VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

OPERATION AND CONTROL OF AN ALTERNATE ARM MODULAR MULTILEVEL CONVERTER

J. M. Kharade[1] and A. R. Thorat[2]
[1]Department of Electrical Engineering, Rajarambapu Institute of Technology, Islampur, India
[2]Department of Electrical Engineering, Rajarambapu Institute of Technology, Islampur, India
E-Mail: jyoti.kharade99@gmail.com

ABSTRACT

An Alternate Arm Modular Multilevel Converter (AAMMC) is the recently introduced power electronics converter topology suitable for High Voltage DC Transmission (HVDC) system applications. This paper focuses on the operating principle of an Alternate Arm Modular Multilevel Converter. At the beginning the advantages of multilevel converter, basic schematic of converter topology, and its operation is discussed. For the controlling of the converter the simple sorting technique is employed. The AAMMC is a new converter topology which offers several advantages over existing multilevel converter topologies such as scalable and modular structure, low switching losses, DC fault tolerance property which eliminates the need of AC/DC breakers of large size and ratings, lower number of cells as compared to modular multilevel converter. The performance of the 21 level AAMMC without sorting and with sorting technique is verified with MATLAB Simulation.

Keywords: Alternate Arm Modular Multilevel Converter (AAMMC), Voltage Source Converter (VSC), submodule (SM), sorting technique.

INTRODUCTION

The multilevel converter topology have gained more prominence for the various power applications such as HVDC, high voltage power drives, reactive power compensation devices, filters, industrial applications etc. They offer the various features suitable for such applications. The advancement in semiconductor technology leads to development in power electronics technology and thus have changed the scenario of the power system industry [1]. The power quality issues have drawn the more attention on the power electronics based power system. The power electronics converter based on simple thyristor switching is much mature converter topology also called as Current Source Converter (CSC) or Line Commutated Converter (LCC) [2]. The development of new semiconductor switching devices such as IGBTs and GTOs have made a great evolution in the field of power electronics based power system.

The huge research is being carried out to improve the power system reliability, power transfer capability, and also power quality. The high power and high voltage applications are generally based on the AC/DC/AC conversion system [1]. So different multilevel converter topologies are designed and employed for HVDC applications to achieve these features.

There are mainly three existing types of multilevel converters such as Diode clamped multilevel converter, Flying capacitor multilevel converter and Cascaded H- bridge multilevel converter. The recent trends of multilevel converters are the Modular multilevel converter (MMC) [3], [4] and hybrid converter topology called as an Alternate Arm Modular Multilevel Converter (AAMMC).

The dynamic model of three level neutral point or diode clamped converter has designed with mathematical model for back to back HVDC system [6]. The control for the model has designed by simple state space averaging method and evaluated the accuracy of the model performance for the AC and DC side controllers at different operating conditions like weak and stiff AC systems.

The multilevel switched capacitor converter designed [7] with reduced capacitor bank. The switching loss has reduced by increasing the clamping capacitor size without adversely affecting the system performance. The mathematical expressions for three level and four level switched capacitor converters have derived for voltage, current and energy stored in clamped capacitors.

The applications of multilevel cascade H-bridge inverter/ converter with seven level has analyzed [8], [9] for power quality improvement. The modified active power filter has designed with advanced PWM technique to maintain the power factor and THD level. The modified harmonic PWM algorithm has employed for transient and steady state conditions for HVDC transmission system.

In 2003, the modular multilevel converter was first proposed by R. Marquardt and Lesnicar and in 2010 [10], [12]; Siemens have employed a new converter design with HVDC PLUS technology. Simultaneously the HVDC Light products have been upgraded by ABB with generally similar technology in the market. The effective switching steps or levels are achieved through number of series connected sub modules. The MMC is composed of similar structured self controllable submodules, either be two level half bridge or two level full bridge converters with capacitor across the device as an energy storage device. The output waveforms appear almost sinusoidal which does not require any DC or AC filters. The HVDC system voltage level requirements determine the number of sub modules connected in series. This technology is well suited for high voltage transmission system with recent advances in technology [16]. The typical losses per converter for MMC are less (1%) per converter as compared to two level (3%) and three level diode/ neutral point clamped converter (2.2%) [5]. Due to low voltage level at each sub module and operating at low frequency, the switching losses are less.

MMC is a prominent step forward VSC topology well suited for many applications especially for HVDC [11], [13], [16]. The MMC offers some features which do not satisfied by existing multilevel converters. It has DC fault blocking capability. Thus the main advantage of MMC with two level full bridge sub modules does not require any AC/DC circuit breakers.

Thus these multilevel converters provides the various features such as lower losses, less dv/dt, improving DC voltage and power transfer capability due to recent advancement in voltage source converters. Generally these features are well suited for offshore (also for onshore) HVDC and HVAC systems [15].

The Alternate Arm Modular Multilevel Converter (AAMMC) is recently proposed advanced hybrid multilevel converter topology. It has the potential characteristics for the HVDC applications. It provides several features such as improved voltage and current levels, power transfer capability, fast response, fault blocking property. The MMC topology is not much effective for failure condition and failure of submodule itself with half bridge submodules. So this problem is overcome by introducing the hybrid Alternate Arm Modular Multilevel Converter (AAMMC).

The paper mainly focuses on the operating principle and controlling of AAMMC. The paper is organized in the following sections. The section II deals with advantages of multilevel converters. Section III presents the basic schematic and operating principle of an AAMMC. The sorting modulation technique is discussed in section IV. The section V discusses the implementation of 21 level AAMMC and result analysis. Finally paper summarizes its conclusion followed in section VI.

Advantages of Multilevel Converters

The different types of multilevel converters are preferred for different applications due to their different attractive features and advantages. The limitations of previous converter topologies are minimized or eliminated by improving their structures, by changing its combinations for connections etc to achieve the required characteristics for particular applications. Some of them are briefly discussed as follow:

- The simple diode clamped [6] and capacitor clamped multilevel converters [7] provide the high efficiency by using fundamental frequency for all switching devices and able to regulate reactive power effectively.
- It eliminates the need of large sized filters.
- The cascade H- bridge multilevel converters [8], [9] requires the less number of devices per level leads to reduce the size, weight and cost of the converter.
- Also it provides the more scalable and modular operation of the system [18].
- The simple Modular Multilevel Converter (MMC) provides the better performance as compared to other voltage source converters.
- The MMC reduce the dv/dt voltage level, so it gives the damage free switching operation of the submodules.
- The MMC also minimizes the harmonics, so does not require the filters of large size and ratings for high voltage applications [14].
- The MMC also has fault tolerant or fault blocking capability which is suitable for HVDC transmission system [13].

Schematic and Operating Principle Of an Alternate Arm Modular Multilevel Converter

The Alternate Arm Modular Multilevel Converter (AAMMC) topology is a hybrid composition of multilevel converter with stacks of H-bridge submodules and two level converter. The converter structure is as illustrated in Figure-1 which consists of two arms for each phase or leg as upper arm and lower arm. Each arm is composed of H bridge submodules, series connected director switch as two level converter with series connected string of IGBTs and an arm inductor. Thus the series connected H bridge cells generate the multistep AC voltage by conducting either in positive or negative through director switch alternately at upper and lower arms.

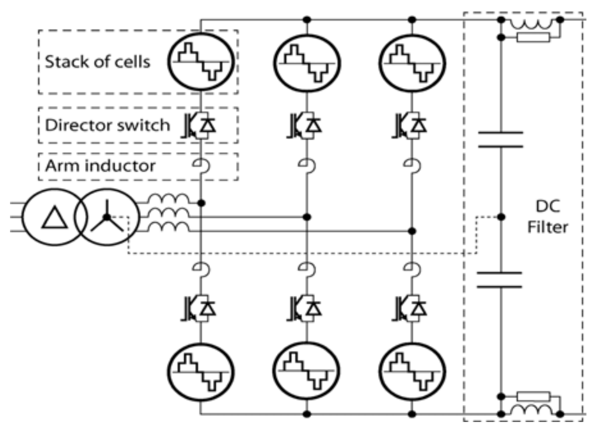

Figure-1. Schematic of an Alternate Arm Modular Multilevel Converter (AAMMC) [17].

The voltage across each submodule is adjusted by switching the number of submodule by proper switching pattern. The main purpose of the director switch is to determine which arm will conduct the current. Thus the operation of AAMMC is mainly based on the modulation schemes and switching pattern. The balancing of the capacitor voltage is the main problem of Modular Multilevel Converter (MMC) and AAMMC. So the

VOL. 10, NO. 4, MARCH 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

sorting technique and capacitor voltage balancing scheme is the best solution to overcome this problem.

The hybrid multilevel converters are the most suitable and attractive form than simple conventional modular multilevel converter due to their innovative, remarkable properties needed for advanced VSC HVDC transmission system.

Sorting Technique for Aammc

There are different controls and modulation techniques using simple PWM, SPWM, carrier phase shifted PWM etc. for multilevel converters. The main objective of the sorting technique is to maintain the power and voltage across each submodule uniformly, by inserting or bypassing the submodules of the wave shaping circuit. The submodules are selected to insert or bypass the switching voltage either in ascending or descending order to charge or discharge the capacitors. The sorting function mainly depends on the arm current direction either positive or negative (ia), sequence of n number of submodules and modulation index. For example in case of positive arm current the capacitors get charged and sorting is carried out by setting reference value of capacitor voltage. For charging mode the lowest capacitor voltages get inserted and iterations are carried out by comparing the different conditions for each submodule. The same procedure is carried out for lower arm or negative arm current for discharging mode of submodules.

Thus the systematic way of charging and discharging of capacitors can be possible to maintain all submodule capacitor voltages uniformly.

Simulation

A) Three phase 21 level AAMMC without Sorting technique:

The three phase AAMMC converter is designed for 21 level AC output voltage based on Figure-2. The circuit consists of wave shaping circuits as upper and lowers H bridge submodules, two level converter with string of IGBTs. The modulation index is set to 1.3.

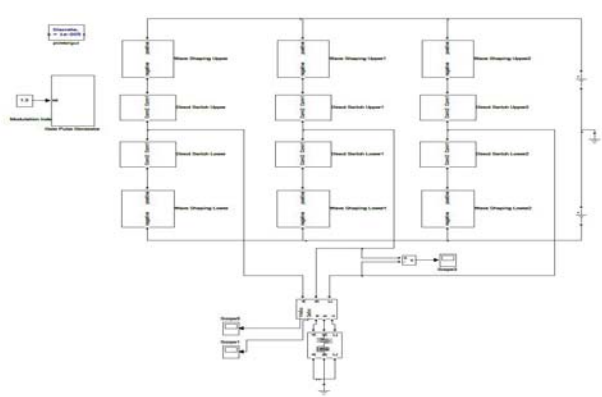

Figure-2. AAMMC without sorting technique.

The Capacitor voltages of all upper submodules and their average value are shown in Figure-3. Whereas the Capacitor voltages of all three phases of upper submodules is illustrated in Figure-4. It is seen that for the AAMMC without sorting the capacitor voltage value deviates from its nominal value of the capacitor. The capacitor voltages across all upper submodules are not maintained uniformly at their nominal value. So the sorting technique is needed to overcome this problem.

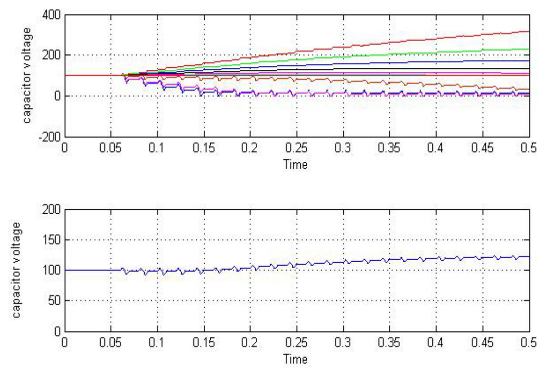

Figure-3. Capacitor voltages of all upper submodules and their.

Average value at M. I. =1.3

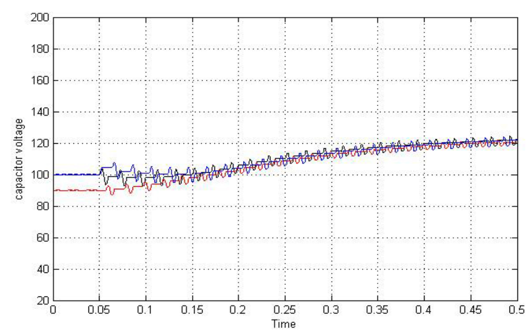

Figure-4. Capacitor voltages of three phases of upper submodules.

The output of AAMMC with three phase 21 level AC voltage is shown in Figure-5.

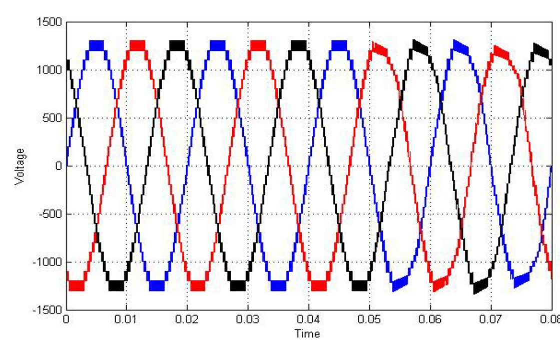

Figure-5. Three phase 21 level AC output voltage at t=0.05 sec.

B) Three phase AAMMC model with Sorting technique:

The three phase AAMMC model with sorting technique Figure-6 is designed similar to previous converter model but with sorting functions and gate signal functions for all three phases. The operation of the converter is mainly dependent on the modulation function and control strategy. The modulation index is set to 1.27. The capacitor voltage across upper submodule of phase 'a' and the their average value is illustrated in Figure-7 It is seen that due to sorting technique the capacitor voltages of all submodules in the arm remains at its nominal value uniformly. It is possible due to proper sequential switching of submodules i.e. due to sorting technique.

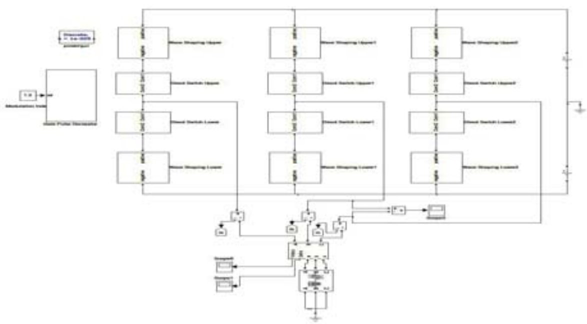

Figure-6. Three phase 21 level AAMMC with sorting technique.

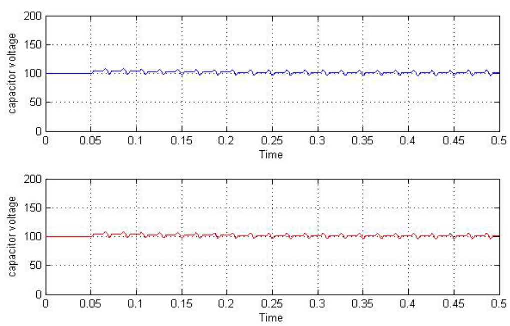

Figure-7. capacitor voltage across upper submodule of phase 'a' and their average value at t=0.05sec.

The output voltage and current of three phase 21 level AAMMC with sorting technique is shown in following Figure-8 and Figure-9 respectively.

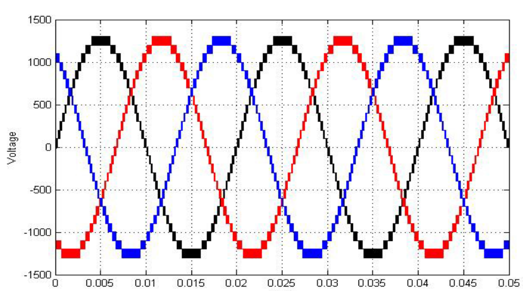

Figure-8. Output AC voltage of AAMMC with sorting technique.

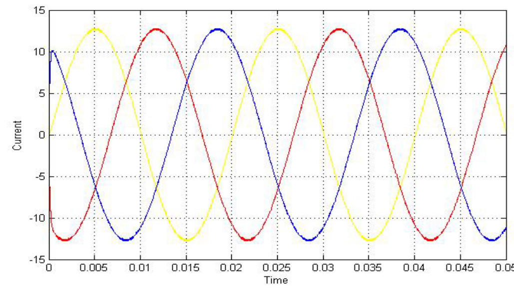

Figure-9. Three phase AC current.

CONCLUSIONS

The Alternate Arm Modular Multilevel Converter is a recently proposed promising converter topology for VSC based HVDC applications. Its basic schematic and operating principle have explained in detail. The major concern of sequential proper switching of capacitors of each submodule can be solved by sorting technique. The performance of the 21 level AAMMC without sorting and with sorting technique is verified with MATLAB Simulation. The converter operation without sorting shows the variation in the capacitor voltages of submodules and deviates from nominal or set value. Due to the sorting technique the capacitor voltages across all submodules can be maintained at its nominal or set value. The simulation of small scale AAMMC converter model shows the efficient performance and generates almost sinusoidal AC output voltage with reduced number of submodule cells and with less loss. The modular structure enables to improve the output levels and employ another optimized modulation schemes have the better scope to work in future. Thus the AAMMC is a recent, scalable, modular converter topology and has great potential for the projects in the field of HVDC transmission systems.

REFERENCES

[1] Amirnaser Yazdani., Voltage-Sourced Converters In Power systems: Modeling, Control, & Applications, IEEE press, Wiley publication, ISBN 978-0-470-52156-4, 2010.

[2] Leopoldo G. Franquelo., Jose Rodríguez., Jose I. Leon., Samir Kouro., Ramon Portillo. and Maria A.M. Prats. The age of multilevel converters arrives. IEEE Industrial Electronics Magazine, pp. 28- 39. June 2008.

[3] Ashish Kumar Sahoo., Ruben Otero-De-Leon., Visweshwar Chandrasekaran. and Ned Mohan. New 3-level Submodules for a Modular Multilevel Converter based HVDC System with Advanced Features. IEEE 2013,pp .6269-6274.

[4] Remus Teodorescu., Emanuel-Petre Eni., Laszlo Mathe Pedro Rodriguez. Modular Multilevel

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Converter Control Strategy with Fault Tolerance. International Conf. Renewable Energies and Power Quality (ICREPQ'13), ISSN 2172-038 X, No.11, March 2013.

[5] Elisabeth N. Abildgaard., Marta Molinas. Modeling & Control of the Modular Multilevel Converter. Elsevier, pp. 227-236, 2012.

[6] Amirnaser Yazdani., Reza Iravani. Dynamic Model and Control of the NPC-Based Back-to-Back HVDC System. IEEE Trans. Power Delivery. Vol. 21, No. 1, Jan. 2006, pp. 414-424.

[7] M. N. Gitau., C. L. Kala-Konga. Multilevel Switched-Capacitor DC-DC Converter with Reduced Capacitor Bank. IEEE 2010, pp.576-581.

[8] Rakan Khalil Antar., Basil Mohammed Saied., Rafid Ahmed Khalil. Using Seven-Level Cascade H-Bridge Inverter with HVDC System to Improve Power Quality", National Conf. Engineering Sciences FNCES'12 / November, 2012.

[9] Feel-soon Kang., Yeun-Ho Joung. A Cascaded Multilevel Inverter Using Bidirectional H-bridge Modules", Journal of International Conf. Electrical Machines and Systems. vol. 1, no. 4, pp. 448- 456, 2012.

[10] R. Marquardt. Modular Multilevel Converter: An universal concept for HVDC-Networks & extended DC-Bus-applications", IEEE 2010, International Power Electronics Conf., pp. 502- 507.

[11] Fang Z. Peng., Wei Qian. and Dong Cao. Recent Advances in Multilevel Converter/Inverter Topologies and Applications, International Power Electronics Conf., pp. 492-501, 2010.

[12] Yeqi Wang., Rainer Marquardt. Future HVDC-Grids employing Modular Multilevel Converters and Hybrid DC-Breakers.

[13] S. Ali Khajehoddin., Alireza Bakhshai., Praveen Jain. The Application of the Cascaded Multilevel Converters in Grid Connected Photovoltaic Systems. IEEE Canada Electrical Power Conference 2007, pp.1-6.

[14] Kurt Friedrich. Modern HVDC PLUS application of VSC in Modular Multilevel Converter Topology IEEE conf. 2010, pp. 3807-3810.

[15] Firas Obeidat, Xu Lie, and Li Yongdong, "Simulation of Grid Connected HVDC Offshore Wind Farm Topolgies",IEEE 2013, pp. 897-902.

[16] Fang Z. Peng., Wei Qian. and Dong Cao. Recent Advances in Multilevel Converter/Inverter Topologies and Applications, International Power Electronics Conf., pp. 492-501, 2010.

[17] Michael M. C. Merlin., Tim C. Green., Paul D. Mitcheson., David R. Trainer., Roger Critchley., Will Crookes. and Fainan Hassan. The Alternate Arm Converter: A New Hybrid Multilevel Converter with DC-Fault Blocking Capability. IEEE Trans. Power Del., vol. 29, no. 1, pp. 310-317, February 2014.

[18] Javad Ebrahimi., Ebrahim Babaei., Gevorg B. Gharehpetian. A new multilevel converter topology with reduced number of power electronic components", IEEE Trans. Industrial Electronics, vol. 59, no. 2, pp. 655- 667, February 2012.