INTERNATIONAL JOURNAL OF INNOVATIVE TRENDS IN ENGINEERING (IJITE) ISSN: 2395-2946
ISSUE: 51, VOLUME 31, NUMBER 01, 2017

An Extensive Survey on Controlling of Harmonic In Circulating Current For MMC-HVDC

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Abstract - The modular topology of MMC enables to build high voltage converters with a higher scalability and fault tolerance. By increasing the number of voltage levels in the output using more sub modules, the power capability can be increased and the switching frequency can be effectively reduced. Furthermore, as the harmonics of the output voltage are reduced due to increased voltage levels, less filtering is required hereby improving the compactness of the system. The reduced switching frequency will also help in decreasing the switching losses significantly and thus leading to increased power ratings of the converter. Besides, as there is no direct series connections of the several semiconductor switches involved, problems related to simultaneous switching are also avoided. Nevertheless, low order voltage harmonics at low switching frequencies put a larger energy storage requirement than as in traditional two level converters. Thus, deriving a model that can completely describe the technical characteristics of the converter, including the internal dynamics of the SM capacitor voltages and currents circulating between the legs of the converter is of significant importance. Grid-connected high-power converters are found in high-voltage direct current transmission (HVDC), static compensators (STATCOMs), and supplies for electric railways. Such power converters should have a high reliability, high efficiency, good harmonic performance, low cost, and a small footprint.

Keywords- Modular multilevel converter (MMC), feed-forward control, modulation, switching frequency, energy storage.

I. INTRODUCTION

HVDC technology based on Voltage Source Converters (VSC-HVDC) is the successful and environmentally-friendly way to design a power transmission system for a submarine cable, an underground cable, using over head lines or as a back-to- back transmission. Combined with extruded DC cables, overhead lines or back-to- back, power ratings from a few tenths of megawatts up to over 1,000 MW are available. VSC-HVDC is based on Insulated Gate Bipolar Transistors (IGBT) and operate with high frequency pulse width modulation in order to achieve high speed and, as a consequence, small filters and independent control of both active and reactive power and they offer several advantages compared to earlier HVDC classic technology based on Current Source Converters (CSC-HVDC) using thyristors.

Modular Multilevel Converters (MMCs) have gained researcher's attention due to their ability to handle high voltage and power ratings. VSC-HVDC is getting increasingly important for integrating renewable energy sources such as large offshore wind farms, providing flexible interconnection between two weak AC grid network using back-to-back configuration, or simply transmitting power using underground cables. The VSC-HVDC also has fast and precise control over the active power-flow as well as it can independently control the reactive power injection at the local ac grid. There are numerous operational MMC-HVDC projects such as HVDC PLUS (Siemens) with an 88 km undersea transmission link between San Francisco’s City Centre electrical power grid and a substation near Pittsburg. The main supporting functions HVDC PLUS provides are AC voltage Control, black-start capability, compact converter station space usage, four quadrant operation, compensation of asymmetrical loads, and flexible integration into HVDC multi terminal systems or future HVDC grids.

Another MMC-HVDC installation named HVDC Light by ABB, is an adaptation of HVDC classic used to transmit electricity in power ranges (50-2500MW) transmit-ted using overhead lines and environmental friendly underground and sub-sea cables. It is used for grid interconnections and offshore links to wind farms. With HVDC Light, it is possible to transmit power in both directions and to support existing AC grids in order to increase robustness, stability, reliability and controllability. HVDC Light offers many other advantages and can be used in different applications which are explained. As outlined before, the main limitation of the two level converters is its high switching losses due to relatively high switching frequency which necessitates high insulation requirements of the transformer, as well as filters. The use of modular multilevel converters overcomes many of the aforementioned shortcomings, but at the expense of twice as many semi-conducting devices and a large distributed capacitor for each submodule. The principle idea of the hybrid VSC-HVDC, as used in HVDC MaxSine developed by Alstom, is to use a two level converter as the main switching component with low switching frequency and an MMC to provide a voltage wave shaping function on the AC side in order to eliminate the harmonics.

Such a feature was already known from the Cascaded H-Bridge (CHB) converter. It was not after almost twenty years that this topology started being investigated for static synchronous compensator (STATCOM) application, electric drives as well as traction converters. An inductive element completes the converter branch, aiming at the limitation of undesirable currents caused by the parallel connections of voltage-source-behaving power circuits as well as enhancing the converter control and protection. The latter gives finally a current-source nature to the branch. During the last decade, however, research on different branch configurations for the achievement of several conversion schemes, has rather led to a whole family of power converters, which the term MMC can be attributed to.

II. MMC MODELING

As it can be shown in Figure 2.1, the circuit structure of MMC consists of three phase legs, each comprising of two arms connected in series between the dc-link. There are N number of Sub Modules (SM) in each arm in series with the arm inductor and resistor. The main objective of the inductor is to limit the surges in the arm current and also arm current harmonics; thus they are significant in the control of circulating currents. The resistances are operational variables, as they model the converter losses and the resistances of the inductor.

The SMs are the basic building blocks of the MMC and consist of either of the most popular configurations; half bridge or full bridge configurations. The half bridge configuration, which is the focus of this exploration, is depicted in Figure 2.2. It comprises of two switches, which dictates the charging and discharging of the capacitor. The switches consist of a controllable power switch (e.g. an IGBT) and an anti-parallel diode. When a switch is turned on, either the IGBT or the antiparallel diode in the same switch conducts. Only one switch is turned on at a time and thus there are three possible switching modes; inserted, bypassed and blocked. The SM is said to be inserted if switch S1 is turned on and the capacitor can be either charging or discharging depending on the direction of the arm current. If the arm current flows into the SM through the anti-parallel diode of S1, then the capacitor will be charged. However, if the current flows out of the SM through the IGBT of S1, then the capacitor will be discharged. Nevertheless, regardless of the direction of the arm current, the terminal voltage of the SM is the same as the capacitor voltage. The SM is operating in its bypassed mode if switch S2 is turned on. In this mode whichever the direction of the arm current is (either the IGBT or the anti-parallel diode will conduct depending on the direction of the arm current), the capacitor voltage remains constant and the terminal voltage of the SM is zero. The blocked mode of operation of the SM is when both the switches are turned off. This is impractical mode of operation as the capacitor can only charge (through the anti-parallel diode), but never discharge. As a result of the two practical modes, the SM can be controlled to provide either the capacitor voltage or zero output voltage. This way, the SMs are switched on and off generating stepped, near-sinusoidal waveforms.

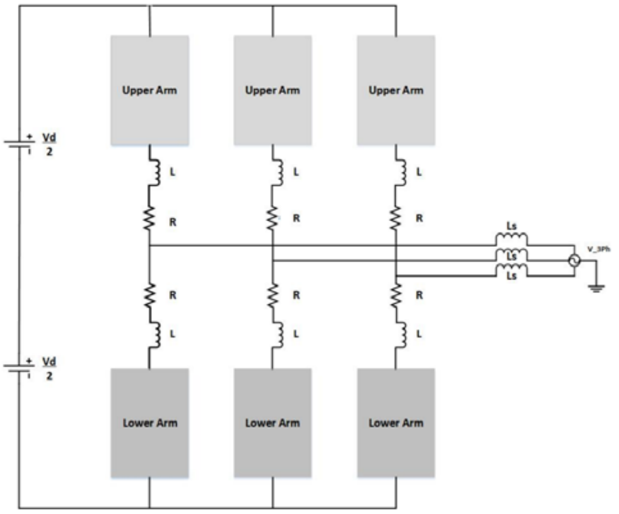

Figure 2.1 Schematic model of three phase MMC.

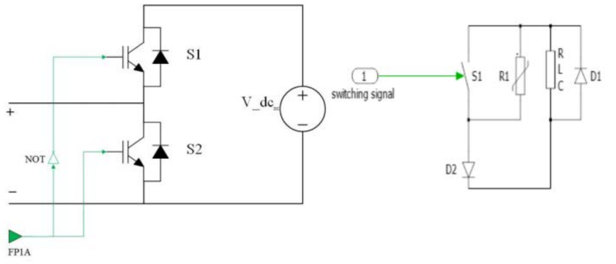

Figure 2.2 (a) Half-bridge SM (b) IGBT valve (detailed model).

III. RELATED WORK

Heejin Kim, Sangmin Kim, Yong-Ho Chung, Dong-Wook Yoo, Chan-Ki Kim and Kyeon Hur,[1] The operating region of modular multilevel converter (MMC) is limited by the maximum allowable voltage ripple of cells, which is associated with the arm energy variation. Injecting the controlled second-order harmonic component into the circulating current can reduce energy variation of arm and thus extend the operating region of MMC. Care must be taken, however that the second-order circulating current affects the arm current and inappropriately injected harmonic current may cause the arm current polarity change undesirably. Therefore, this work first investigates and proposes the maximum allowable second-order circulating current for extending the operating region reliably and efficiently. The active and reactive power capability of MMC is further elaborated and illustrated in line with the maximum excess energy capability for two cases, running with (1) the original operating region and (2) the extended operating region. Finally, the P-Q diagrams for contingent operating conditions with faulty or disabled submodules are presented. Understanding unique shape and change of P-Q capability with credible submodule failure contingency should be crucial for planning MMC-HVDC lines, and determining the energy requirements and the level of redundancy in submodules properly in order to achieve the envisioned benefits of the new HVDC. The efficacy and accuracy of the research findings are validated for MMC-HVDC system using PSCAD/EMTDC.

S. Cui, H. J. Lee, J. J. Jung, Y. Lee and S. K. Sul,[2] The AC side Single Line to Ground (SLG) fault is one of the most frequent faults in power systems. And, in an HVDC system based on modular multilevel converter it calls for the fault ride through strategy to transmit maximum possible electricity during the fault to secure power system stability. It presents different characteristics of SLG faults at the voltage regulator side and the power dispatcher side. In this work a comprehensive fault ride through strategy for AC side SLG fault occurred at both converters of the HVDC system is proposed. The proposed method presents fast dynamics and promises maximum possible electricity transmission during the faults. Voltage fluctuation and current overshoot in transmission line during SLG fault can be fully suppressed by the proposed method. Moreover, the proposed control strategy is free of inter-station communication and secures the reliability of HVDC transmission system. Validity of the proposed method is verified by simulation of a ±200kV, 400MW point-to-point HVDC system (216 sub-modules per arm).

K. H. Ahmed and A. A. Aboushady,[3] One of the main challenges of voltage source converter based HVDC systems is DC faults. In this work, two different modified half-bridge modular multilevel converter topologies are proposed. The proposed converters offer a fault tolerant against the most severe pole-to-pole DC faults. The converter comprises three switches or two switches and 4 diodes in each cell, which can result in less cost and losses compared to the full-bridge modular multilevel converter. Converter structure and controls are presented including the converter modulation and capacitors balancing. MATLAB/SIMULINK simulations are carried out to verify converter operation in normal and faulty conditions.

H. J. Lee, J. j. Jung and S. K. Sul,[4] A switching loss of Modular Multilevel Converter(MMC) might increase drastically in HVDC system because the number of sub-module(SM) is proportional to the DC-link voltage. And, a special strategy for reducing switching frequency has been significant research issue in terms of overall operating efficiency of MMC for HVDC system. The voltage fluctuation of capacitor in SM, however, increases as the switching frequency decreases, and the capacitor with large capacitance which is the main portion of equipment cost for SM is required to mitigate the voltage fluctuation. In this work, the switching frequency reduction strategy is proposed using the sorting method with a virtual capacitor voltage of individual SMs. In addition, this work presents the 2nd order harmonic circulating current injection to suppress the voltage fluctuation. By numerical loss analysis, it is identified that the 2nd order harmonic current injection does not incur severe additional loss. Thanks to the harmonic current injection, the capacitance of SM capacitor could be reduced by 33% at the cost of only 0.05 % efficiency degradation in the given simulation condition. To evaluate the effectiveness of the proposed strategies, the computer simulation with 400 kV, 400MA, 221-level MMC has been performed and the results are discussed. Additionally, validity of the proposed strategies has been verified by 7-level down scaled prototype experimental setup.

A. Schoen, A. Birkel and M. M. Bakran,[5] The main advantage of a modular multilevel converter is the very low total harmonic distortion. Even a very high modulation frequency leads to only a moderate switching frequency per IGBT and therefore, compared to other converter topologies very low switching losses. However, this low switching frequency per submodule in combination with a high output modulation frequency leads to an uneven loss distribution between the submodules. With an average of only six to eight switching events per AC period the distribution of conduction and switching losses within a submodule can lead to unbalanced semiconductor temperatures and additional temperature cycles. Based on simulation results, this work investigates the single module losses of a modular multilevel converter for HVDC applications with a high submodule count per phase and a low switching frequency per submodule.

B. R. Baroni, M. A. S. Mendes, P. C. Cortizo, A. C. Lisboa and R. R. Saldanha,[6] The modular multilevel converter (MMC) is based on the cascaded interconnection of half-bridge switching sub-modules. It features modular characteristics that allow its expandability while providing high quality voltage and current output waveforms and removing the need for bulky passive filters. This work proposes a control technique and two modulation techniques for the modular multilevel converter. For the first time a multiple cuts ellipsoidal algorithm is used in order to find the switching angles for the selective harmonic elimination (SHE PWM).

Xu She and A. Huang,[7] Modular multilevel converter is regarded as a promising technology in high voltage application, such as off-shore wind farm system. This work proposes control technique for modular multilevel converters, aiming at suppressing the AC components in the circulating current. Specifically, an additional proportional-resonant control loop is designed to regulate the AC component of the circulating current to zero. The proposed method can effectively suppress the AC circulating current even in the unbalanced/fault condition. Simulation results for a 10MVA, 25KV DC system are provided to demonstrate the feasibility of the proposed method.

Table 1 Summary of Literature Review.

SR. No.	Title	Authors Name	Year	Approach
1	Operating region of modular multilevel converter for HVDC with controlled second-order harmonic circulating current: Elaborating P-Q capability	Heejin Kim, Sangmin Kim, Yong-Ho Chung, Dong-Wook Yoo, Chan-Ki Kim and Kyeon Hur	2016	The P-Q diagrams for contingent operating conditions with faulty or disabled submodules are presented
2	A comprehensive AC side single line to ground fault ride through strategy of a modular multilevel converter for HVDC system	S. Cui, H. J. Lee, J. J. Jung, Y. Lee and S. K. Sul,	2015	A comprehensive fault ride through strategy for AC side SLG fault occurred at both converters of the HVDC system is proposed
3	Modified half-bridge modular multilevel converter for HVDC systems with DC fault ride-through capability,	K. H. Ahmed and A. A. Aboushady,	2014	Two different modified half-bridge modular multilevel converter topologies are proposed
4	A switching frequency reduction and a mitigation of voltage fluctuation of modular multilevel converter for HVDC	H. J. Lee, J. j. Jung and S. K. Sul,	2014	The switching frequency reduction strategy is proposed using the sorting method with a virtual capacitor voltage of individual SMs
5	Modulation and Losses of Modular Multilevel Converters for HVDC Applications,	A. Schoen, A. Birkel and M. M. Bakran,	2014	Low switching frequency per submodule in combination with a high output modulation frequency leads to an uneven loss distribution between the submodules
6	Application of modular multilevel converter for HVDC transmission with selective harmonics	B. R. Baroni, M. A. S. Mendes, P. C. Cortizo, A. C. Lisboa and R. R. Saldanha,	2013	A control technique and two modulation techniques for the modular multilevel converter.
7	Circulating current control of double-star chopper-cell modular multilevel converter for HVDC system	Xu She and A. Huang,	2012	Aiming at suppressing the AC components in the circulating current. Specifically, an additional proportional-resonant control loop is designed to regulate the AC component of the circulating current to zero.

IV. PROBLEM STATEMENT

HVDC transmission applications the MMC technology is being investigated for a wide range of applications such as railway feeding interties and medium voltage industrial drives for its numerous benefits. Consequently, it is an active research area where investigations aiming at a deep understanding and optimum solutions for modeling, modulation schemes. So far, different topologies of MMC have been proposed addressing specific concerns. A frequency domain model of MMC, for steady-state analysis of all operating point variables has been derived. In addition to mimicking the results of the detailed time domain computations, the model has a further advantage of clearly separating the dynamic and steady state effects. However, several assumptions in the model such as ignoring the switching harmonics, were made and thus it has a setback as it is not able to model the dynamics of the system. Consequently, it can't be used for further control system analysis, such as in the design and evaluation of the closed loop control systems.

V. CONCLUSION

In this work various methods for MMC has discussed for HVDC transmission application With the trend of increasing in the penetration of distributed energy resources, the VSC (Voltage Source Converter) is becoming a key role player in integrating these renewable energy resources with the existing grid. Moreover, it is being used as a fundamental block in different power electronic based devices, to solve differ challenges in the power system; starting from integrating renewable energy resources to HVDC (High Voltage Direct Current) applications. However, to meet the rising demands of power capabilities and harmonic performance of converters, a VSC based technology. The aim is to provide analytical tools and a deeper understanding of the dimensioning factors in MMCs. Not only will this make it easier to compare the MMC with other cascaded converter topologies, but identifying the limiting factors will also contribute to the possible development of future improved converter topologies.

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