CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The process of electric energy generation, transmission, and distribution is conducted via a large-scale central generation (CG) to meet increasing demand at industrial, commercial, and residential loads. The generation of power through central generation is done via coal-fired, fossil-fuel, hydro, and steam turbines. These resources are converted to electrical energy then processed through different technologies to meet growing load demands. Similarly, the transmission of power from generating units requires high investment, including numerous energy-processing technologies to transfer power to load centers. This is done via transformers and solid-state switching devices at very high voltages. Distribution-system networks are also significant for dispatching power at low voltage via step-down transformers to domestic consumers. Given the different direct current (DC) and alternating current (AC) load models and categories, energy-processing devices such as converters and inverters are needed especially when issues of safety, quality of power, security, and processing are important to meet different loads from various sources.

In recent years, many new distributed generation (DG) sources have been introduced with the aim of reducing losses and increasing reliability, regardless of economy of scale of CG, which can be huge when accounting for cost of transmission and reliability during failure.

DG created from solar, mini-hydro, wind, stirling engines, and fuel cells is of common interest. The debate on how to determine to what extent one should drive CG or DG is a research topic under the future grid initiative. In this paper [1], we were able to show three criteria for selecting which energy sources and processing options should be selected. The criteria included economy of scale, resilience, sustainability, and reliability. Regardless of the choice, appropriate energy processing tools and concepts are a dominant concern moving forward. It is therefore important for a book to be dedicated to addressing appropriate fundamental concepts and technologies for designing, building, and validating the performance of the future grid. That is the goal of this book.

In this book, we propose to provide an integrated foundational knowledge that harnesses the role of energy conversion machines and devices with some new topics

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for energy generation, transmission, distribution, delivery, and consumption. First, it is relevant to provide the working definition of *microgrid*.

The microgrid involves a stand-alone or grid-connected system to:

- match generation with load
- serve as a reserve margin
- help stabilize the power system
- increase reliability and affordability
- reduce the impact of threats on the bulk power system

In contrast, the smart grid is a two-way digital system with active participation of customers within the grid that includes renewable energy resources (RER) with the aim of sustainability and allows reasonable penetration levels and interoperability [2]. It possesses self-healing capabilities; cyber security; and real-time, design-based functions such as reconfiguration, demand-side management (DSM), demand response, and power quality.

We present eight points in this book to support control communications and energy processing for the smart grid. They are the basis of the seventeen chapters, categorized as follows:

1. A basic review of network (circuit) analysis and electromagnetics is provided. This includes discussion on the fundamental concepts of three-phase analysis of AC sources to different load configurations. The text assumes the sources are AC that can be converted to DC or AC/DC or DC/AC using inverters and converters, as discussed in Chapter 12. A set of hand-calculation exercises is presented although software tools such as NEPLAN [3], Electrical Transient and Analysis Program (ETAP) [4], and Personal Computer Simulation Program with Integrated Circuit Emphasis (PSPICE) [5] can also be used. Balanced or unbalanced conditions can also be analyzed using symmetrical components.

2. Electromagnetic concepts are introduced by providing the unified theory of Maxwell's equations and their applications for understanding machinery concepts, including transformers, synchronous and induction machines, and DC machines. The unified theories of Faraday, Lenz, and Ampère are given to illustrate the concept of electromagnetic computation. Equivalent analogous forms of magnetic circuits in electric circuits are given for magnetic circuits with rectangular and toroidal shapes with and without air gaps for different ferromagnetic materials.

3. Fundamental understanding of machines is discussed. This includes the conversion process and the role of Maxwell's equations. The construction and model of the machines using electrical network equivalents are given using short-circuit and open-circuit analyses for determining the equivalent parameters [6]. The power flow in each machine—accounting for conversion, electrical, mechanical, and stray losses—is given. Following this, the text provides a guide for computing efficiency of the power input relative to the output power received. In addition, voltage regulation and control strategies to achieve optimum energy processing are discussed.

4. Fundamental knowledge of storage and renewable resources is important for development of future grids where sustainability and mobile power are needed. Storage is safe, inexpensive, and the reason for interest in the design of future environmentally friendly grids. The text provides a working model, description, size, and metrics of different resources and storage technologies. Software packages are recommended for studying the impact of RER for reliability and cost–benefit analysis for stand-alone distribution system topologies for the future grid.
5. Efficient technology to handle processing energy from one state or form to another includes inverters and converters, which provide AC/DC, DC/DC, or DC/AC conversion from a given resource to given loads. To minimize poor power quality, different electronic devices and filters are used. The text provides a fundamental knowledge of power electronics to allow the reader appropriate choices of electronic devices for energy processing.
6. In designing the operation and management of the smart grid and microgrids, real-time processing of energy and information is essential. We present an overview of real-time data such as voltage, current, power, and frequency, which measure the status of the grid via smart meters and phasor measurement units (PMUs). The formulations and specifications of the devices and their use in communication and control schemes are given. Work in areas of real-time voltage-stability management, power quality, frequency control, voltage/volt-ampere reactive (var), reconfiguration, and several other grid functions are included in the proposed exercises.
7. We provide a description for understanding the smart grid and microgrid, including functionality, architecture, and the test bed. The chapters integrating the concept of microgrids in this text are an evolving process. Research work and laboratory exercises are important activities for general electrical installations.
8. Finally, the design of microgrid systems with smart grid functions is described.

Our research involving the design and construction of a microgrid test bed consisting of solar power, super capacitors, batteries, metering devices, converters and inverters, and a real-time simulator is ongoing at Howard University. The introduction of the OPAL-RT real-time digital simulator (RTDS) to the array of research and educational equipment at the Center for Energy Systems and Control (CESaC) at Howard University is allowing us to develop functions such as power quality, voltage stability, voltage/var, DSM, and restoration.

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