insulators covered with ice or snow; it takes us through the modelling, testing, design and mitigation stages. Finally, Chapter 8, *Design of Transmission Lines for Atmospheric Icing*, is the ABC of structural design for adverse winter conditions – a thorough description of transmission line design, taking into account snow and ice overloads and other extreme weather effects. All in all, the book is a comprehensive and exhaustive examination of atmospheric icing, its causes, effects, and how to best mitigate the various hazards it poses.

The work is intended as a useful tool for utilities, first and foremost, looking to implement or adjust company-wide design policies with regard to severe wind and ice loads on overhead lines, and utility maintenance engineers and operators, who try to balance the costs and benefits of mitigation options when addressing specific icing problems. As well, professionals involved with the IEEE Power Engineering Society (PES), CIGRE and IEC, in their efforts to develop international icing standards, will find the book useful in their detailed studies of specific areas of research and consulting. The volume is also intended to be used as a fundamental text for students and researchers in the area of high voltage power transmission in university and college programs, who will find in it many worked examples for evaluating network reliability under various load conditions.

In the end, we hope that this book will, first of all, fill the need for up-to-date knowledge about the progress of research in the field of atmospheric icing of power network equipment and other sensitive man-made structures in recent years. Secondly, we hope we have achieved the purpose we had in mind, by compiling, in a single volume, much essential information that would otherwise remain dispersed throughout various technical journals and workshop proceedings.

As Editor, I would like to sincerely thank everyone who contributed to the publishing of this endeavour, and particularly the authors, who put in countless hours to provide us with the core of their research and developments. These utility and academic experts jointly participate in a biennial conference series called the International Workshop on Atmospheric Icing of Structures (IWAIS), where they are motivated to discuss ways to reduce the devastation from atmospheric icing at a practical cost. The rich content of these workshops, two of which I have had the honour to Chair, in Chicoutimi in 1996 and in Montreal in 2005, is at the root of the idea for this book. Indeed, on the occasion of the 11th IWAIS in Montreal, I invited keynote speakers to head the individual sessions of the conference and I subsequently asked them to expand their presentations for inclusion in this book. Once again, I thank them and I hope that the fruit of their efforts will find its place everywhere that atmospheric icing issues need to be managed.

Masoud Farzaneh
Editor

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About the Editor

Professor Masoud Farzaneh is an internationally renowned expert in the field of power engineering, including atmospheric icing of power network equipment, insulation and corona-induced vibration (CIV). He is currently Director of the International Centre on Icing and Power Network Engineering (CENGIVRE), as well as Chairholder of the NSERC/Hydro-Quebec Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE) and of the Canada Research Chair on Engineering of Power Network Atmospheric Icing (INGIVRE) at the University of Quebec in Chicoutimi, Canada. His fruitful and long-term collaboration with Hydro-Quebec, which led to the creation of the most complete icing research laboratory worldwide, was officially recognized when he received the prestigious NSERC Leo-Deriks award in 2005. In 2008, he received the prestigious Charles Biddle Award highlighting his exceptional contribution to the scientific development of Quebec. He has authored as many as 600 scientific publications, including 360 refereed papers, as well as several books and chapters in the areas of high voltage, insulation, CIV and atmospheric icing.

He is Associate Editor of IEEE Transactions on Dielectrics and Electrical Insulation, Chair of IEEE DEIS Outdoor Insulation Committee, as well as Convenor of CIGRE WG B2.29 on HV and UHV overhead line anti-icing and de-icing systems. He is also Chairman or member of several IEEE and CIGRÉ task forces dealing with atmospheric icing of HV equipment.

Dr Farzaneh is Chartered Engineer of the Engineering Council (U.K.), Charter Member of International Society of Offshore and Polar Engineers (ISOPE), as well as member of Conseil international des grands réseaux électriques (CIGRÉ). He is Fellow of IEEE, Fellow of the Institution of Electrical Engineers (IEE), Fellow of the Engineering Institute of Canada (EIC), member of the New York Academy of Sciences and the American Association for the Advancement of Sciences.

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Chapter 1
Modern Meteorology and Atmospheric Icing

Svein M. Fikke, Jón Egill Kristjánsson and Bjørn Egil Kringlebotn Nygaard

1.1 Introduction

Atmospheric icing affects a wide variety of man-made structures in many countries. It is generally well known to occur in northern countries like Japan (Admirat and Sakamoto 1988), Canada (Farzaneh and Savadjiev 2001), United Kingdom (Wareing and Chetwood 2000), Iceland (Thorsteins and Elíasson 1998), Finland (Lehtonen et al. 1986), Hungary (Krómer 1993), Norway (Fikke and Johansen 1987), Czech Republic (Popolanský 2000), Romania (Goia 2000) and Russia (Golikova et al. 1989), as well as many other countries in both hemispheres.

Man-made structures at the top of mountains are often exposed to rime icing. In other areas, wet snow or freezing rain likewise affect infrastructures at lower altitudes. Therefore, power lines, wind turbines, telecommunication towers or high masts, ski lifts and other buildings are designed to withstand the loads and other adverse effects due to icing, as well as ice loads affecting their mechanical strength or operational reliability in many ways. Most countries have their own standards to take care of ice loads on their structures. At the international level, efforts are made to establish and improve standards and methodologies for handling the impacts of icing on various structures in the most economical and rational manner by both the International Electrotechnical Commission (IEC 1997; IEC 2003), the International Standardisation Organisation (ISO 2000) and the International Council on Large Electric Systems (Cigré 2001).

Some examples of icing are illustrated in Figs. 1.1, 1.2 and 1.3. Figure 1.1 shows the largest ice loading ever recorded on an overhead power line. This accretion was observed in Norway in April 1961, and the greatest elliptic cross-section diameter was measured at 1.4 m and the smallest at 0.95 m. A one-metre length of the accretion was collected and weighed 305 kg.

Figure 1.2 shows a wet snow incidence in Iceland. The cross-section accretion is in this case quite uniform in physical appearance, without a pronounced pattern showing the elliptic build-up.

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Fig. 1.1 Rime icing on a 22 kV electric power line in Norway April 1961, 1 400 m above sea level. The ice load was measured to 305 kg/m (Photo: O. Wist, reproduced by permission of S. M. Fikke)

Figure 1.3 is from a Swiss test station on the mountain Gütsch, near Andermatt, in the Alps. Together with an operating wind turbine, there is a test site where a variety of meteorological instruments as well as icing detectors and devices for measuring ice loads are installed for the purpose of performance and feasibility testing. The project is a part of the European Cooperation in the field of Scientific and Technical Research (COST) Action 727: "Atmospheric Icing on Structures Measurements and Data Collection on Icing", operating through the years 2004–2009. The project also generates data sets to be used for calibrating atmospheric models for icing forecasts, see (Fikke 2005a, 2007a,b).

During the last century, when societies expanded their economic developments and new infrastructures had to be established in hitherto unknown places, experience

Fig. 1.2 Wet snow accretion on a collapsed power line in Iceland (Reproduced by permission of Á. Elíasson, Landsnet, Iceland)