Yi Ding · Yonghua Song · Hongxun Hui ·
Changzheng Shao

Integration of Air Conditioning and Heating into Modern Power Systems

Enabling Demand Response and Energy Efficiency

Springer

Integration of Air Conditioning and Heating into Modern Power Systems

Yi Ding · Yonghua Song ·
Hongxun Hui · Changzheng Shao

Integration of Air Conditioning and Heating into Modern Power Systems

Enabling Demand Response and Energy Efficiency

Springer

Yi Ding
Zhejiang University
Hangzhou, Zhejiang, China

Hongxun Hui
Zhejiang University
Hangzhou, Zhejiang, China

Yonghua Song
University of Macau
Macau, Macao

Zhejiang University
Hangzhou, Zhejiang, China

Changzheng Shao
Zhejiang University
Hangzhou, Zhejiang, China

ISBN 978-981-13-6419-8 ISBN 978-981-13-6420-4 (eBook)
https://doi.org/10.1007/978-981-13-6420-4

Library of Congress Control Number: 2019930966

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

The release of carbon dioxide and other greenhouse gases due to human activity results in a host of environmental issues. The enhanced public concern for adverse environmental impacts associated with the use of conventional energy sources requires a transition toward clean energy systems. Moreover, the de-carbonization of electric power systems plays a significant role in reducing anthropogenic carbon emissions, since electric power systems remain the primary source of carbon emissions in the world. As a result, the application of renewable energy in electric power systems generates great interest. Among renewable energy sources, wind energy has experienced rapid development and has made significant inroads into electrical power systems. Over the past decade, the global cumulative installed capacity of wind energy has been growing at a rate of more than 21% annually. In 2015, global wind power capacity increased by about 17%. In China, wind power has become the third largest power source, following thermal and hydroelectric power, and generates 4.8% of the country's electricity in 2017.

However, the power generated from renewable energy such as wind is fluctuating and uncertain, which presents significant challenges to the efficient utilization. As electricity demand and supply must be maintained in balance at all times, power systems need to absorb the electricity fluctuation from renewable energy. An increasing capacity of fluctuating renewable energy will increase the need for flexibility during power system operation. Flexibility is the ability of the power system to deploy its resources for rebalancing customer demand and generation when fluctuations exist. For example, downward reserve is required to ensure power system balance when the amount of injected wind power is higher. Conversely, upward reserve is required when the amount of wind power injection is lower. If there is not sufficient operational flexibility, the efficient utilization of renewable energy cannot be achieved. The serious wind power curtailment issue in China could well prove that. The coal-dominated generation mix in China works against the high level of wind penetration, since the flexibility of coal-fired generating units is constrained by their ramp-up and ramp-down rates as well as their minimum stable generation output. China's inflexible generation mix, which cannot respond well to changes in wind power output, forces it to curtail a large amount of wind energy every year, despite the country's renewable energy ambitions. Wind energy curtailment in China is becoming increasingly serious. The total energy loss from wind curtailment from 2011 to 2015 was approximately 95.9 billion kWh, nearly equal to the gross electricity generated by wind energy in Denmark in 2013.

The development of information and communication technologies and electricity market has made the remote control of flexible loads much easier. Thus, it is possible for small end customers to provide operating reserve to support power system operation. As one of the most popular and easily controlled flexible loads, air conditioners and heating equipment account for a large share in power consumption due to the mass application across the world. Statistical data have shown that air conditioners account for approximately 35, 33, and 40% of the electricity consumption during the peak hours in many cities in China, Spain, and India, respectively. Therefore, these flexible loads have yielded enormous potential in serving as energy storage devices, which can provide operating reserve by reducing power consumption temporarily. In this field, some researches have been conducted.

The book focuses on integration of air conditioning and heating as demand response into modern power system operation and planning. Both models and methods have been addressed with engineering practice. This is achieved by providing in-depth study on air conditioner aggregation providing operating reserve and frequency regulation service for helping power system operation. Different models of air conditioner aggregation and corresponding control methods are studied in detail. Moreover, the comprehensive and systematic treatment of incorporating flexible heating demand into the integrated energy system is one of the major features of the book, which is particularly suited for readers who are interested to learn methods and solutions of demand response in smart grid environment. The book can benefit researchers, engineers, and graduate students in the fields of electrical and electronic engineering, control engineering, computer engineering, etc.

There are eight chapters in this book.

- Chapter 1 introduces the development of the air conditioning and heating loads as demand response in modern power systems. The advantages and some existing studies are also introduced in this chapter.
- Chapter 2 is devoted to the operating reserve evaluation of aggregated air conditioners. The thermal model of the room and the operating reserve characteristics of an individual air conditioner are developed. The performance of the operating reserve provided by aggregated air conditioners and the corresponding evaluation indexes are proposed, respectively. The numerical studies are presented to illustrate the effectiveness of the proposed model and methods.
- Chapter 3 is devoted to the operating reserve capacity evaluation of aggregated heterogeneous thermostatically controlled loads (TCLs) with price signals. The individual TCL model on account of consumer behaviors is developed. On this basis, the moment estimation method and the probability density estimation method are proposed to estimate the reserve capacity with insufficient data.

- Chapter 4 is devoted to the lead–lag rebound effect from the aggregate response of air conditioners controlled by the changes of the set point temperature. The impacts of the lead–lag rebound are quantified by a proposed capacity–time evaluation framework of operating reserve. On this basis, an optimal sequential dispatch strategy of air conditioners is proposed for the entire mitigation of the lead–lag rebound and the provision of operating reserve with multiple duration time.
- Chapter 5 is devoted to the frequency regulation service (FRS) provided by the inverter air conditioners. The equivalent modeling of the inverter air conditioners is developed. In this manner, the inverter AC can be scheduled and compatible with the existing control system. A stochastic allocation method of the regulation sequence among inverter ACs is proposed to reduce the effect of FRS on customers. Besides, a hybrid control strategy by considering the dead band control and the hysteresis control is developed to reduce the frequency fluctuations of power systems.
- Chapter 6 expands the demand response to the heat and power integrated energy system (HE-IES). HE-IES, based on combined heat and power (CHP), is one of the most important forms of IES. It is assumed that both electricity energy system and heat energy system are managed by a single ISO and all the aggregators seek to minimize their energy costs. Incorporating the aggregators' flexible energy demand into the central energy dispatch model therefore forms a two-level optimization problem (TLOP), where the ISO maximizes social welfare subject to aggregators' strategies, in which aggregators adjust their energy demand so as to minimize the energy purchase cost.
- Chapter 7 analyzes the demand response potential of customers (usually refer to buildings) in the distribution-level heat and electricity integrated energy system. This chapter proposes a framework for utilizing the demand response to improve the operation of the integrated energy system which has gained rapid development recently. The framework involves three levels of the integrated energy system: aggregation of the smart buildings, distribution system, and transmission system or sub-transmission system. In the framework, the buildings' demand response potential can be fully utilized and the operational flexibility of the transmission-level integrated energy system can be significantly improved.
- Chapter 8 is devoted to the evaluation of the economy of the three different flexibility resources to find the advantages/disadvantages of different resources and to provide guidance for investment in these flexible resources.

The authors shared the work in writing this book.

It was a pleasure working with Springer Associate Editor, Ms. Jasmine Dou.

Hangzhou, China — Yi Ding
Macau/Hangzhou, China — Yonghua Song
Hangzhou, China — Hongxun Hui
Hangzhou, China — Changzheng Shao

Contents