Reliable and Sustainable Electric Power and Energy Systems Management

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Reliability Modeling and Analysis of Smart Power Systems

Springer

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Preface

This book series titled “Reliable and Sustainable Electric Power and Energy Systems Management” intends to provide a platform for researchers, planners, and policy makers to share their research outputs, ideas, and opinions on the critical issue of sustainable and reliable power and energy systems, and provide impetus for critical research in this highly important area for modern society in the context of a meshed and complex environment that is affected by events taking place throughout the world. This is the second volume of the book series, and is titled “Reliability Modeling and Analysis of Smart Power Systems.”

Power systems throughout the world are undergoing significant changes creating new challenges to system planning and operation in order to provide reliable and efficient use of electrical energy. The appropriate use of smart grid technologies is an important drive in mitigating these problems, and requires considerable research activities. This book is focused on new innovative research from academia and industry on understanding, modeling, and quantifying the risks associated with different ways of implementing smart grid technologies in power systems in order to plan, operate, and maintain a modern power system economically and with an acceptable level of reliability. These are important issues in modern electric power systems anticipating the use of smart grid technologies.

This book consists of 13 chapters. Out of the 13 chapters in this volume, 10 are extended versions of papers presented at the PMAPS-2012 Conference, June 10–14, 2012 in Istanbul, Turkey. The biennial “Probabilistic Methods Applied to Power Systems” conferences are highly focused gatherings of international experts. Reliability analysis and evaluation of smart grid systems have been a major presentation and discussion topic in recent years and this activity is expected to continue in the future. The authors of all chapters in this book are actively involved in PMAPS and many of them participated in the recent conference in Istanbul.

The modernization of power systems with the application of smart-grid technologies is perceived to be a means to achieve reliability and efficiency with environmental compliance. Chapter 1 presents discussions on challenges in the ensuing reliability studies in the wake of an anticipated influx of smart-grid technologies. Though there are several shared visions among research organizations, industry, and academia on the philosophy of smart-grids, the means advocated to go about achieving them are quite disparate. The main objective of this chapter is a preparatory exercise to get ready for the anticipated challenges from the perspective of a reliability engineer.

There is a growing trend of integrating intermittent distributed generation into active distribution networks, which results in increased risks in the security of power supply to consumers. Plug-in Hybrid Electric Vehicles (PHEV) can be used to mitigate the intermittency of generated power, and to provide strategic supports to microgrids. Chapter 2 proposes a methodology to mobilize strategic microgrids for improved security of supply in an active distribution network considering PHEV. The proposed method incorporates many uncertainties that can be embedded in an active distribution network using a Monte Carlo simulation approach to quantify the feasible improvement in security of supply in PHEV based strategic microgrids.

A microgrid is vulnerable when operating in an islanded mode as the operators rely on local resources to ensure the balance between generation and load. The microgrid is then more sensitive to power quality issues such as voltage unbalance, caused by the connection of single-phase loads and sources. Electric vehicles can be envisaged as an active and flexible resource that can provide additional load or storage capacity to improve the microgrid emergency operating conditions. Chapter 3 analyzes the microgrid architecture and evaluates the impact of the active participation of electric vehicles on the microgrid frequency regulation in emergency conditions in an islanded mode.

Chapter 4 proposes an intelligent adaptive protection scheme for distribution systems integrated with distributed generators. The scheme utilizes digital directional over-current relays connected with a communication network to a central relaying unit. The presented scheme can identify the faulty section of the feeder and update the settings of the primary and backup relays to speed up the fault clearance. A linear optimization technique is used to coordinate the over-current relays whenever a change in the system topology is detected.

Application of intelligent electronic devices together with advanced peer-to-peer communication systems are recent developments in nonconventional protection systems in a smart grid platform. Failures of protection system components play a significant role in the outage events of breaker oriented power systems and protected components. Chapter 5 presents event tree analysis to evaluate the reliability of different alternative digitized protection schemes supported by an IED and a communication system. The results from the studies show that high penetration of advanced technologies in protection systems must also be associated with highly reliable components for enhanced system performance.

PHEV have received increasing attention in power system planning and operation. Uncontrolled charging and discharging of PHEV impose challenges in reliable system operation. They can however, support the system with ancillary services through “smart charging.” Chapter 6 introduces an approach to derive day-ahead charging profiles that minimize generation costs while respecting network and drivers’ end-use constraints, as well as taking into account the uncertainty in driving patterns. A probabilistic method is used to model individual driving behavior, which is then integrated as virtual batteries in the power system evaluation model.

Chapter 7 proposes a copula-based stochastic approach to derive the load demand of a fleet of domestic PHEV. Home arrival time, daily travelled distance, home departure time, driving habits, and road traffic conditions are the most effective factors on the load demand of PHEV. Deterministic methods used previously to model these factors cannot recognize the stochastic nature of these factors. A probabilistic approach is used in this chapter to create appropriate probability density functions from data collected from randomly selected vehicles. Monte Carlo simulation is used to generate random samples and estimate the probability density function of the hourly aggregated load of the PHEV. The power delivered to the PHEV can then be obtained and used in analyses, such as network planning, load management, and probabilistic load flow, as well as sitting and sizing problems.

As mentioned above, a PHEV consumer exhibits a stochastic behavior. Probabilistic methods can be used to effectively incorporate these inherent uncertainties in real world applications. Chapter 8 incorporates PHEV uncertainties into home load controlling to achieve economic benefits. An optimization problem is formulated based on mixed-integer programming, and numerical studies are conducted in order to illustrate the effectiveness of the developed model. The presented method can be used to economically schedule the consumption periods of responsive appliances as well as the PHEV battery charge/discharge periods. The results show that the vehicle to grid capability of PHEV can dramatically reduce energy costs.

Smart grid technologies, such as AMI, smart monitors, smart appliances, and smart controllers, will facilitate load management activities. Chapter 9 reviews the effects of advanced load management on smart grid reliability. The existing reliability indices may require modifications and additions in the new environment due to significant changes in load management methods in future smart grids. This chapter discusses the changes in reliability indices of distribution systems, and proposes some modifications for these indices.

Chapter 10 investigates the effect of reliability worth in the optimal economic operation of a small autonomous power system (SAPS) that is based on renewable energy sources (RES) technologies. The optimization procedure is implemented with a combined genetic algorithm (GA) and local search procedure. This chapter also examines the effects of component forced outage rates and uncertainty in weather and cost data using Monte Carlo simulation.

Nonconventional and smart technology is receiving attention in different areas of power system planning, operation, and maintenance. Chapter 11 describes the use of real time data in the maintenance of offshore wind turbines. This chapter focuses on the role of condition monitoring to lower costs and risks associated with short-term reliability and long-term asset integrity. The studies carried out in this chapter illustrate how a monitoring system can be optimized for risk reduction and for the reduction of the expected structural integrity management costs.

The application of reliability centered maintenance to a fleet of wind turbines is presented in Chap. 12. Maintenance records were analyzed to identify the key components and failure modes. The chapter provides discussions on corrective actions and implementation issues to mitigate such failures, and the need for a robust set of RCM tools to better quantify and minimize operational expenditures.

Chapter 13 presents an optimization model that incorporates diagnostics, economy, and reliability to determine cable segment replacement in distribution systems. The optimization is based on diagnostic measurements, which typically could be made online with temperature sensors and/or partial discharge detection. The method identifies cable segments for replacement under a budget constraint and encourages replacement of continuous segments of cable.

Smart grid technologies are receiving significant attention in the electric power industry and in academia. Their applications in power systems are still in the development stage, and are expected to encounter various challenges. This book provides valuable insight and discussions on development of methodologies to assess risk and reliability in smart grid applications in the planning, operation, and protection of power generation and distribution systems, and focuses attention on reliability related maintenance of system components.

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Dr. Roy Billinton is Professor Emeritus in the Department of Electrical Engineering, University of Saskatchewan, Saskatoon, Canada. He obtained his Bachelor's and Master's degrees from the University of Manitoba, Winnipeg, MB, Canada, and PhD and D.Sc. degrees in electrical engineering from the University of Saskatchewan, Saskatoon, Canada. He was with the System Planning and Production Divisions, Manitoba Hydro, Canada. In 1964, he joined the University of Saskatchewan, where he served as the head of the Electrical Engineering Department, Associate Dean for Graduate Studies, Research and Extension, and the Acting Dean of Engineering. He has authored or coauthored 8 books and more than 940 papers on power system reliability evaluation, economic system operation, and power system analysis. Dr. Billinton is Fellow of the IEEE, Engineering Institute of Canada, Canadian Academy of Engineering, Royal Society of Canada. He is also Foreign Associate of the United States National Academy of Engineering, and Professional Engineer in the Province of Saskatchewan, Canada. In 2010, the IEEE-PES honoured Dr. Billinton by initiating the Roy Billinton Power System Reliability Award.

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