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The Role of Power Electronics in Modern Energy System Integration

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The Role of Power Electronics in Modern Energy System Integration

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ABSTRACT

This monograph will discuss different aspects of power electronics in modern energy systems. The transition from conventional, centralized power systems with large-scale generations to modern, deregulated systems with distributed generations is discussed. Furthermore, the function of some dominant green energy generation technologies based on power electronics is explained. Moreover, the fundamentals of the control and operation of modern systems with power electronics-based generations are presented in this monograph. The major technical challenges that are deteriorating the overall system performance and reliability are addressed and feasible solutions are explained.

Keywords: Power system; energy system; power electronics; power converter; energy conversion; reliability; stability; energy storage; power-to-x; power to gas; control; planning; operation.

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Introduction

Decarbonization is the key to move toward climate neutrality and electrification plays a dominant role in making a greener society [38]. Modern society is becoming more and more dependent on electricity. Interconnections among various sectors, e.g., heating/cooling, transportation, water supplies, and traffic controls are doable with electric power. This curtails/eliminates the carbon footprint in different sectors. Furthermore, the supply chain of electricity from generation down to distribution also needs to be greener. This has been started with renewable generations many years ago to produce clean energy instead of using carbon-based fuels. Today, the renewable technologies are quite mature and the contribution of green energy generation is remarkable, as shown in Figure 1.1.

Technically, moving toward renewable generations needs fundamental changes in power system structures both in physical and control/operation domains. This is due to the fact that (1) the capacity of renewable generation units is very small compared to the traditional power plants, and (2) they are integrated and controlled with power electronic converters. These factors induce major technical challenges to the more or full green power systems. Less flexibility in power control,

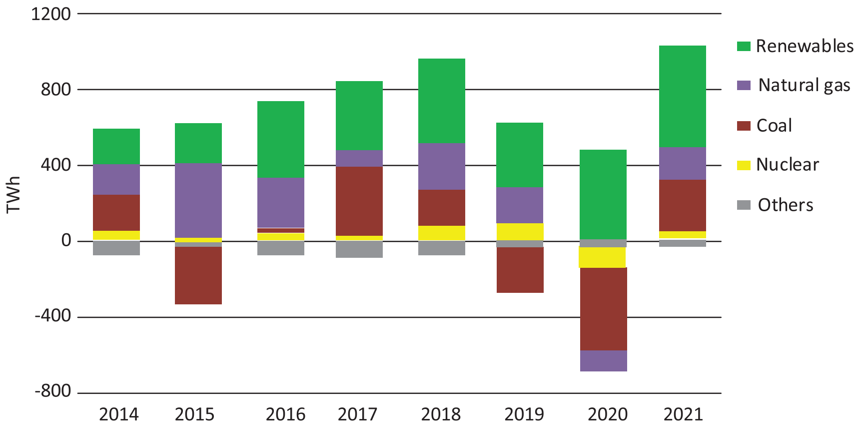

Figure 1.1: Change in global energy generation, 2014–2021 [38].

lower inertia, fast response, and need for communications are some of the major issues introduced by renewable generations. These challenges can affect system reliability and performance, thus introducing socio-economic issues. As the latest example, the Texas 2021 power crises in the state of Texas affected more than 4.5 million homes and businesses due to the shortage of electricity, water, food and heat. The power cut was initiated by frozen wind turbines and solar panels [102]. Another interesting example is the 900-MW photovoltaic (PV) power outage in California in 2017, which was due to the misfunction of power converter control units, more specifically its phase lucked loop in measuring the frequency [63]. These examples show how the transition from reliable but non-clean energy sources to the unreliable but green sources can affect human life. Therefore, those moving toward green energy technologies need to understand the basics and provide solutions to guarantee energy security and prevent irrecoverable damages.

Looking from an electricity supply chain perspective, power electronics converters become one of the major components in different parts of power systems. They are used in interconnecting renewable generations, transferring high power among various location electronic transmission systems, distributing energy using AC/DC medium voltage transmission systems, and load point applications like electric vehicle (EV) chargers. Therefore, their performance can remarkably affect the entire power and energy system security. This monograph aims to provide the fundamentals of energy transition in power systems with a specific focus on power electronics. First, the power systems structure will be described. Then, the concepts of planning and operation are explained in order to understand the basics of power system reliability. Afterward, the modern electrical energy conversion with wind and solar PV is discussed and the application of energy storage and power to X is presented. Next, the basic structures of power converters and their control and operation principles are explained. Moreover, the principles of reliability in power electronics and the fundamentals of system reliability assessment are discussed. Finally, some technical challenges of modern green power systems with more power electronics are presented.

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