

Power Systems

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Planning, Operation,  
and Security  
of Communication  
Networks for Regulating  
Large-scale Flexible  
Resources in Modern  
Power Systems

 Springer

# Power Systems

Electrical power has been the technological foundation of industrial societies for many years. Although the systems designed to provide and apply electrical energy have reached a high degree of maturity, unforeseen problems are constantly encountered, necessitating the design of more efficient and reliable systems based on novel technologies. The book series Power Systems is aimed at providing detailed, accurate and sound technical information about these new developments in electrical power engineering. It includes topics on power generation, storage and transmission as well as electrical machines. The monographs and advanced textbooks in this series address researchers, lecturers, industrial engineers and senior students in electrical engineering.

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# Preface

The growth of renewable energies elevates the significance of maintaining system balance and imposes more demands on regulation resources. Flexible resources have been extensively regarded as prospective regulation resources for providing ancillary services within power systems, including frequency regulation, primary reserve, and synchronized reserve. However, the dispatch of flexible resources presents significant challenges of communication accessibility, frequent data transmission, and explosive data volume, leading to substantial pressure on communication networks.

To find solutions and improve communication performance, this book explores planning, operation, and security enhancement strategies for communication networks in modern power systems, focusing on regulating large-scale flexible resources. This book can potentially highlight the interconnected relationship between power and communication networks, build the foundation of coordinated optimization methods of the coupling networks, and propose specific communication security methods from the perspective of data protection, bridging the dynamic communication performance with the flexible regulation resources in power systems. This book is organized as follows:

- Chapter 1 introduces the background of regulating large-scale flexible resources, the detailed architecture of communication networks, global power communication strategies, and the challenges that communication networks face. And the organization of this book is outlined to address the related challenges.
- Chapter 2 reviews the relationship between communication networks and power networks. First, the concept of flexible resource regulation as demand response (DR) and recent practical advances are investigated, especially the application of communication technologies. Then, a comprehensive review of the cyber security, consumer privacy, and reliability of DR is presented. These topics received little attention in the past, but they will be among the most crucial factors in the future. In addition, the essential features and typical application scenarios of typical ICTs in communication networks are investigated. On this basis, taking

5G as an instance, the advantages, methods, recent advances, and implementation planning of 5G on DR are studied.

- Chapter 3 proposes a planning strategy in communication networks, to deploy hybrid Internet of Things (IoT) terminals for dispatching large-scale flexible loads to provide regulation resources in power systems. This chapter includes: (1) a deployment strategy of hybrid IoT terminals considering various communication performances; (2) a bi-level optimization model integrating the interaction between the power system regulation scheme and the communication system deployment strategy; (3) an iterative algorithm addressing communication demands of load aggregators and the communication performance of different IoT terminals. Moreover, the numerical results demonstrate that the proposed strategy can provide effective communication accessibility and further improve local access services.
- Chapter 4 proposes a coordinated operation framework of power-communication coupling networks for dispatching large-scale flexible loads to provide operating reserve. A power-communication equivalent model is established to couple the regulation power and transmitted data from flexible loads. The data nodes and branches in the communication network are formulated equivalently with power nodes and branches in the power network. On this basis, considering spatially and temporally dynamic power-communication coupling networks, the power flow and communication flow are coordinately optimized to minimize the regulation costs and communication costs. The proposed scheme is validated based on the 5-bus and 118-bus power-communication coupling networks. Numerical results illustrate that the coordinated optimization framework reallocates operating reserve capacities and decreases the regulation cost of power-communication coupling networks.
- Chapter 5 further investigates a data valuation-aware operation method of communication networks for dispatching flexible loads to provide hybrid ancillary services. The method employs: (1) a data valuation approach considering inherent characteristics and ancillary services to distinguish the data transmission preference; (2) an analogous model of communication networks to power networks, formulating the relationships between different components (e.g., nodes, branches, et al.) within coupled networks; and (3) a coordinated optimization model for coupled networks, which analyzes the impact of data valuation-aware transmission in communication networks on the dispatching of flexible loads in power networks. Numerical results demonstrate that the proposed method can effectively organize massive data flow from flexible loads involved in hybrid ancillary services.
- Chapter 6 analyzes the impact of communication latency (CML) and frequency detection errors (FDE) on regulating flexible loads to provide frequency regulation resources. First, this chapter develops the aggregation models of ON-OFF flexible loads and continuously adjustable flexible loads, respectively. The centralized and distributed control methods considering the CML and FDE are developed, respectively. On this basis, a novel hybrid control method is proposed to compensate the CML and FDE, in which the modification method is developed

for improving the estimation accuracy of the FDE. The results in the numerical studies show that the maximum system frequency deviation extends due to the FDE and CML, respectively. After the modification by the proposed hybrid control method, the maximum frequency deviation is decreased, which is almost equal to the ideal value when there is no FDE and CML. Therefore, this research can compensate the CML and FDE well, which is useful for guiding demand response projects in smart grid.

- Chapter 7 specifies the impact of time delay on regulating flexible loads to provide emergency resources involved in accidental outages. First, in order to analyze the dynamic regulation process of power systems in accidental outages, the power system model in a faulty condition is reconstructed to obtain the regulation power from well-running generators. On this basis, flexible loads are modeled and integrated into the novel reconstructed power system model as an alternative method of making up for the fast regulation capacities. Considering that the inevitable communication time delay probably leads to the slowdown of response speed and endangers the system security, an adaptive time-delay control (ATDC) scheme is proposed and integrated into the control process of aggregated flexible loads. In this manner, the regulation speed of flexible loads can be accelerated, the control precision of response capacities can be improved, and the power system frequency deviations caused by time delay can be decreased. Finally, the proposed models and methods are verified by numerical studies. The results in the test system show that the frequency deviations can be decreased effectively in accidental outages by using the ATDC scheme of flexible loads.
- Chapter 8 proposes a security solution with value-based data governance tailored for large-scale flexible loads' data. Our approach introduces a real-time data value assessment model within a comprehensive framework that employs a fine-grained hierarchical management and protection strategy. This strategy dynamically adjusts governance and security measures based on the data value of large-scale flexible loads, addressing all stages of its life cycle. Numerical analysis demonstrates that the solution enhances data protection and system performance while reducing security costs. It also promotes data circulation and value generation, outperforms traditional methods in both security and efficiency, and supports a sustainable and intelligent power system transition.
- Chapter 9 concludes the planning, operation, and security work of communication networks in this book, and introduces the prospective insights on how to utilize resilient communication resources as an emergency resource, enhancing the resilience of modern power systems.

For reading this book, a basic knowledge of advanced mathematics, including linear algebra, optimization theory, and control theory, is required. Besides, readers are advised to have a fundamental understanding of power systems and communication systems. This book explores the role of communication networks in enabling local access and remote communication services for the regulation of large-scale flexible loads. It also examines the impact of the communication performance on the control of such loads and proposes strategies to enhance communication

security, with a particular focus on data protection. By reading the book, scholars, engineers, technicians, and students can gain a comprehensive understanding of the architecture of communication networks and the key challenges associated with regulating large-scale flexible loads in modern power systems. We do hope this book can be useful to potential readers.

Macao, China  
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# Declaration

**Competing Interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this book.

The authors have no competing interests to declare that are relevant to the content of this manuscript.

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