Preface

Medium and large-scale renewable power plants require large areas of land, and are usually installed in offshore or remote areas, far from cities, in order to capture large amount of energy. For power transmission and grid integration, the low voltage, e.g., 690 V for a typical wind turbine generator, at which the electricity is generated from renewable energy sources is transformed to the medium-voltage (e.g., 11–33-kV) commonly by using the step-up transformers. In many cases, the power transformers operated at the frequency of 50/60 Hz are heavy, large, and inefficient. These technological drawbacks would have significant impacts on offshore and remote renewable power plants where the costs of installation and regular maintenance are extremely high.

With the fast development of power electronics, it is becoming a reality to replace the combination of low voltage inverter and step-up-transformer by a medium-voltage converter for direct grid connection to reduce the system volume and weight, as well as the cost. Traditionally, two- and three-level converters are commonly used for high power applications. When applied to medium-voltage systems, very expensive semiconductor switching devices of high-voltage ratings are required. To reduce the cost, multilevel converters made of cascaded switching devices of relatively low-voltage ratings are developed. In comparison with the conventional two- and three-level converters, the multilevel converters present lower switching losses, lower voltage stress on switching devices, and higher quality output power, and thus suit better the medium-voltage applications. Although several multilevel converter topologies have been developed in the last few decades, most of them are not suitable for medium-voltage applications as their number of auxiliary components scales quadratically with the number of levels. Because of some special features (e.g., the number of components scales linearly with the number of levels, and individual modules are identical and completely modular in construction hence enabling high-level number attainability) the modular multilevel cascaded (MMC) converter topology can be considered as a possible candidate for medium voltage applications. However, the MMC converter requires multiple isolated DC sources that must be balanced, and as a result its application is not straightforward, especially in wind power generation systems. Moreover, the multilevel converter requires a number of switching and control PWM signals, which cannot be generated by a digital signal processor (DSP) because the currently available DSP can only provide about six pairs of PWM channels. In this instance, a field programmable gate array (FPGA) becomes the natural choice. Most of the available design techniques require special software such as HDL coder, System generator, PSIM and ModelSim, which increases the developmental time and cost.

Chapter 1 of this book discusses various aspects, such as historical growth of two dominating renewable, i.e., wind and solar, energy sources, the existing technologies, technical challenges, and possible solutions for large-scale power generation from these energy sources.

An extensive literature survey has been conducted in Chap. 2 focusing on various aspects of medium-voltage converter development for step-up-transformer-less direct grid integration of photovoltaic (PV) power plants. The main objective is to show how power electronic converter topologies, power electronic devices, and control complexities have affected the development of medium-voltage converters, and how to make an excellent choice of the suitable converter topologies for step-up-transformer-less grid integration through medium-voltage converters, which is really a critical problem and highly affects the converter performance and cost.

The main aim of Chap. 3 is to find out a suitable converter topology, which can interconnect the renewable generation units directly to the medium-voltage grid with the commercially available matured semiconductor devices. Different multilevel converter topologies, such as the neutral point clamped (NPC), flying capacitor (FC), and MMC converters, have been considered and compared for the design of an 11-kV converter system. The comparison is made in terms of the number of semiconductors, semiconductor cost and commercial availability, total harmonic distortions (THDs), filter size and control complexity of the converters. The performance is analyzed and compared in the MATLAB/Simulink environment.

To couple a renewable energy source to the MMC converter, a high-frequency magnetic-link with multiple secondary windings can be an excellent option and is explored in Chap. 4. The high-frequency magnetic-link is used to generate the isolated balanced multiple DC supplies for all of the H-bridge inverter cells of the MMC converter from a single low voltage power source. Compared with the conventional power frequency transformers operated at 50 or 60 Hz, the high-frequency magnetic-links (in the range of a few kilohertz to megahertz) have much smaller and lighter magnetic cores and windings, and thus much lower costs.

The capability of parallel processing of the FPGA affords the opportunity to the switching controller to update all gate signals simultaneously. Various design techniques and software environments are available for the modeling of switching control schemes with the FPGA technology. Most of the techniques require special software, which increases the development time and cost. In Chap. 5, the most common software such as the MATLAB/Simulink and Xilinx ISE-based alternative design technique is proposed, which may reduce the developmental time and cost of the switching controller.

To verify the feasibility of the high-frequency MMC converter, a scaled down 1-kV laboratory prototype test platform with a 5-level MMC converter is developed. Furthermore, the prototype design and implementation, test platform, and experimental results are analyzed and discussed in Chap. 6. The component selection, converter fabrication, and experimentation techniques are equally applicable to any other converter applications.

In Chap. 7, an 11-kV system and a 33-kV system are designed and analyzed taking into account the specified system performance, control complexity, and cost and market availability of the power semiconductors. It is found that, the 19-level and 43-level converters are the optimal choice for the 11-kV and 33-kV systems, respectively. Besides the design and analysis of medium voltage converters, the traditional low voltage converters with power frequency step-up-transformers are also discussed.

Chapter 8 concludes the book. Future directions have been recommended for further research and development. It is expected that the technology presented in this book has a great potential to be implemented in future wind farms, PV power plants, and smart micro-grid applications.

http://www.springer.com/978-3-662-44528-0

Power Converters for Medium Voltage Networks

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2014, XLI, 278 p. 356 illus., 70 illus. in color., Hardcover
ISBN: 978-3-662-44528-0