An Extensive Review on Repetitive Control Scheme for Harmonic Suppression of Circulating Current in Modular Multilevel Converters

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Abstract: This dissertation provides insight into state-of-the-art Modular Multilevel Converters (MMC) for medium and high voltage applications. Modular Multilevel Converters have increased in interest in many industrial applications, as they offer the following advantages: modularity, scalability, reliability, distributed location of capacitors, etc. Modular multilevel converters are beneficial for medium voltage motor drives because the properties of this converter topology, such as low distortion, allow for an efficient motor drive design.

Key words: Circulating current, harmonic suppression, modular multilevel converter (MMC), repetitive control.

I. INTRODUCTION

Power electronics are fundamental components in consumer electronics and clean energy technologies. For today's high-power applications, multilevel converters are gaining a lot of attention, and are becoming one of the top clean power and energy conversion choices for new topologies and control in industry and academia. Currently, multilevel converters are commercialized in standard and customized products that power a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, high-voltage direct-current (HVDC) transmission, hydro pumped storage, wind energy conversion, and railway traction, to name a few. Several well-known companies offer multilevel converters commercially for these applications in the field. In Fig. 1.1, the applications of multilevel converters are shown. Although the technology of multilevel converters is already developed such that they can be considered a mature and proven technology, they still have quite a few associated challenges.

The recent attention in environment protection and preservation increased the interest in electrical power generation from renewable sources: wind power systems and solar systems are diffusing and are supposed to occupy an increasingly important role in world-wide energy production in coming years.

Not only house utilities, but industrial applications and even the electrical network requirements display the importance that energy supply and control will have in the future researches.

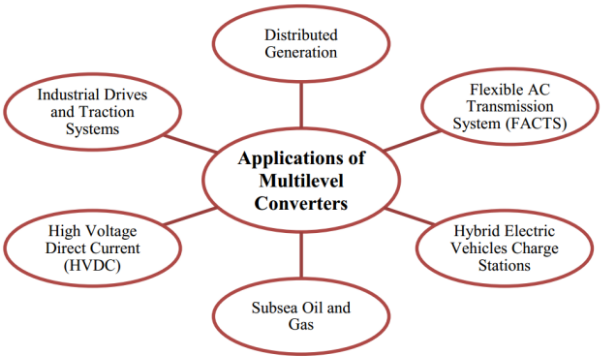

Fig. 1.1: Applications of Multilevel Converters.

As a consequence, power conversion and secondly control is required to be reliable, safe and available in order to accomplish all requirements, both from users and legal regulations, and to reduce the environmental impact.

Voltage Source Converter (VSC) technology is becoming common in high-voltage direct current (HVDC) transmission systems (especially transmission of offshore wind power, among others). HVDC transmission technology is an important and efficient possibility to transmit high powers over long distances.

The vast majority of electric power transmissions were three-phase and this was the common technology widespread. Main advantages for choosing HVDC instead of AC to transmit power can be numerous but still in discussion, and each individual situation must be considered apart. Each project will display its own pro and con about HVDC transmission, but commonly these advantages can be summarized: lower losses, long distance water crossing, controllability, limitation short circuit currents, environmental reason and lower cost.

One of the most important advantages of HVDC on AC systems is related with the possibility to accurately control the active power transmitted, in contrast AC lines power flow can't be controlled in the same direct way.

However conventional converters display problems into accomplishing requirements and operation of HVDC transmission. Compared to conventional VSC technology, Modular Multilevel topology instead offers advantages such as higher voltage levels, modular construction, longer maintenance intervals and improved reliability.

Description and principle of operation of MMC

The typical structure of a MMC is shown in Fig. 2, and the configuration of a Sub Module (SM) is given in Fig. 1. Each SM is a simple chopper cell composed of two IGBT switches (T1 and T2), two anti-parallel diodes (D1 and D2) and a capacitor C. Each phase leg of the converter has two arms, each one constituted by a number N of SMs. In each arm there is also a small inductor to compensate for the voltage difference between upper and lower arms produced when a SM is switched in or out.

Topology Evaluations

The conceptual background of the MMC comes back to the two-level voltage source converter when there are top and bottom switches in each arm of the converter. The problem with the two-level converter in medium and high power applications is extremely high converter switching losses, as achieving a desirable harmonic content in the converter, requires a high switching frequency.

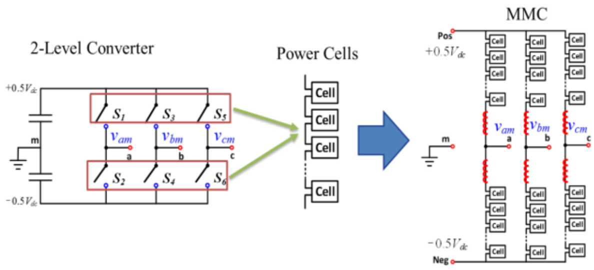

Fig. 1.2 Modular Multilevel Converter conceptual realization

Therefore, there needs to be an alternative converter that provides lower switching losses while achieving high voltage ratios. Figure 1.3 shows how the modular multilevel converter idea first developed.

By replacing the single switch or series connected switches, which normally is an insulated-gate bipolar transistor (IGBT) with a series of single-phase two-level converters sub-modules where each SM can be typically realized by the half-bridge converter, the MMC topology was formed.

II. LETERATURE SURVEY

SR. NO.	TITLE	AUTHORS	YEAR	METHODOLOGY
1	A Repetitive Control Scheme for Harmonic Suppression of Circulating Current in Modular Multilevel Converters	L. He, K. Zhang, J. Xiong and S. Fan	Jan. 2015	Presents a plug-in repetitive control scheme to solve the problem
2	Recent Advances and Industrial Applications of Multilevel Converters	S. Kouro et al.	Aug. 2010	Presents a brief overview of well-established multilevel converters strongly oriented to their current state in industrial applications to then center the discussion on the new converters that have made their way into the industry.
3	An innovative modular multilevel converter topology suitable for a wide power range	A. Lesnicar and R. Marquardt	2003	Presents a new multilevel converter topology suitable for very high voltage applications, especially network interties in power generation and transmission.
4	A new AC/AC multilevel converter family	M. Glinka and R. Marquardt	June 2005	A new ac/ac modular multilevel converter (M2LC) family will be introduced.
5	Classification, Terminology, and Application of the	H. Akagi	Nov. 2011	Discusses the modular multilevel cascade converter (MMCC) family based on cascade connection of multiple

	Modular Multilevel Cascade Converter (MMCC)			bidirectional chopper cells or single-phase full-bridge cells.

L. He, K. Zhang, J. Xiong and S. Fan, [1] In a modular multilevel converter (MMC), the interaction between switching actions and fluctuating capacitor voltages of the submodules results in second- and other even-order harmonics in the circulating currents. These harmonic currents will introduce extra power loss, increase current stress of power devices, and even cause instability during transients. Traditional methods for circulating current harmonic suppression have problems such as limited harmonic rejection capability, limited application area, and complex implementation. This paper presents a plug-in repetitive control scheme to solve the problem. It combines the high dynamics of PI controller and good steady-state harmonic suppression of the repetitive controller, and minimizes the interference between the two controllers. It is suitable for multiple harmonic suppression, easy to implement, and applicable for both single-phase and three-phase MMCs. Simulation and experimental results on a single-phase MMC inverter proved the validity of the proposed control method.

S. Kouro et al., [2] Multilevel converters have been under research and development for more than three decades and have found successful industrial application. However, this is still a technology under development, and many new contributions and new commercial topologies have been reported in the last few years. The aim of this paper is to group and review these recent contributions, in order to establish the current state of the art and trends of the technology, to provide readers with a comprehensive and insightful review of where multilevel converter technology stands and is heading. This paper first presents a brief overview of well-established multilevel converters strongly oriented to their current state in industrial applications to then center the discussion on the new converters that have made their way into the industry. In addition, new promising topologies are discussed. Recent advances made in modulation and controls of multilevel converters are also addressed. A great part of this paper is devoted to show non-traditional applications powered by multilevel converters and how multilevel converters are becoming an enabling technology in many industrial sectors. Finally, some future trends and challenges in the further development of this technology are discussed to motivate future contributions that address open problems and explore new possibilities.

A. Lesnicar and R. Marquardt, [3] this work presents a new multilevel converter topology suitable for very high voltage applications, especially network interties in power generation and transmission. The fundamental concept and the applied control scheme are introduced. Simulation results of a 36 MW-network intertie illustrate the efficient operating characteristics. A suitable structure of the converter-control is proposed.

M. Glinka and R. Marquardt, [4] A new ac/ac modular multilevel converter (M2LC) family will be introduced. The new concept stands out due to its modularity and superior control characteristics. The stringent modularity results in a very cost-efficient and versatile converter construction. This new M2LC concept is well suited to a wide range of multiphase ac/ac converters. The basic working principle together with the static and dynamic behaviour is explained in detail on a single-phase ac/ac converter enabling four-quadrant operation. It is demonstrated that this converter concept fulfils the demanding requirements for future ac-fed traction vehicles very well.

H. Akagi, [5] This paper discusses the modular multilevel cascade converter (MMCC) family based on cascade connection of multiple bidirectional chopper cells or single-phase full-bridge cells. The MMCC family is classified from circuit configuration as follows: the single-star bridge cells (SSBC); the single-delta bridge cells (SDBC); the double-star chopper cells (DSCC); and the double-star bridge cells (DSBC). The term MMCC corresponds to a family name in a person while, for example, the term SSBC corresponds to a given name. Therefore, the term "MMCC-SSBC" can identify the circuit configuration without any confusion. Among the four MMCC family members, the SSBC and DSCC are more practical in cost, performance, and market than the others although a distinct difference exists in application between the SSBC and DSCC. This paper presents application examples of the SSBC to a battery energy storage system (BESS), the SDBC to a static synchronous compensator (STATCOM) for negative-sequence reactive-power control, and the DSCC to a motor drive for fans and blowers, along with their experimental results.

III. PROBLEM IDENTIFICATION

The second-order as well as other higher orders harmonics in circulating current brings extra power losses and may affect stable operation of the MMC. This paper proposed a "PI + Repetitive" control scheme to suppress these harmonics in the circulating current. It greatly improves the harmonic suppression of the conventional PI controller. It is applicable to both single-phase and three-phase systems, and is able to eliminate multiple harmonics with a single controller. Compared with another "PI + Repetitive" control scheme in which the two controllers are paralleled, the control structure proposed in this paper results in a more friendly plant for the repetitive controller, and poses no design limit on the PI controller

IV. CONCLUSION

This literature review on multilevel converters, fault detection and isolation as well as sliding mode control and observers. Due to the large number of sensitive devices, including power semi-conductor devices and capacitors, multilevel converters can be subject to component failures. Hardware and analytical fault detection and isolation methods can be applied to multilevel converters to improve their availability and resilience. A sliding mode observer can reject certain external disturbances as well as internal model uncertainties and is a good candidate for fault detection. Three analytical fault detection and isolation methods for a modular multilevel converter based on sliding mode observers are therefore proposed in this work.

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