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Introduction

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Wind power development and the issues related to wind integration are very vital. For those who appreciate engineering, electrical engineering aspects of wind integration is one of the most interesting disciplines around, because of the required rethink of power system operation not seen in electrical engineering for decades. However, if you compile a book about this topic you face the significant challenge of keeping it up to date. Hence, for this second edition of the book, almost all of the previous edition’s chapters needed to be completely updated to consider the ongoing development since the first edition was published.

When the first edition of this book was finalized in 2004, more than 83% of the worldwide wind energy capacity was concentrated in five countries, namely, Germany, the USA, Denmark, India and Spain. At the end of 2010, this share of worldwide wind capacity had dropped to 53%. In 2004, only those five countries had more than 1000 MW wind capacity each installed, at the end of 2010 already 20 countries have more than 1000 MW installed.

In 2004, the aim of the book was mainly to spread the experience and knowledge from those countries with wind integration experience to those with increasing interest in wind power development. Of course this has not changed, because many countries still have a very low penetration level of wind power, and are trying to gain a better understanding of the possible impact of increasing wind power penetration in the future. But in 2004, the expected share of wind generation in the future power system was rather low compared to expectations six years later, as many countries have significantly increased their renewable energy targets over the past years. Within the next 10–30 years, many countries in Europe aim to generate 50% or more of their energy consumption from renewable energy sources, which will often include significant shares of wind power. Integrating such high wind penetration levels will require a complete rethink of the overall power system control architecture as well as the operation of the power system and a redesign of the affected markets.

The book does not provide final solutions for the challenges ahead, but its main objective is to give an overview of lessons learned in integrating wind power into power systems so far (particularly in Part E of the book). Power systems around the world are some of the largest infrastructure systems developed over the last 100 years. The different power systems vary in terms of power generation technology, transmission system, market arrangements and
technical rules and regulations. Due to those differences, a purely academic approach to the upcoming challenges is not sufficient, because the differences in the various power systems must be considered. Hence, this book aims to present industry experience from around the world. I am therefore particularly grateful for the various contributions from transmission system operators as well as wind turbine manufactures on practical experience and solutions that have already been implemented.

The final version of the book now comprises seven parts. Part A presents the basic theoretical background knowledge. Here, Chapter 5, which was written by Anca-Daniela Hansen, is central to the entire book as it presents an overview of current wind turbine designs. Throughout the book, the authors refer to the wind turbine designs (Type I, II, III and IV)\(^1\) from Chapter 5 and do not describe them in the individual chapters again. In addition, this part of the book presents a general discussion of power system requirements regarding wind power (Chapters 4 and 6) and of the value that wind power contributes to a power system (Chapter 7).

Part B provides an overview of technical regulations and grid code validation related to wind power. It covers power quality standards (Chapter 8), power quality measurements (Chapters 9 and 10), network interconnection standards (Chapter 11) as well as validation and certification to fulfil grid code requirements (Chapter 12).

Part C on wind power plant and transmission issues starts with a discussion of the electrical design of a wind power plant (Chapter 13), followed by the transmission system for offshore wind power plants (Chapter 14) and the presentation of innovative cable solutions for offshore wind power plants (Chapter 15) as well as a new wind power plant control concept (Chapter 16).

Part D provides an overview of international studies related to wind integration, starting with an overview of methodologies and results of integration studies (Chapter 17), compiled by IEA Task 25 working group; followed by an overview of studies in Europe (Chapter 18) and the USA (Chapter 19). Finally, results of academic studies on transmission congestion (Chapter 20), storage (Chapter 21) and present economic issues that have come up with the integration of wind power in the deregulated electricity industry, particularly in Denmark, are presented in Chapter 22.

Part E presents practical international experience regarding the integration of wind power. It starts with contributions from Energinet.dk, the Transmission System Operator (TSO) in Denmark (Chapter 23) and a German TSO (Chapter 24), followed by a chapter about the experience in Portugal (Chapter 25), Spain (26), Ireland (Chapter 27) and Texas (Chapter 28). These six countries/regions currently lead the world in wind power penetration. In addition, the unique experience from New Zealand during a major event is presented in Chapter 29 and the challenges of the fast increase in wind power installations in China in Chapter 30.

Practical experience from wind power in isolated systems is presented in Chapter 31 and from developing countries such as India in Chapter 32. Part E also includes a chapter on current issues regarding wind power forecasting (Chapter 33).

Part F shows how dynamic modelling is used to study the impact of a large-scale integration of wind power. As a start, general wind power modelling issues are presented and discussed (Chapter 34). This is followed by chapters on generic models (Chapter 35), low-order models (Chapter 36) and high-order models (Chapter 37) for wind turbines as well as on the full verification of dynamic wind turbine models (Chapter 38). The impact of wind power on power system stability is discussed in Chapter 39, and the last chapter in this part (Chapter 40)

\(^1\) In the first edition we had named the different types A, B, C and D but over the past years the naming convention I, II, III and IV has become the standard in the industry.
discusses aggregated wind turbine models that represent a whole wind power plant and not only a single wind turbine.

Finally, Part G discusses future concepts related to an increasing penetration level of wind power in power systems. The issues cover active management of distribution systems (Chapter 41), wind power and smart grids (Chapter 42), voltage control (Chapter 43) and the use of hydrogen as an alternative means of transporting wind power (Chapter 44).

Due to the large number of contributors, it was not always possible to avoid overlaps between the chapters. Even though I have tried to limit them, these overlaps show that there may be diverging opinions regarding individual subjects. The careful reader will certainly notice these overlaps and sometimes even contradictions. There remains a substantial amount of research to be done and experience to be gathered in order to arrive at a more consistent picture.

I would like to thank all authors of the individual chapters for supporting this time-consuming project. A special thanks goes to Charlie Smith from UVIG, who was a great help in identifying suitable authors in North America and Asia. In particular I like to thank Gill Whitley for great project management and language editing, and for being so supportive of the whole project. I would also like to thank Laura Bell, Peter Mitchell, Simone Taylor, Liz Wingett and Genna Manaog from John Wiley & Sons for moving this project forward, and Prakash Naorem from Thomson Digital for a good typesetting job. I would also like to acknowledge the many and valued contributions of Wiley’s Nicky Skinner to the genesis of this book. She passed away without seeing this book come into fruition but her enthusiasm with her job and this manuscript is very much alive in the pages of this book.

Finally, I would like to thank all the contributors and participants of the annually held Workshop on the Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Power Plants. The workshop was an important source for compiling and updating this edition of Wind Power in Power Systems.

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Introduction to the First Edition

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Wind energy gains increasing importance throughout the world. This fast development of wind energy technology and of the market has large implications for a number of people and institutions: for instance, for scientists who research and teach future wind power and electrical engineers at universities; for professionals at electric utilities who really need to understand the complexity of positive and negative effects that wind energy can have on the power system; for wind turbine manufacturers; and for developers of wind energy projects who also need that understanding in order to be able to develop feasible, modern and cost-effective wind energy projects.

2 http://www.windintegrationworkshop.org/
Currently, the five countries Germany, the USA, Denmark, India and Spain concentrate more than 83% of the worldwide wind energy capacity in their countries. Here, we also find most of the expertise related to wind energy generation and its integration into the power system. However, the utilization of this renewable source of power is fast spreading to other areas of the world. This requires the theoretical knowledge and practical experience accumulated in the current core markets of wind energy to be transferred to actors in new markets. A main goal of this book is to make this knowledge available to anybody interested and/or professionally involved in this area.

The utilization of wind energy has a tradition of about 3000 years and the technology has become very complex. It involves technical disciplines such as aerodynamics, structural dynamics and mechanical as well as electrical engineering. Over the past years, a number of books on aerodynamics and the mechanical design of wind power have been published. There is, however, no general publication that discusses the integration of wind power into power systems. This book wants to fill this gap.

I first realized the need for such a book in 1998, shortly after arriving at the Royal Institute of Technology in Stockholm. There I met Lawrence Jones who wrote his PhD on the high voltage DC (HVDC) technology. We had long discussions on possible applications of HVDC technology for offshore wind farms. The more we discussed, the more questions there were. As a result, in 2000 we organized a workshop on the topic of ‘HVDC Transmission Networks for Offshore Wind Farms’. This workshop turned out to be a successful forum for the discussion of this subject, resulting in the decision to hold workshops on the same subject in 2001 and 2002. The discussions during these workshops became broader and so did the subject of the workshop. Hence, in 2003, the workshop was entitled: ‘Fourth International Workshop on the Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms’. That time, the co-organizer was Eltra, the transmission system operator of Western Denmark, and 175 participants from academia and industry attended the workshop.

During the workshops it became clear that the subject of wind power in power systems met an increased general interest. In order to satisfy this interest, the initial idea was to simply summarize the papers from the workshop. This turned out to be more complicated than initially assumed. Designing a publication that can be of interest to a wider readership, including professionals in the industry, authorities and students, was not easy. Another challenge was to keep the content to a large extent consistent. Finally, I wanted to include not only papers from the workshop, but also contributions from other authors who are renowned researchers in this field.

Initially, it was my intention to win contributors not only from academia and TSOs, but also from wind turbine manufacturers as these have valuable experience to share. However, with the exception of one wind turbine manufacturer, the design of this book was considered to be too ‘academic’ by those I have approached. In my opinion, wind turbine manufacturers have been developing and introducing interesting solutions for the integration of wind power into power systems and should present such solutions in any possible future edition of this book.

I would like to thank all authors of the individual chapters for supporting this time-consuming project. I would also like to thank Kathryn Sharples and Claire Twine from Wiley for their continuous support and great patience, and Dörte Müller from powerwording.com for her language editing, which has improved the book’s general readability. I would also like to thank Professor Lennart Söder and the entire Department of Electrical Engineering at the Royal Institute of Technology in Stockholm.
Institute of Technology, Stockholm, Sweden. Special thanks go to Göran Andersson, now with the Swiss Federal Institute of Technology, Zurich, Switzerland, who was very open to the initial idea of holding workshops on these subjects. He also provided valuable comments on the workshops and this book.

I hope that the book proves to be a useful information and discussion basis for readers with diverse backgrounds.

In connection with this publication, the editor will introduce a website (http://www.windpowerinpowersystems.info) with more information regarding this book, a discussion group and information on forthcoming workshops and other events.

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