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Editorial

Multi-Level Converters

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1. Introduction

In the history of modern power electronics evolution, we are now going through the era of multi-level converters [1]. Multi-level voltage source converters are characterized by more than two voltage levels of phase voltage compared to traditional converters which have two voltage levels. Back-to-back connection of two converter units gives DC-link four-quadrant AC-AC conversion [2]. This class of converters is used in high (or medium) voltage, high power (multi-MWs) applications, replacing the classical thyristor-based cycloconverters, and line and load-commutated current-fed converters. The applications of multi-level converters include induction and synchronous motor drives for various industrial applications, high voltage DC (HVDC) systems, flexible AC transmission systems (FACTS), static VAR compensators (SVC, or STATCOM, or static VAR generators (SVG)), photovoltaic and wind generation systems, *etc.*

A traditional two-level converter can be used in high-voltage, high-power applications by series-parallel connection of matched power semiconductor devices. An application example is HVDC converters by ABB (called HVDC LIGHT) [3]. However, such converters have high dv/dt and di/dt, large EMI and common mode current, besides low efficiency. Two-level phase-shifted converter units can also be coupled through a step-up transformer to generate multi-level stair case voltage wave for such applications [2].

Multi-level converters have the general advantages of improved efficiency, lower dv/dt and di/dt, reduced harmonics, reduced EMI, lower common mode current, and the advantages of transformerless and fault-tolerant operations. The era of multi-level converters started by the introduction of three-level neutral-point-clamped (NPC) converter in 1981 by Nabae, Takahashi and Akagi [4]. The advent of NPC converters, quickly replaced the phase-controlled cycloconverters and current-fed converters for four-quadrant motor drives. Because of self-commutated devices (such as GTOs, IGCTs and IGBT), the harmonic quality of line current wave improved substantially with control of line active and reactive (leading or lagging) powers and substantial improvement of reliability. Gradually, other topologies of multi-level converters, such as flying capacitor converter (FCC) and modular multi-level converters (MMC) and various hybrid topologies were introduced. The MMCs are sub-classified into cascaded H-bridge (CHB) and cascaded half-bridge topologies. The MMC topology has the inherent advantages of low device voltage rating and fault-tolerance capability with redundancy. The MMC topology with half-bridges is particularly becoming popular in recent applications [5]. It is interesting to note here that Siemens uses this topology (called HVDC PLUS) for offshore wind energy transmission [6,7].

2. The Present Issue

This Special Issue received altogether six papers, of which five were accepted for publication. All the papers, except the first one, are application oriented with different topologies that combine the basic units of three-level NPC converters and H-bridge two-level converters.

The first paper by Kim and Lee tends to make reliability prediction of half-bridge based MMC used for HVDC applications using the failure rate table of the circuit components [8]. In the beginning, the basic principles of reliability along with mathematical expressions have been reviewed, and then using the failure rate table, the mean time to failure for submodule has been evaluated. Then, unavailability curve of module has been predicted with number of redundancy. The second paper by Chen considers application of NPC rectifier in permanent magnet synchronous generator based wind generation system [9]. The DC is converted to three-phase AC for autonomous load (balanced or unbalanced) by using H-bridge inverters and coupling transformer at the output. The NPC has the advantages of lower line harmonics and control of unity power factor. The system analysis, control development and experiments are done in detail. The third paper by Nunes *etc.* considers an STATCOM using cascaded H-bridge converter, where DC-link voltage levels are different. The system has been analyzed and tested with detailed control formulation [10]. The fourth paper by Filippini *etc.* considers converter configuration for combining wind and PV powers and feeding to the utility grid [11]. The system uses single-phase NPC inverters for PV and three-phase NPCs for wind, where DC links are isolated for PV but a common dc bus links the wind systems. The analysis, simulation study and control development have been done in detail. The fifth or final paper by Moonem *etc.* considers a high-frequency link DC-DC converter which uses H-bridge two-level converter on low voltage side and NPC H-bridge converter on high voltage side [12]. The analysis and experimental studies have been done in detail.

3. Future

What is the prognosis of multi-level converters? From the recent literature and the current trend of applications, it is evident that MMC (with half-bridges) will be the most important topology for future applications.

Power semiconductor devices play the most important part in multi-level converters. Originally, GTOs were used in the converters, but because of low switching frequency and need for large snubbers, multi-stepped stair-case voltage wave fabrication through transformer coupling was popular because the device switching frequency is the same as line frequency. However, for motor drives [2] with variable frequency, PWM switching was used with regenerative snubbers. Gradually, GTOs were replaced by IGCTs, but the modern multi-level converters invariably use IGBTs. We are now at the start of a new era of large bandgap power semiconductor devices [13], such as SiC and GaN with higher switching frequency, lower conduction drop, and higher temperature. These properties improve the converter efficiency, and converter size becomes smaller. Unfortunately, the passive devices (such as capacitors) and silicon-based gate drivers are temperature limited that do not permit higher temperature operation of the converters. The PEBB (power electronic building block) construction of the converter along with integration of control ICs improve system reliability with reduction of size. It is evident that future smart grid with integration of renewable energy systems will extensively use multi-level converters. The diagnostic techniques of converter system faults, fault-tolerant control, modeling and simulation, particularly real-time simulation [14] with hardware in the loop (HIL), are now being studied extensively. The advent of supercomputers (such as Opal-Rt eMEGAsim [15]) are extremely important for such studies in large systems. For fault diagnostics and fault-tolerant control, artificial intelligence (AI) techniques, such as fuzzy logic and neural network, are extremely important [2].

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Conflicts of Interest

The author declares no conflicts of interest.

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