Lecture Notes in Electrical Engineering 780

Chandima Gomes *Editor*

Lightning

Science, Engineering, and Economic Implications for Developing Countries

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Foreword

I feel very privileged to write this foreword for this book on lightning, which has been the subject of predilection of my scientific research for almost 35 years. My relationship with the book Editor, Prof. Chandima Gomes, goes back to the late 1990s, when I met him during a visit to Uppsala University. At that time, Chandima was a young graduate student working towards a Ph.D. degree under the supervision of my dear friend and colleague, Prof. Vernon Cooray, who is one of the world's most eminent lightning scientists. I remember an interesting discussion I had with Chandima on return stroke modelling, which, among many others, was one of the topics in his thesis. I was very much impressed by his knowledge and maturity, despite his young age. Later, in 2000, he published a paper in the IEEE Transactions on Electromagnetic Compatibility[1] in which he presented a very general categorization of the return stroke models, showing that all of the models can be described by two general sets of mathematical equations. This paper is considered today as a classic in return stroke modelling.

After finishing brilliantly his Ph.D. thesis, Chandima established a successful international academic career starting at the University of Colombo in Sri Lanka. Over the following years and during the past 20 years or so, I was in close contact with him and watched him develop into a first-class researcher.

Beyond his outstanding scientific achievements, especially in the field of lightning and lightning protection, Chandima always felt concerned about the ethical aspects of scientific work, in general, and, in particular, about how to reduce deaths, injuries and property damage from lightning in the developing countries, hence this book. Who else but Chandima could have designed and edited it?

The book comprises a logically organized sequence of 11 chapters that are, at the same time, self-contained and can therefore also be read separately. It starts with three fundamental and general chapters describing the physics of lightning, basic approaches for lightning detection and warning systems, and risk assessment, making the book also very accessible to the technical non-expert. The ensuing chapters are focused on the protection of different types of systems and infrastructure, with

[1] C. Gomes and V. Cooray, Concepts of Lightning Return Stroke Models, IEEE Trans. EMC, Volume 42, Issue 1, Feb 2000.

special attention to the protection of renewable energy systems. The final chapters are concerned with economic, human and technical aspects of lightning protection, with a strong emphasis on developing countries.

One of the particularly remarkable aspects of the book is that, except for two chapters, Chandima has solicited authors who are lightning scientists from developing countries in Asia, Africa and South America.

In 2015, the United Nations adopted Agenda 2030, which includes 17 Sustainable Development Goals (SDGs) which aim at fighting poverty in all forms and at promoting sustainable development. This book presents, in a comprehensive way, methods and technologies that can greatly contribute to the attainment of these 17 SDGs.

October 2020

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Preface

Lightning is one of the most revered extreme natural events revered by many civilizations for a few millennia. Started nearly three hundred years ago, lightning was explored as per the modern scientific methodologies in many countries by a number of scientists, so far. These researches shed light on many phenomena related to lightning; however, the bulk of the physics of lightning is still far being fully understood. On the other hand, technologies of lightning protection measures of structures and systems, and methods of lightning safety of human beings and animals have been deeply studied. The outcomes of these researches have been documented as standards and guidelines, and consequently put into practice, however, mostly in developed countries. As such, the temporal records of many developed countries clearly delineate that lightning-related losses of both property and life in these countries have significantly reduced over the last century.

The lightning ground flash density maps reveal that the occurrence of lightning is much higher in equatorial and oceanic tropical regions in the world than that in temperate regions. Unfortunately, most of the countries in this region belong to the developing world where the literacy rate, level of education, quality of sheltering, medical facilities, infrastructure, etc., are below par compared to the same in the developed world. In turn, these countries experience the highest fatality rates, property damage, service interruption and down time-related losses due to lightning. The scientists and researchers, engineers, educators and social activists in these countries are at a distinct disadvantage of accessing the latest knowledge and know-how due to both economic and strategic reasons. These lapses further suppress the development of their own technology or methodologies in the developing world for curbing lightning accidents.

This book has been developed in the above backdrop; thus, its major goal is to channel the concurrent knowledge from the leading scientists and engineers in the field to the scientific public in the developing countries. The contents of the book will also be a very valuable source of information for academics, researchers, funding agencies and business communities in developed countries who interact with fellow professionals, grantees and clients/customers of developing countries. The will also be a very useful handbook for early career researchers and engineers involved with lightning-related research and consultancy, irrespective of their location.

The concept of developing such a book has been proposed by Dr. Amitava Bandopadhyay, Director General, NAM S&T Centre, New Delhi. Since 2007, NAM S&T Centre has generously supported organizing international symposia on lightning sciences in Sri Lanka, Nepal, Uganda and Zambia, during which several authors of this book gathered invaluable facts and figures on lightning-related incidents in developing countries. They could also acquire first-hand information on the level of awareness on lightning safety and protection among both educated masses and the general public of these less-privileged communities. I may confidently state that this wealth of knowledge has made the platform for several authors of this book for understanding the needs of the potential readers.

This book contains eleven chapters contributed by 19 authors from Brazil, China, Colombia, France, Germany, India, Mexico, South Africa, Sweden and the USA. The contents basically cover the physics of lightning, lightning detection, lightning protection of structures, low-voltage systems and high-risk installations, lightning accidents, injury mechanisms and safety guidelines, economic implications and future research opportunities.

I would like to express my heartfelt gratitude to all the authors, Prof. Vladimir Rakov, Dr. Anirban Guha, Dr. Yakun Liu, Prof. Earle Williams, Dr. Carina Schumann, Dr. Hugh Hunt, Mr. Alain Rousseau, Mr. Alexis Barwise, Prof. Ruy Alberto Corrêa Altafim, Mr. Sergio Roberto Silva dos Santos, Prof. Hélio Eiji Sueta, Dr. Arturo Galván Diego, Prof. Michael Rock, Mr. Ronald L. Holle, Prof. Emerita, Dr. Mary Ann Cooper, Dr. Norberto Navarrete-Aldana, Mr. Ashen Gomes and Prof. Adônis F. R. Leal, who kindly accepted my invitation to write the chapters and providing the complete contents well in time.

Thanks are also due to Dr. Amitava Bandopadhyay and his team at NAM S&T Centre, for all the support rendered; Prof. Farhad Rachidi, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland, for writing the forward; and Dr. Loyola D'Silva, Senior Editor, Springer Nature, Singapore, and his team for making this endeavour a success.

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Introduction

Lightning and thunderstorms are of concern for the human beings for many centuries. Even today, many communities and tribes believe that lightning is a God itself or it is a weapon hurled by the divine powers. As people started analysing lightning as a physical phenomenon, around 300 years back, the attention was mainly on understanding the nature of lightning and the ways of avoiding the lightning strikes damaging their properties. With time, this focus was shifted to safeguarding of human beings and livestock, protecting power lines that stretch over hundreds of kilometres over highly exposed land, protection of defence systems and electronics & communication system.

In the 1970s, scientists realized that similar to other atmospheric phenomena, lightning may also be forecasted in advance. Such forecasting could play a significant role in planning outdoor activities and preparation of emergency crews for power system breakdowns. However, the enormous number of dynamic variables that determines the spatio-temporal location of lightning flashes prevented them from making these predictions with reasonable accuracy, at least by few minutes in advance. Such limitations gave birth to a new term, *Lightning Nowcasting*, where the detection system could reconstruct the lightning strike point as soon as it is attached to a ground point. More specifically, *Lightning Nowcasting* refers to the prediction of areas and times where lightning activity may occur within 0–1 hour based on intelligent software. Even such systems could provide very useful information on planning outdoor activities in the event of an approaching thunderstorm, developing lightning density maps which are essential in the risk assessment of buildings and properties and flight control management at airports.

In the last decade, as super-fast computers and smart algorithms started emerging, scientists were empowered with the ability of processing millions of data with real-time feedback loops. Thus, gradually prediction of lightning and even the movement of thunderstorms became a possibility with high accuracy. In parallel, several research groups found that there could be some strong correlations between electric discharge activities in thunderclouds and extreme weather events to take place subsequently, such as tornadoes, micro-bursts, cloud bursts and flash floods. At present, many researchers focus on their research in this direction, so that highly expensive and

complex weather radar systems could be replaced by an accurate lightning detection system.

The frontiers of lightning protection of buildings are rather stagnating for the last couple of centuries, although there were moderate successes in developing more accurate risk assessments and documentation of protection measures. Some developments emerged as "Modern Technologies" in the 1970s onwards still struggle to justify the validity of their abilities. In the safety measures of equipment, known as surge protection, there is a significant development as the protection industry has to meet the demands of safeguarding electronic systems that become highly sophisticated, vulnerable and miniaturized at a rapid pace.

Research has also been underway for the last three decades to trigger atmospheric lightning artificially, mainly for the purpose of testing and evolving the protection methods and understanding the physics of lightning. So far, rocket-triggered lightning has been done very successfully, now with a success rate of over 80%, in USA, China and few other countries. The interesting phenomena of laser-triggered lightning have been started and abandoned few times in several countries during this period. In the last few years, this topic came back to the fore due to the latest development of high-power pulsed lasers. There are speculations that if laser-triggered lightning is successful, one could avoid undesired lightning by discharging the charged clouds into predetermined destinations.

For the last few decades, scientific world has also been working on several other concepts of academic interests, such as ionospheric lightning (red sprites, blue jets and whistlers), lightning in volcanic eruptions and discharge phenomena in the atmospheres of other planets. However, now several researchers, specifically those who emerged from the developing world, work intensively on developing low-cost structural protection measures and personal protection gears targeting at safeguarding the underprivileged communities in the world, where a clear majority of lightning mishaps occur annually.

In this connection, I am proud to mention that in the past, the NAM S&T Centre has made significant contributions in capacity building and exchange of knowledge for its member countries on the subject of lightning and other extreme natural events in partnership with various S&T institutions and agencies by organizing international workshops, roundtables, symposiums and training programmes. These programmes of the centre also led to the establishment of the *African Centre for Lightning and Electromagnetics Network (ACLENet)* based in Kampala, Uganda and *Zambian Centre for Lightning Information and Research (ZaCLIR)*. Recently, similar network has been established in South Asia (SALNet) of which the present headquarters is in Kathmandu, Nepal. Several other African countries such as South Africa, Kenya and Zimbabwe are now in the process of establishing their own national centres.

I am extremely delighted that the NAM S&T Centre has reached another milestone by publishing its first scientific monograph titled *Lightning—Science, Engineering and Economic Implications for Developing Countries*. I gratefully acknowledge the contributions made by eminent experts from various countries with their papers on different themes on lightning including lightning science research; protection of buildings, structures and power systems; lightning detection and warning, etc.

I express my sincere gratitude to Prof. Chandima Gomes, Professor of High Voltage Engineering, University of the Witwatersrand, Johannesburg, South Africa, for accepting our request to take charge of our first monograph project as the *Chief Editor.* He has conceived and planned the entire monograph, and we are thankful to him for his guidance and support to the centre in bringing out this valuable publication. We are also thankful to Prof. Farhad Rachidi, Professor and Head of the EMC Laboratory at the Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland, for kindly agreeing to write the *Foreword* of the monograph in spite of his extremely busy schedule.

I am thankful to Dr. Loyola D'Silva, Senior Editor, Springer Nature, Singapore, for considering this book worthy for publication under the reputed name of *Springer Nature*. I am also thankful to Dr. Suvira Srivastav, Associate Editorial Director, Springer, New Delhi, for her initial guidance to the NAM S&T Centre and helping us to get in touch with Dr. D'Silva. I am confident that our first ever association with "Springer" would be highly successful and would lead to many more such collaborative endeavours in future.

My sincere thanks are also due to the entire team of the NAM S&T Centre, especially to Mr. M. Bandyopadhyay, Senior Adviser, and Ms. Jasmeet Kaur, Programme Officer, for facilitating this new initiative of the centre.

I am sure that this book would be a valuable reference material for the scientists, researchers and other professionals working in the area of "lightning" and other relevant fields.

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