Preface

Power systems are among the **most complex technical systems built by humans**. Hundreds of generators, which are located at great distances from each other, are working synchronously day and night. They supply hundreds of millions of people with continuous, high-quality electrical energy. This is the result of more than 140 years of power-system technology development.

Nowadays, **power systems** are undergoing far-reaching **transformations.** The imperative to contain the rate of climate change has put into question the generation of power in large **coal-burning power plants. Nuclear power plants**, although emission-free and efficient, **have also lost societal acceptance** after the catastrophes of Chernobyl and Fukushima. Other forms of **renewable energy**, today mainly from wind and solar generators, are **replacing** the large "dirty" **power plants.** This **conversion process** has been taking place for over 20 years in developed countries and has already **resulted** in a **high share of renewable generation** in today's energy mix worldwide. The member states of the European Union and the USA, China, and many other countries are increasing their respective share of clean generation in the overall mix at varying speeds. In the European Union, renewable generation already makes up about 20 % of overall generation and is scheduled to grow to 80 % by 2050. However, in some European countries, e.g., Denmark, Germany and Spain, the power generated by renewable technologies is already at a higher level than the maximal demand. In those countries, hours or days—e.g., sunny and windy Sundays—can be observed where 100 % of the local demand is covered by electric energy produced by renewables. In **China**, renewables have reached 17 % of the energy mix, and the country became the **number one producer of wind energy** in **2015**.

Renewable generation depends strongly on the **weather conditions**. Solar generation is possible only during daytime and can fluctuate greatly. Volatility is also a factor in wind-energy generation. The wind does not blow constantly, neither on- nor off-shore. The **strict quality requirements** concerning the delivery of energy (i.e., voltage and frequency) to customers—especially to modern industrial customers—**must be fulfilled** despite the challenging conditions. Consequently, there is a

strong need to find new or activate known **flexibility options** in power systems that would enable a **smoothing of the fluctuations of RES** generation. One of the **best natural options** to smooth the volatility of renewable generation is buffering the energy production with **electric energy storage (EES).**

The **EES** is a **well-known technology,** which has been used successfully from the beginning of power systems. Generally, the self-stabilizing functionality of large generators resulting from the torque of inertia did not need the smoothing function of EES in the past. Today, and even more so in the future, the **use of storage for stabilizing the power system,** or for the development of local power systems based on renewable energy sources (RES), will be increasingly necessary.

This **book** gives **new insight** into the **use of EES** in the power systems of today and the future. It **concentrates** on the **systematic description of storage use**, taking into account the technical and regulatory requirements. In this book, **storage** is considered to be an **essential part of a power system,** which plays various roles, depending on localization or technical and economic conditions. Only an integrated storage consideration will lead to a correct and complete placement of the EES in future power systems.

The **book is designed** as follows: Chap. 1 gives an overview of the technical and regulatory boundaries of the **technological evolution of** the **power system towards smart grids** and demonstrates the obvious **need** for more **flexibility**. Chap. 2 systematically describes the general role of EES in power systems. Furthermore, the power system and **electric storage devices** are represented in one system using a joint **formal description.** This enables a deeper understanding of the systematic use of storage based on defined **business cases**. A **generic model of EES** is also developed in this chapter, and some **basic algorithms** are presented to illustrate how planned processes (e.g., computing of optimal storage or storage module unification) can be realized with use of complementary EES. Chap. 2 focuses on the **distribution system**, where most of the EES are already located to contribute to the local smoothing of RES fluctuations.

Based on those general remarks, the need for storage is discussed extensively in Chaps. 3 and 4. The **results of a study undertaken by the CIGRE** working group C6.15 (electric energy-storage systems) are the basis for the results presented here. This recent study (completed in 2011) was carried out under the leadership of the authors of this book. Chap. 5 **deals with EES technologies**. It covers standard solutions and trends in storage technologies. The use of **battery storage in e-vehicles** for power-system issues is a very recent technology which is discussed in detail in Chap. 6. The **monetary aspects of storage use** are analyzed in Chap. 7. Finally, the influence of storage on **power-system reliability** is the subject of Chap. 8.

This book is the result of more than **20 years of work by the authors** in the research and application of EES. Since their contribution to the DFG[1] German National Program "Information Technologies and Storages in Power Systems" at

[1] DFG: German Research Foundation (Deutsche Forschungsgemeinschaft)

the beginning of the 1990s, the **authors** have been **involved in numerous** other **projects and activities**, such as:

- EU Project "Intelligent Computation and Simulation in Planning and Operation of Power Systems Taking into Account Energy Storages" and Smart Grid Platforms
- German National Projects addressed to storage—ESPEN and Adele-Ing,
- German National Project—Harz.EE-mobility,
- Russian National Project—Resolution 220—Project Baikal,
- Project of the German Academies of Sciences—"Flexibility options",
- Working groups of the EU, CIGRE and IEEE.

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[2] IBN: German syndicate: Big Batteries in Power System (Interessengemeinschaft Großbatterien im Netz).

[3] EU: Smart Grid Coordination Group in the work of EU Commission Mandat M490.

[4] CIGRE: International Council of Large Electric System, Paris.

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We wish that readers gain interesting insights into this evolving and important topic, and we welcome feedback about our book.

The book **is meant** for students in **master-level courses**, as well as **planning engineers** who are engaged in the electric-energy storage topic and are interested in the optimal design of future power systems (smart grids) incorporating EES.

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