Hybrid Multi-level Converter with Fault Blocking Capability: A Review

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Abstract – An Alternate Arm Converter (AAC) is the new hybrid converter technology based on modular multilevel converter technology. For HVDC dc application. In this work a brief review on the modular multilevel converter topologies has been presented. MMC technology is getting increasing interest for its modular design, filter-free feature and low semiconductor device switching frequency. One promising application for MMCs is to be utilized in a complicated application environment such as HVDC. The study of fault management and DC-fault Blocking Capability in a medium voltage DC system is at preliminary stage has also been reviewed and represented. The research results from this study may bring new ideas for VSC-HVDC protection design which may be used for better coordination of regional power flow, voltage regulation, and relay setting. The multi-MMC based system also requires a baseline for coordination control.

Index Term- an Alternate Arm Converter (AAC), VSC-HVDC, Modular Multi Level Converter (MMC), fault Blocking.

I. INTRODUCTION

Increasing trend of energy demand and its mitigation by use of several conventional and non-conventional energy sources and transportation of energy from generating station to remote areas is a great challenge. To serve the above purpose it is needed to have a bulk power transmission over a long distance through overhead transmission line and undersea cable, this becomes hectic in case of AC transmission due to high charging current and losses caused by capacitance. Problem related to interconnect the unsynchronized grids to the existing grid, where the voltage level and frequency is the main constraint which restricts the interconnection through an AC link. For the eradication of above problem, it is having a solution by using DC transmission, where a controlled DC transmission provides the flexibility for a bulk power transmission over a long distance through a DC link.

Converter stations are being used at the generating end for AC/DC conversion in a controlled manner which enables a controlled power flow. A rapid development and research on power electronics switches provides a better, efficient technique for control mechanism, hence control over power flow.

HVDC transmission resides a two basic type of converter technology. Those are classical line commutated current source converter (CSCs) and self-commutated voltage sourced converters (VSCs) [3]. Classical HVDC technology employs line commutated current source converters with thyristor valve used as a base technology for DC transmission in 1950s. Where thyristors are not fully controlled switches, hence it put limitation to control mechanism used for controlled power flow. Voltage source converter based transmission technology introduces flexibility in power transmission, as it uses fully controllable switches like IGBT which provides one of the efficient control mechanisms for control of power flow. Both classical and VSC-HVDC are used for the applications like long distance transmission, underground and undersea cable transmission and interconnection of asynchronous networks. But from control point of view VSC-HVDC having more flexibility and efficient power flow mechanism, as it is capable of controlling both active power and reactive power independently of each other, to keep stable voltage and frequency. Particularly self-commutation, dynamic voltage control and black start capability allows VSC transmission technology to serve isolated loads on islands over long distance submarine cables.

Thyristor based classical HVDC mostly used for point to point large power transmission long distance over land or undersea cables. It has certain disadvantage like commutation failure as thyristors can't be off immediately, and it requires 40 ~ 60 % reactive power supply of the total active power transmission. To have a solution IGBTs are used that can be switched off and on immediately, no commutation problem, active and reactive power control independently, no reactive power compensation required, filter requirement is less as to filter out high frequency signals from PWM, no requirement of telecommunication between two stations of VSC-HVDC system.

VSC -HVDC link consist of a back to back voltage sourced converters (VSCs), a common DC link, which includes a large DC capacitors and DC cables. The control strategy is being designed to coordinate the active power control between two station which is realized by controlling the DC side voltage of one converter where other converter control the active power. Automatic control of power flow between stations is the result of a constant DC voltage source gives “slack bus”. AC voltage control and reactive power control will switch as per the requirement. The switching state of these director switches determines which arms are both generating the converter voltage waveform and carrying the AC current to the respective DC terminal. This approach has proven to be both power and volume effective, resulting the number of cells be significantly reduced, e.g. up to half the number of cells compared to the MMC, the average cell voltage deviation is lower allowing smaller capacitors in the cells and the use of full H-bridge cells instead of half-bridge cells, thus the AAC is able to block DC-side faults without compromising its overall power efficiency.

II. MODULAR MULTI-LEVEL CONVERTER

The multilevel converter is a revolutionary innovation in the power electronic industry. This topology is able to make solid-state devices like IGBTs work in high voltage application (e.g. power system). As the power semiconductor became commercially available, the multilevel topology gained widespread attention in research circles because this topology made low voltage devices applicable in high-voltage scenarios. It is hard for a new power electronics engineer to distinguish cascaded multilevel inverters and modular multilevel converters [9]. The main reason for confusion is that when references mention the multi-level terminology, they do not give any information about the detailed circuit configuration.

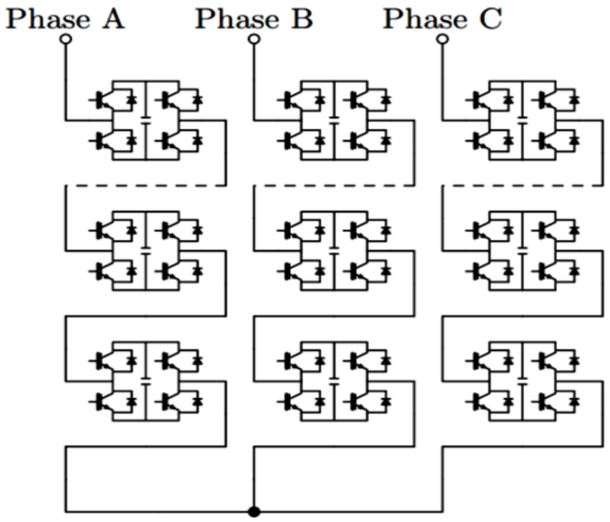

Figure 2.1 The circuit of Cascaded Multilevel Converter.

A. Cascaded Multilevel Converter

This topology is presented in figure where each phase is powered by several cells connected in series, and the input of each cell is provided by a secondary wing of a phase-shifted transformer. A similar topology named a cascaded inverter. Fig. 2.1 depicts the topology of the cascaded H bridge converter, and Fig. 2.2 describes the topology presented.

Where the capacitor of each cell is simplified as an equivalent DC side capacitor. The major difference between these two topologies is that the later is connected to the grid through a phase-shifted transformer, and the former is directly connected to the grid through an inductor. The no grid-tried inductor is used in Peng's early design.

The cascaded multilevel topology was designed to overcome the limitation of the solid-state switch ratings so that it can be bridge converters applied in high voltage systems

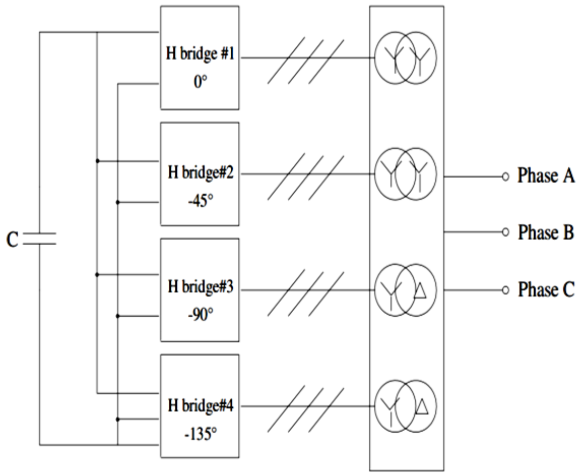

Figure 2.2 The circuit of transformer phase-shifted cascaded H bridge converters.

B. The Modular Multilevel Converter

The Space Vector Modulation (SVM) was used for generating gate pulses for firing IGBTs. This modulation method was no longer utilized for MMC with a large number of power cells since it becomes very complicated for real time calculation of the space vectors. A three-layer control architecture is also proposed in this exploration. In this architecture, the supervisory computer dealt with high level control. The central controller unit was designed for PWM generation and an embedded local controller was also implemented in the converter cubicle for the fast arm current control. But this exploration concluded that the capacitor voltage needed to be sent to the central unit every sample time which creates a heavy communication load. This is very cumbersome when a high number of sub-modules are used in a single phase branch. M. Glinka presented a full picture of MMC circuit configuration shown in Fig. 2.3 and its control. Controller, which deals with low speed tasks such as output voltages and currents as well as the arm energy stored in the DC capacitor and (ii) the local controller that deals with the gate pulse assignment and the power cell voltage balancing, which is an important control target for the MMC topology. More importantly, the local controller acts as a fast arm protector when the MMC converter encounters a short-circuit condition.

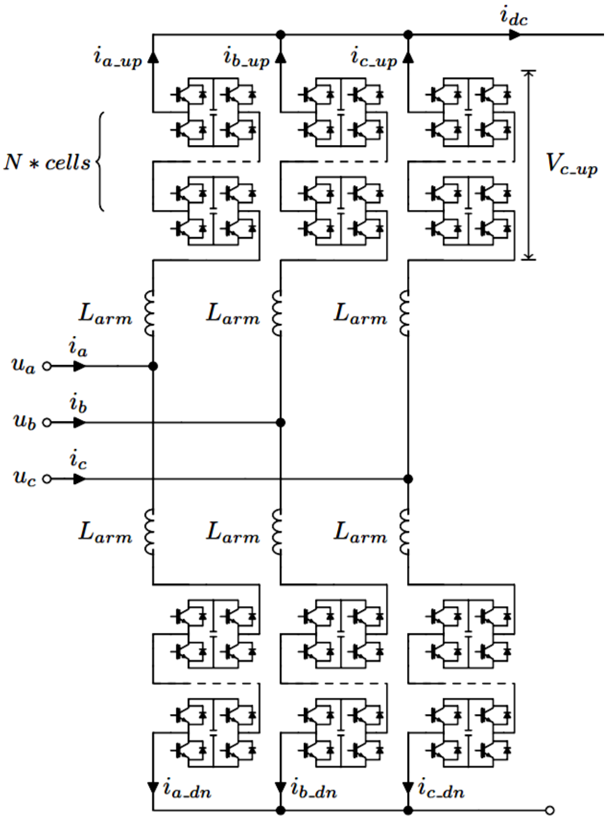

Figure 2.3 MMC topology with a full-bridge cell configuration

III. RELATED WORK

M. M. C. Merlin et al.[1] This exploration explains the working principles, supported by simulation results, of a new converter topology intended for HVDC applications, called the alternate arm converter (AAC). It is a hybrid between the modular multilevel converter, because of the presence of H-bridge cells, and the two-level converter, in the form of director switches in each arm. This converter is able to generate a multilevel ac voltage and since its stacks of cells consist of H-bridge cells instead of half-bridge cells, they are able to generate higher ac voltage than the dc terminal voltage. This allows the AAC to operate at an optimal point, called the "sweet spot," where the ac and dc energy flows equal. The director switches in the AAC are responsible for alternating the conduction period of each arm, leading to a significant reduction in the number of cells in the stacks. Furthermore, the AAC can keep control of the current in the phase reactor even in case of a dc-side fault and support the ac grid, through a STATCOM mode. Simulation results and loss calculations are presented in this exploration in order to support the claimed features of the AAC.

R. Marquardt,[2] Demanding future applications in power transmission and drives like solar-thermic power plants and off-shore wind power require advanced converter systems. Modular Multilevel Converters are well adopted to these needs, owing to industrial scalability, high efficiency and fast dynamic controllability under transient and fault conditions including DC-Side faults. The respective features of the established concepts for the high power range (M2C) and of new concepts for the low power range (MHF) are explained.

C. M. Franck,[3] The continuously increasing demand for electric power and the economic access to remote renewable energy sources such as off-shore wind power or solar thermal generation in deserts have revived the interest in high-voltage direct current (HVDC) multiterminal systems (networks). A lot of work was done in this area, especially in the 1980s, but only two three-terminal systems were realized. Since then, HVDC technology has advanced considerably and, despite numerous technical challenges, the realization of large-scale HVDC networks is now seriously discussed and considered. For the acceptance and reliability of these networks, the availability of HVDC circuit breakers (CBs) will be critical, making them one of the key enabling technologies. Numerous ideas for HVDC breaker schemes have been published and patented, but no acceptable solution has been found to interrupt HVDC short-circuit currents. This exploration aims to summarize the literature, especially that of the last two decades, on technology areas that are relevant to HVDC breakers. By comparing the mainly 20+ years old, state-of-the art HVDC CBs to the new HVDC technology, existing discrepancies become evident. Areas where additional research and development are needed are identified and proposed.

D. Jovcic, D. van Hertem, K. Linden, J. P. Taisne and W. Grieshaber,[4] This exploration examines the current status of technology and discusses technical options for developing DC transmission grids. The fast advances in VSC HVDC, the recent offshore VSC projects, the experience with multiterminal HVDC and recent development of fast DC circuit breakers bring large meshed DC grids closer to reality. The most important and most difficult remaining technical challenge is the system level protection of DC grids. The article further discusses some of the ongoing research directions like the use of travelling wave detection for fast protection or deployment of DC/DC converters for isolation of DC faults. One of the main work packages in EU funded Twenties project studies the major prerequisites for operation of DC grids. This project has delivered some major studies of DC grids and two hardware demonstration systems are under development: a mock-up DC grid at University of Lille and fast DC Circuit Breaker at ALSTOM.

R. Marquardt,[5] For demanding future applications in power transmission - like grid connection of large off-shore wind parks, solar thermic power generation or power supply of mega cities - there is a global need for advanced power electronic systems. The novel concept of Modular Multilevel Converter (M2C) offers superior characteristics for these applications. Its operations for HVDC-systems is explained and investigated with respect to new requirements - including failure management in Multi-terminal-HVDC-Networks.

J. Yang, J. E. Fletcher and J. O'Reilly,[6] The multi-terminal DC wind farm is a promising topology with a voltage source inverter (VSI) connection at the onshore grid. Voltage source converters (VSCs) are robust to AC side fault conditions, however, they are vulnerable to DC faults on the farm side of the converter. This exploration analyses DC faults, their transients and resulting protection issues. All kinds of fault over currents are analyzed in detail and these contribute to protection system design. The radial wind farm topology with star or string connection is considered. The outcomes are applicable for VSCs in both the multi-VSC DC wind farm collection grid and VSC-based high voltage direct current (HVDC) transmission systems for offshore wind farms.

Table 1 Summary of Literature review.

Sr. No.	Title	Author	Year	Approach
1	The Alternate Arm Converter: A New Hybrid Multilevel Converter With DC-Fault Blocking Capability,	M. M. C. Merlin et al.,	2014	The Alternate Arm Converter: A New Hybrid Multilevel Converter With DC-Fault Blocking Capability,
2	Modular Multilevel Converter topologies with DC-Short circuit current limitation,	R. Marquardt,	2011	established concepts for the high power range (M2C) and of new concepts for the low power range (MHF)
3	HVDC Circuit Breakers: A Review Identifying Future Research Needs	C. M. Franck	2011	summarize the literature, especially that of the last two decades, on technology areas that are relevant to HVDC breakers
4	Feasibility of DC transmission networks,	D. Jovcic, D. van Hertem, K. Linden, J. P. Taisne and W. Grieshaber,	2011	the use of travelling wave detection for fast protection or deployment of DC/DC converters for isolation of DC faults
5	Modular Multilevel Converter: An universal concept for HVDC-Networks and extended DC-Bus-applications	R. Marquardt,	2010	HVDC-systems is explained and investigated with respect to new requirements
6	Multi-terminal DC wind farm collection and transmission system internal fault analysis,	J. Yang, J. E. Fletcher and J. O'Reilly,	2010	Analyses DC faults, their transients and resulting protection issues

IV. PROBLEM STATEMENT

An efficient and reliable transport of bulk energy over a long distance is a great challenge. Charging current put a limitation to the power transmission through underground cable and undersea cable over a long distance. Problems in interconnection of asynchronous grids with the existing power grids due to frequency and voltage levels not suitable for grid connection. An efficient and stable operation of AC system during and post disturbance conditions is a great challenge for an AC transmission system. For the above problem it is needed to have a HVDC transmission. Which provides a greater flexibility and control of power flow through a DC transmission line and hence stability.

HVDC transmission can be achieved by using a back to back configuration of converter stations. Control of those stations brings a reliability of power flow and efficient operation. Converter station are classified into two categories for high power applications. Classification based on commutation process one is line commutated and forced commutated or self -commutation. Classification based on the terminal voltage and current wave form called as current source converter (where DC side polarity remain same, power flow decided by DC side voltage polarity) and voltage sourced converter (where DC side voltage polarity will remain same, power flow direction decided by DC side current polarity).

V. CONCLUSION

This work focused on the key issues of MMC controls and Alternate Arm Converter (AAC), and the fault current limiting features of using multiple MMCs. The fundamentals of MMC topology was analyzed in this work through a brief literature survey. The designing and concept of hybrid multi level controller was studied and observed the performance of it to achieve a better controllability of the DC side. The description of the MMC control is presented. The modeling of MMC based alternate arm converters is a difficult task. Multilevel MMC converter consists of several level of converter. Those increase the complexity of the model.

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