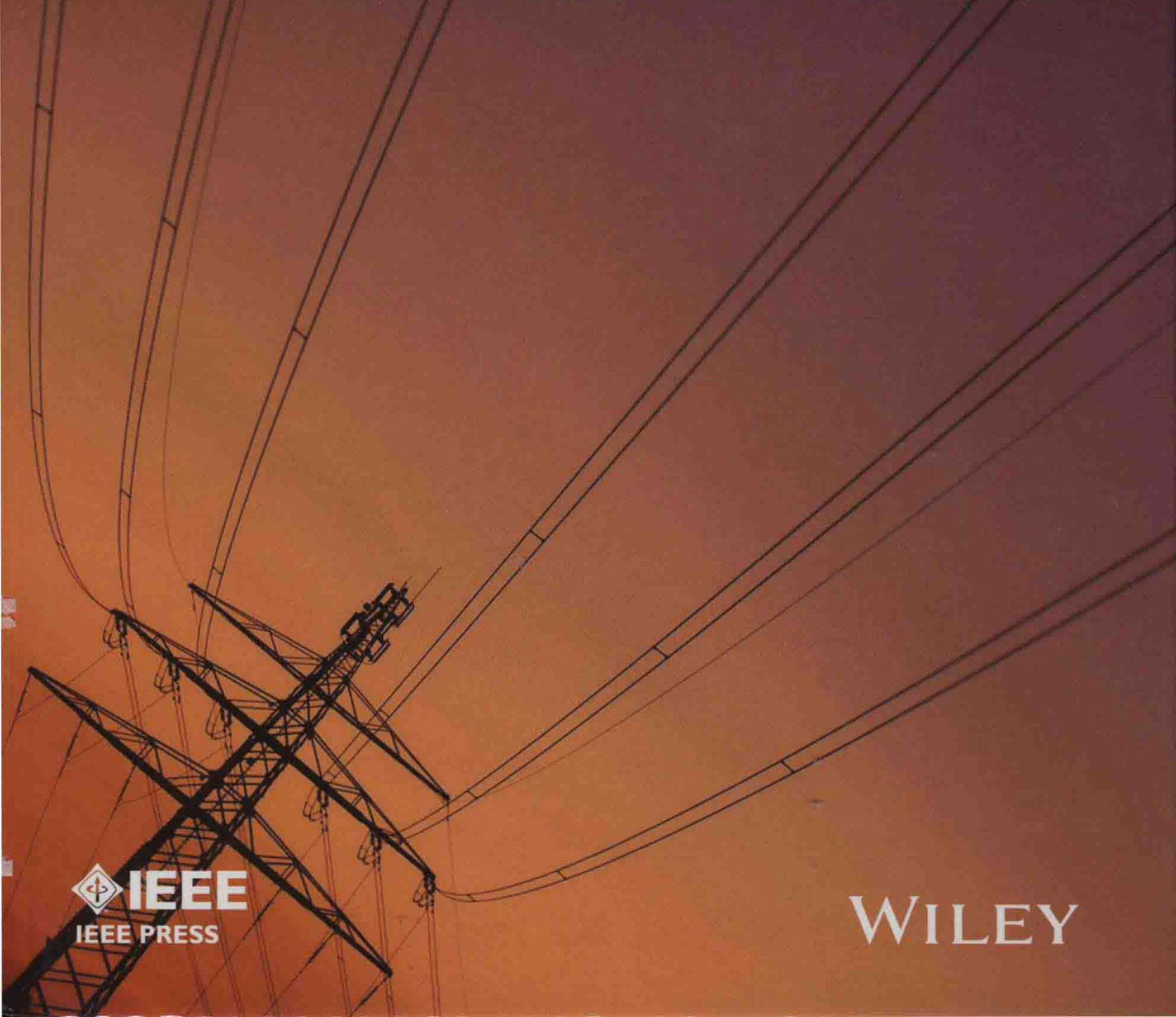
QI HUANG
SHI JING
JIANB
WEI Z

INNOVATIVE TESTING AND MEASUREMENT SOLUTIONS FOR SMART GRID



IEEE
IEEE PRESS

WILEY

INNOVATIVE TESTING AND MEASUREMENT SOLUTIONS FOR SMART GRID

Qi Huang, Shi Jing, and Jianbo Yi

University of Electronic Science and Technology of China, China

Wei Zhen

Sichuan Electric Power Research Institute, State Grid of China Company, China

IEEE

WILEY

This edition first published 2015

Registered office
John Wiley & Sons Singapore Pte. Ltd., 1 Fusionopolis Walk, #07-01 Solaris South Tower, Singapore 138628.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

Huang, Qi (Electrical engineer)
Innovative testing and measurement solutions for smart grid / Qi Huang, Shi Jing, Jianbo Yi, University of Electronic Science and Technology of China, Wei Zhen, Sichuan Electric Power Research Institute.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-88992-3 (hardback)
1. Smart power grids–Testing. I. Title.
TK3105.H83 2015
621.31028′7 – dc23

2015005390

Typeset in 9/11pt TimesLTStd by Laserwords Private Limited, Chennai, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

1 2015

INNOVATIVE TESTING AND MEASUREMENT SOLUTIONS FOR SMART GRID

To our families

About the Authors

Qi Huang was born in Guizhou Province, China. He received a BSc degree in electrical engineering from Fuzhou University, Fuzhou, Fujian, China, in 1996, an MSc degree in electrical engineering from Tsinghua University, Beijing, China, in 1999, and a Ph.D degree in electrical engineering from Arizona State University, Tempe, in 2003.

Currently, he is a professor at the University of Electronic Science and Technology of China (UESTC), Chengdu, Sichuan, China; executive dean of School of Energy Science and Engineering, UESTC; and the director of Sichuan State Provincial Lab of Power System Wide-area Measurement and Control.

His current research and academic interests include power system high-performance computing, power system instrumentation, power system monitoring and control, and integration of distributed generation into the existing power system infrastructure.

Shi Jing was born in Jiangsu Province, China, in 1980. He received a BSc degree in electrical engineering from South West University for Nationality, Chengdu, Sichuan, China, in 2003, an MSc degree in automation engineering in 2006, and Ph.D degree in electrical engineering in 2013, both from UESTC, Chengdu, Sichuan, China.

He is currently an assistant professor at School of Energy Science and Engineering, UESTC. His current research fields include distributed measurement and control as well as smart grid and time synchronization technology for power systems.

Jianbo Yi was born in Gansu Province, China, in 1981. He received a BSc degree in measurement techniques and instruments in 2003, an MSc degree in automation engineering in 2007, and Ph.D degree in electrical engineering in 2013, from UESTC, Chengdu, Sichuan, China.

He is currently a lecturer at School of Energy Science and Engineering, UESTC. His current research fields include power system fault diagnosis and stability analysis of wide area power systems.

Wei Zhen was born in Hebei Province, China. He received a BSc degree in power system automation from Xian Jiaotong University (XJTU), Xi'an, Shanxi, China, in 1982. He then served as a senior engineer, and director of the Power System Engineering Research Center, Sichuan Electric Power Test and Research Institute, Chengdu, Sichuan, China.

His research fields include power system relay protection, power system analysis, and state-of-the-art technology development.

Foreword

The lead author of this book, Professor Qi Huang, also my former Ph.D student, invited me to write a foreword for this book. I am honored and proud to express my opinion on this work.

In recent years, cascading outages have led to the need for a well-developed electrical system characterized by efficient computer controls and reliable communication. The development of real time phasor measurements that digitize the voltage and current for each phase, and the use of a phase-lock oscillator along with a Global Positioning System (GPS) to obtain high-speed synchronized time tagged phasors transmitted to a local or remote receiver, therefore, present an excellent opportunity for modernizing the electric system, often referred to as the "smart grid."

Today's smart grid requires technological advancements in areas such as sensors, measurement, communications, and information processing. In addition, any new building block of a smart grid must be tested to ensure its functionality and performance requirements.

Professor Qi Huang and his team have been conducting research in smart grid measurement and testing for many years. They have pioneered the application of novel sensing methods for the smart grid, e.g., use of fiber optic sensors for icing monitoring of overhead transmission lines, and highly-sensitive magnetoresistive sensors for transient magnetic field detection, as well as noncontact fault location or operation state monitoring of high voltage overhead transmission lines. They have also been leaders in the testing area, proposing a holistic testing approach and implementing a test system that is currently widely used by utilities in China.

This book deals with two rather neglected areas of the smart grid technology: First, it explores the use of novel sensors, signal detection methods, and analysis techniques. Second, it presents utility-proven solutions for testing the smart grid with a range of novel components.

The smart grid is both revolutionary and evolutionary in nature. I believe that the publishing of this book will be beneficial to the entire smart grid community by accelerating the deployment of the smart grid, and by assisting the readership in understanding the characteristics of smart grid technologies and their relationship to "smart substations" of the future.

The impact is particularly important in China, which probably has the largest market for the smart grid in the world. It is my pleasure and honor to recommend this book for professionals and stakeholders in the electricity generation and distribution industry.

Dr George G. Karady
Power System Chair Professor
Arizona State University
School of Electrical, Computer and Energy Engineering
Arizona, USA

Preface

A revolution in power industries, including generation, transmission and distribution, driven by environmental and economic considerations, is taking place all over the world. The smart grid allows for integration of diverse generation and storage options, reduced losses, improved efficiencies, increased grid flexibility, reduced power outages, allowing for competitive electricity pricing and integration of electric vehicles and overall becoming more responsive to market, consumer and societal needs. It is bringing profound changes to both power systems and many related industries.

The smart grid has enormous potential to transform our energy infrastructure to become a self-healing electricity grid that will reduce energy consumption, which is exciting and deserves our engineering attention. The concept of smart grid has become more consolidated and has gained more and more attention since 2009 after many countries and economic unions announced their plans for the smart grid. Utilities around the world are investing plenty of money to deploy and implement smart grid technologies to modernize their operational and information systems, with the aim to transform the power grid, enabling utilities to monitor, analyze, and synchronize their networks to improve reliability, availability, and efficiency. The smart grid is generally envisioned as the platform for implementation of strategic development of power grids and optimized allocations of energy and resources. It is not only a revolution of the electric power industry but also the catalyst to create or breed new industries.

Under the driving force of smart grid development, the power grids of the future come into reality by enabling intelligent communication across sensing, measurement, and control layers of the existing power systems. Sensors and measurements become a core part of the grid and new, challenging problems have to be dealt with and solved. Also, to fully enjoy the potential benefits of the smart grid, advanced testing solutions would have to be developed to verify the functionalities as well as performance. Improving the reliability and distribution of electricity through the use of testing and measurement equipment is critical for the growth of the smart grid.

This book presents the most up-to-date technological developments in measurement and testing solutions of power systems under the smart grid environment. Although the authors try to include more aspects in the book, the research conducted in the authors' research labs are our focus. The book is divided into two parts: Sensor, Measurement and Data Management and Advanced Test Technologies for Smart Grid.

Chapter 1 starts with the world-wide state-of-art of the smart grid. The demand and requirements of sensors, measurement and testing in the future smart grid are identified. Measurements and testing become a core part of the grid and new challenging problems have to be dealt with and solved.

Sensors and sensor networks have an important impact on meeting environmental challenges. In order to rout the power in more optimal ways to respond to a very wide range of conditions in a "smart" manner, it is necessary to deploy more (new types of) sensors in the existing power system infrastructure to obtain more information. In Chapter 2, the use of fiber optic sensors (FBG: fiber-optic Bragg grating) for building smart transmission network, and the use of magnetic sensors to build noncontact measurement of current to realize specific purposes, are presented.

Modern electric power protection, monitoring, and control systems rely on the availability of high-accuracy time. The time synchronization techniques are reviewed in Chapter 3. With the wide-area synchronized measurement system, it is possible to detect low-frequency oscillations in the power network on-line. Together with dynamic visualization techniques, wide area situational awareness, which is recognized as a key functionality in smart grids, is possible. These two topics are also discussed in the book.

During the deployment of the smart grid, the measurement technologies for energy balance, efficiency and power quality are evolving. Smart meter, as well as advanced metering infrastructure (AMI), are the fundamental characteristics that differentiate the smart grid from the traditional power grid. They are cost-effective and maximize energy efficiency. Chapter 4 presents the smart meter and AMI for the smart grid, and reviews the measurement progress of power quality. Also, one of the aims of the smart grid is to integrate the clean energy power generation source. Due to the intermittency of the power sources such as wind power and solar power, it is important to measure and predict the output of such a power generation system. The prediction of solar power output by cloud measurement and wind measurement as well as prediction in a wind farm are presented.

The smart grid is an information revolution for utilities. Plenty of data produced by the smart grid requires efficient data management tools. In Chapter 5, data and data processing in the smart grid are reviewed. An efficient integration tool, power system sensor network, is introduced and a vision of data cloud for the smart grid is presented. Big data and its potential in smart grid data analytics are also discussed.

The second part of the book is about testing. Since smart substations are developing quickly in China, the book focuses on the testing of a smart substation.

In a smart substation, a highly complex networked secondary system is required to perform information sharing and exchanging. This presents a novel challenge for the verification of function and interoperability of the secondary systems. In Chapter 6, a novel whole-view test of a secondary system in a smart substation is presented.

In order to build a highly reliable smart substation, the video monitoring system and many environmental monitoring systems are integrated to support the operation of a smart substation. These systems are expected to act in a correlated manner, to enhance security and effectively prevent any accidents. The testing of a video surveillance system and testing of a video linkage system based on simulation are presented in Chapter 7.

Electronic instrument transformers (EIT) are the key elements to implement smart substations. However, many problems are present in the fast deployment of EITs in a smart substation. It is imperative to develop an efficient testing tool to verify the performance of EITs. The test for the dynamic performance of EITs, especially using the Rogowski coil based current instrument transformer, is described in detail in Chapter 8.

Chapter 9 summarizes the results of the book and presents the future vision about sensors, measurement and testing solutions in the smart grid.

Acknowledgments

The authors are grateful to many people who have made the book possible.

Special thanks go to Mr Mingxin Hou and Clarissa Lim from Wiley. Without their encouragement and help, it would have been impossible to finish the writing of the book. Also, the authors would like to appreciate the efforts of all graduate students who ever worked in the authors' research lab. Most of the contents are from the research projects in our research lab.

Special thanks go to Dr Jian Li, Mr Dongsheng Cai, Mr Xiaohua Wang, Mr Yun Chen, and Mr Xiaoning Wang, for their direct contribution to editing, drawing, literature collection and collation during the writing of the book. During the editing, Dr Jian Li solved many of the Latex problems, which greatly speeded up the writing process. Also, the authors would like to appreciate the contribution and effort of our colleagues Dr Weidong He, and Dr Changhua Zhang.

It is our honor that Dr George Karady agreed to write the foreword and the authors would like to express our sincere gratitude to him.

Qi Huang, Shi Jing, and Jianbo Yi and Wei Zhen

Contents