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Business Models and Reliable Operation of Virtual Power Plants

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Preface

The world faces unavoidable multiple climate hazards over the next two decades with global warming of 1.5 °C. Greenhouse gas emissions from human activities are the most significant driver of observed climate change where emissions come from the energy sector accounts for almost three-quarters. Therefore, the solutions to make decarbonization are using electricity from renewable energy. In 2021, global renewable energy installed capacity rises 9%. The total share of global renewable generation capacity in electricity production rose from 36.6% in 2020 to 38.3% in 2021. However, due to the intermittent, volatility, and uncertainties of renewable energy generations, there is an urgent need to improve the power system flexibility. With the development of distributed energy resources, information and communication technologies, flexible resources in demand side can be used to deal with the volatility of new energies. As a solution to solve the problem of clean energy consumption and green energy transformation, virtual power plant (VPP) technology is of great significance to global energy transformation to realize the goal of low carbon by aggregating distributed energy resources.

The main content of this book summarizes the research results of Dr. Heping Jia, Associate Professor of North China Electric Power University, Dr. Xuanyuan Wang, Director General of Technology and Innovation Division in State Grid Jibei Electric Power Co., Ltd., Dr. Xian Zhang, Director of New Energy Exchange Department in Beijing Power Exchange Center Co., Ltd., Dr. Dunnan Liu, Professor of North China Electric Power University, and their collaborators in this field. This book systematically studies the business models of virtual power plants with different practices and develops the reliable operation models of virtual power plants under different operating scenarios, which has important and practical guiding significance for the operation mechanism and optimal operation of virtual power plants.

The structure of the book is as follows. Chapter 1 summarizes the background knowledge of climate change and the emerging of virtual power plants by aggregating distributed energy resources. Chapter 2 introduces the short-term load forecasting for distributed energy resources as the basic analysis for virtual power plants. In Chap. 3, clustering forecasting of virtual power plants aggregated with electric vehicles is presented considering meteorological factors. In Chap. 4, several business models and practices of virtual power plants participating in peak shaving energy market, frequency control market, and comprehensive energy services are provided. In Chap. 5, an integrated electricity/heat demand response modeling approach for virtual power plants with comfort of consumers is presented. In Chap. 6, the bidding strategy and dispatching scheme of virtual power plants participating in auxiliary service market coordinating with energy storage allocation is given. In Chap. 7, a dynamic time-sharing pricing model for virtual power plants is provided based on deep deterministic policy gradient reinforcement learning algorithm. Chapter 8 introduces a reliable operation model for power systems with virtual power plants utilizing reliability network equivalent and time-sequential simulation techniques. In Chap. 9, an operating reliability evaluation framework for multi-state power systems with virtual power plants and wind power is presented considering malfunctions of cyber-systems. In the book, Chaps. 1 and 4 are jointly written by Dr. Heping Jia and Dr. Xuanyuan Wang; Chaps. 2, 3, 5, 6 and7 are jointly written by Dr. Heping Jia, Dr. Xian Zhang, and Prof. Dunnan Liu; Chaps. 8 and 9 are written by Dr. Heping Jia.

This book provides an insight of virtual power plants by aggregating distributed energy resources in smart grids. We believe this book will offer the related researchers a better understanding on business models and reliable operation of virtual power plants.

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About This Book

This book systematically studies the business models of virtual power plants with different practices and develops the reliable operation models of virtual power plants under different operating scenarios, which has important and practical guiding significance for the operation mechanism and optimal operation of virtual power plants. The business models and reliable operation strategies proposed in this book are applicable to virtual power plants with different distributed energy resources. The business operations of virtual power plants participating in demand response and auxiliary service market are provided based on the load forecasting for distributed energy resources. The dynamic pricing strategy for virtual power plants is also presented. Moreover, the reliable operation of power systems integrated with virtual power plants is analyzed. The readers of this book are researchers, engineers, technicians, and graduate students engaged in the fields of energy Internet, electrical engineering, business administration, etc.

Contents

Chapter 1
Climate Change and Virtual Power Plants

For nearly a hundred years, many observations have shown that the Earth's climate is undergoing a significant change with global warming as the main feature. It is reported by the Intergovernmental Panel on Climate Change (IPCC) that global warming in the past 50 years was mainly caused by the warming effect of greenhouse gases such as CO_2, CH_4, N_2O from human activities [1]. In order to jointly address the challenge of climate change and slow down global warming, nearly 200 parties jointly adopted the Paris Agreement in December 2015, making action arrangements on how to tackle climate change after 2020. The main goal of this agreement is to keep global temperature increases in the twenty-first century within 2 °C higher than pre-industrial levels, and to seek to stay further within 1.5 °C [2]. Including the Paris Agreement, China is an active participant and practitioner of global climate change activities such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In September 2020, China announced that it would aim to achieve peak CO_2 emissions before 2030 and carbon neutrality before 2060. The goals for peak CO_2 emissions and carbon neutrality constitute a strategic choice for the sake of humanity's future.

Global carbon emissions have grown rapidly from 2010 to 2020 as demonstrated in Fig. 1, reaching a record high of 34.04 billion tons in 2019 [3]. The huge negative impact of COVID-19 on global social production and life, global carbon dioxide emissions fell by 5.8% in 2020, close to 2Gt of carbon dioxide, the biggest drop since 1945 [3]. The impact of human activities is crucial. For example, burning fossil energy increases the release of CO_2 into the atmosphere, while deforestation weakens the carbon sink process, thus damaging the balance, leading to high CO_2 concentrations in the atmosphere and rising temperatures.

Globally, the energy sector including electricity, heat and transport produces 73.2% of its greenhouse gas emissions [4] as illustrated in Fig. 2. Therefore, driving net zero emissions in the energy sector is the key to tackling climate change. Specifically, for global CO_2 emissions as illustrated in Fig. 3, energy emissions mainly came from energy power generation and heating, transportation, manufacturing and construction, accounting for 43%, 26% and 17% in 2020, respectively [5].

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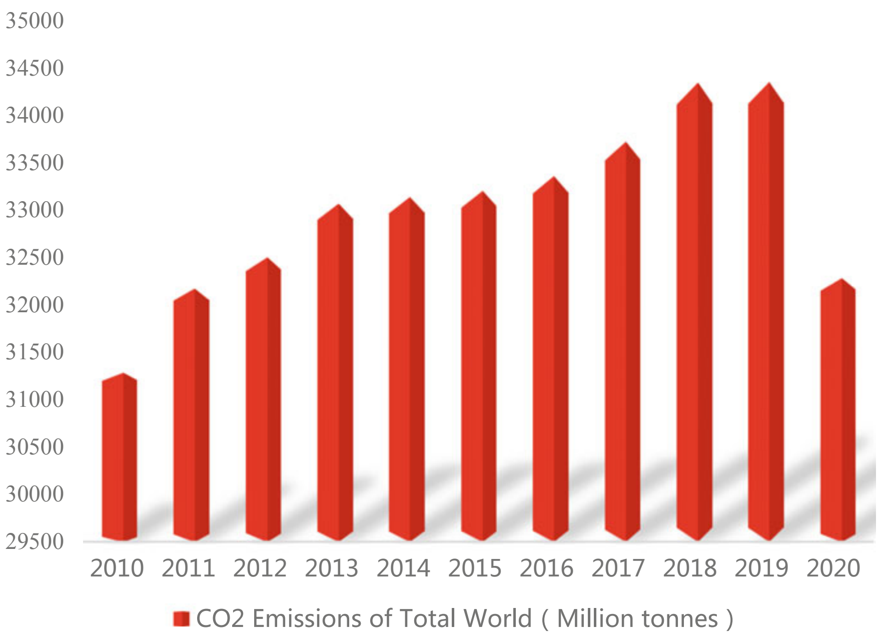

Fig. 1 CO_2 emissions of total world, 2010–2020 (https://www.bp.com/)

Fossil power generation is one of the largest sources of energy-related carbon emissions, accounting for 36% of total energy-related emissions, with renewable energy contributing the most to the decarbonization of the net zero power sector [6]. Note that the CO_2 emissions from power generation and heating were nearly half of the total emissions. Hence, reducing the supply of fossil energy for power generation and heating and increasing the power generation from renewable energy are the keys to dealing with climate change.

For the past decade, renewables have met a higher share of global electricity demand than in the previous year as illustrated in Fig. 4. In 2020, Non-hydro renewables generated an estimated 29.0% of global electricity up from 27.3% in 2019. The share of electricity generated by variable renewable electricity (wind power and solar PV) continued to rise in several countries around the world, which contributed more than 9% of global electricity in 2020. Moreover, much higher shares of variable renewable electricity were globally presented including Denmark with a share of 63%, Uruguay with a share of 43%, Ireland with a share of 38%, Germany with a share of 33%, and the United Kingdom with a share of 28% [7].

In the meanwhile, a record amount of new capacity of the installation of solar PV and wind power has been achieved as presented in Figs. 5 and 6. The world total capacity of solar PV achieved a record-breaking 139 GW of new installations, bringing total capacity to nearly 760 GW. The world total capacity of wind power achieved a record-breaking 93 GW of new installations, bringing total capacity onshore and offshore to nearly 743 GW. Driven by pending policy changes at the

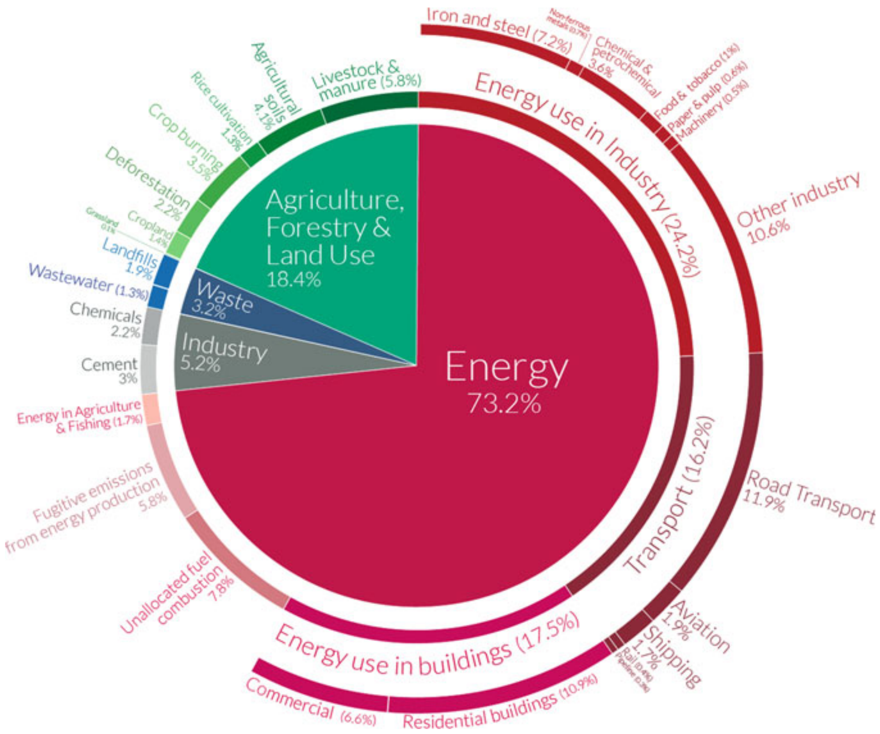

Fig. 2 The global greenhouse gas emissions by sectors (https://ourworldindata.org/emissions-by-sector)

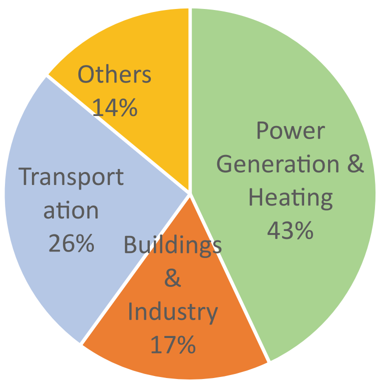

Fig. 3 CO_2 emissions sources by industries, 2020 (https://www.iea.org/)

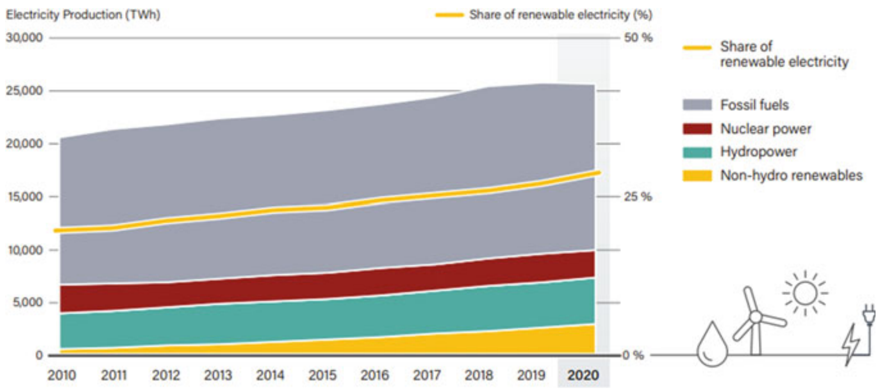

Fig. 4 Global electricity production by source, and share of renewables, 2010–2020 (https://www.ren21.net/)

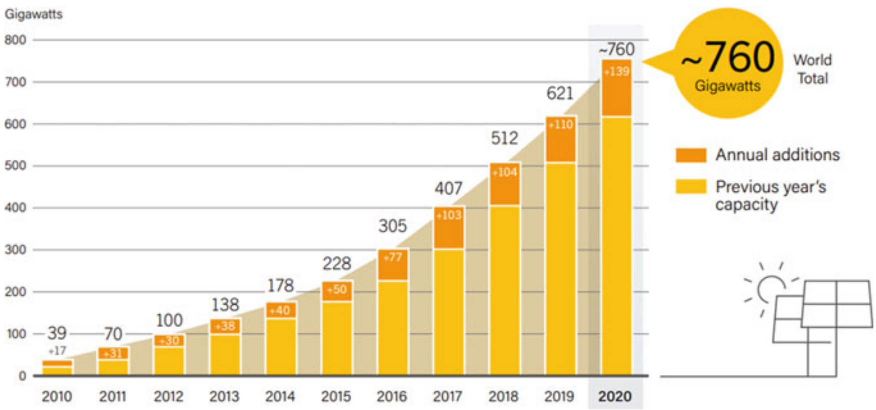

Fig. 5 Solar PV global capacity and annual additions, 2010–2020 (https://www.ren21.net/)

end of 2020 in China and the United States, both countries led the growth in solar PV and wind power with record years. Viewed over a slightly longer period, wind and solar capacity was more than doubled between 2015 and 2020, increasing by around 800 GW, which equated to an average annual increase of 18%.

With the increasing of electricity generation from wind power and solar PV, the characteristics of volatility, and intermittence from renewable energy generation are increasing the demand for flexible resources of power systems [8]. Flexible resources were defined in [9] as generation resources whose operations can be directly controlled (are dispatchable) and quickly start up, shut down, and ramp power output up and down.

Besides flexible resources from electricity generation side, with the development of distributed energy resources (DERs) including distributed generations (DGs),