Grenze International Journal of Engineering and Technology, Special issue

Comparison of Different Modulation Techniques in Single Phase Modular Multilevel Converter

Flavia Johnson K
Electrical and Electronics Engineering, FISAT, Angamaly
flaviajhsn4@gmail.com

***Abstract*—The concept of modular multilevel converter is to achieve high power semiconductor switches with several lower voltage dc sources to perform the power conversion. Voltage levels in modular multilevel converter are used in High voltage applications and electric drives. The project focuses on the comparison of modulation techniques in single phase modular multilevel converter. The carrier based modulation technique is compared with staircase modulation technique. Level shift carrier based modulation technique is used for comparison with staircase modulation technique. The performance of both modulation techniques is compared by total harmonic distortion in MATLAB/SIMULINK. Simulation results for modular multilevel converter are done with seven sub modules in upper arm and lower arm. The level shift modulation technique has lesser percentage of total harmonic distortion.**

***Index Terms*— Modular Multilevel Converter (MMC); Total Harmonic Distortion; level shift modulation; staircase modulation; High Voltage Direct Current (HVDC).**

I. INTRODUCTION

The development of new technologies during this century enhanced the interest in electric power systems. Human activities mainly depended on complex machine studies on electric power generation and distribution. Voltage source converter technology is common in HVDC transmission systems. HVDC transmission technology is an important and efficient to transmit high powers over long distances. One of the most important advantages of HVDC on AC systems is its possibility to control the active power transmitted, whereas ac lines power flow can't be controlled accurate in HVDC systems.

Conventional converters had many problems when accomplished in operation of HVDC transmission. Compared to conventional voltage source converter technology, modular multilevel topology has several advantages such as modular construction, longer maintenance intervals and improved reliability.

A multilevel converter promises a reduction of output harmonics due to sinusoidal output voltage, thus grid filters become negligible and complexity reduction. Modular multilevel converter configuration ensures a more reliable operation, facilities diagnosis, maintenance and reconfigurations of control system etc. During fault, modular configuration isolates the problem, driving the process in safe state easily, and allows normal operation even in faulty conditions. The switching of modular multilevel converter is an important factor during transmission. Different modulation techniques can be applied to Modular Multilevel Converter. Here level shift modulation technique and staircase modulation techniques are considered for comparison. A modular multilevel converter can be a combination of half bridge or full bridge and multilevel converter. The half-bridge cells can generate only zero and positive voltages, so there is inevitably a dc component in the

Grenze ID: 01.GIJET.3.2.14

arm voltage. Therefore half bridge can only be used in dc systems. Full-bridge cells can generate positive, zero, and negative output voltages, hence, they can be used when the MMC is connected to either ac or dc systems [1].

A Modular Multilevel Converters have a number of submodules, which increases the complexity of the control of the MMC. To assure accurate and stable operation, the submodules should share the voltage equally. There are different control strategies aiming to regulate the equal share of charge within the capacitors in the arm. The deregulation of energy markets and decentralized power generation increases demand for advanced power electronic systems. For this application multilevel converters with a high number of voltage levels seem to be the most suitable types, because of the need for series connection of semiconductors in combination with low voltage distortion on the line side [2].

A number of additional submodules can be inserted in each arm to account for future failures; converter will continue its operation without the need for immediate remedial actions. This redundancy is provided to the converter because of the ability to fully bypass submodule without the need for modification of the power or control sections [3].

As the number of submodules and subsequently the number of output levels increases, staircase modulation becomes an alternative for modulation of modular multilevel converter. The advantages of staircase modulation are its simple generation of switching signals and implementation [4]. Staircase modulation technique does not necessarily lead to a reduction in submodule switching frequency and operation of the submodules under fundamental switching frequency and the operation of the submodules under fundamental switching frequency leads to high submodule capacitor voltage ripples [5]. The work in this paper is the comparison of level shift modulation and staircase modulation. The comparison is done by considering the Total Harmonic distortion.

Paper is organized as follows. Section II describes the basic working principle of Modular Multilevel Converter and describes about the level shift and staircase modulation techniques. Comparison of both modulation techniques are done in Section III. Section IV presents simulation results of modulation techniques. Finally, Section V presents conclusion.

II. MODULAR MULTILEVEL CONVERTER

Fig.1 shows the single phase configuration of Modular multilevel converters. The MMC is based on a series connection of identical elements, called submodules or cells. Each sub-module represents the basic component of the MMC. The series connection of submodules in one phase is known as leg. The leg is divided into upper arm and lower arm such that the numbers of the submodules in each arm are equal. The AC voltage terminal is the common point between both arms. Since the leg capacitors share a common DC-link voltage there is no need of bulky DC link capacitors, as in case of two-level or any other converter topologies. Inductors are placed in the arms to limit the transient currents.

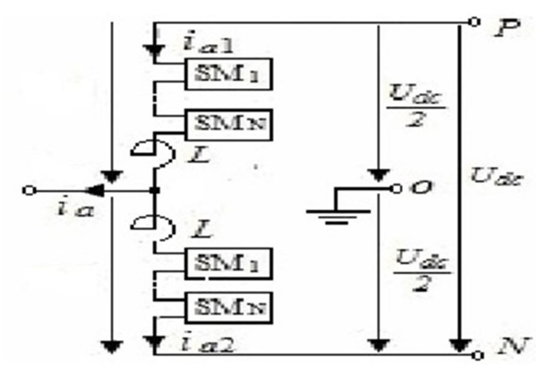

Fig 1. Single phase modular multilevel converter

The operating principle of Modular Multilevel Converter includes the features of multilevel and half bridge converters. Here we use half bridge converter as submodules. Submodule refers to a half-bridge formed by two bidirectional switches with antiparallel diodes and one DC capacitor, as shown in figure below. The capacitor acts as an energy buffer and a voltage source. The switches execute the insertion of the sub-module into the arm circuit while the antiparallel diodes ensure uninterruptable current flow. All the sub-modules are identical; the operation principle of MMC can be resumed to the cell level operation. Each sub-module has two states depending on the switch positions [6].

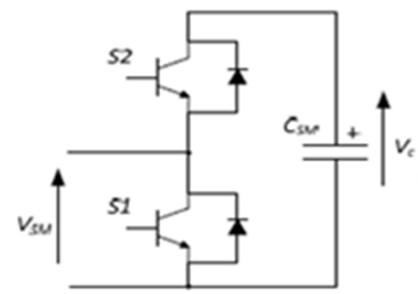

Fig 2. Half bridge converter

Different submodule topologies can be applicable to the MMC depending on the application (STATCOM, HVDC, Electric Drives etc). The difference in the cell structure and the number of cells or submodules results in different possible voltage levels. However, with the increase of elements, the capacitor balancing becomes more complicated.

Each submodule has two states depending on the switch positions. When the switch S_1 in the figure 2 is turned ON and the switch S_2 is turned OFF, the sub-module is inserted into the circuit. The voltage between the terminals V_{SM} is equal to the capacitor voltage V_C. When the lower switch is ON and the upper switch is OFF the submodule is bypassed and the terminal voltage is zero.

In the submodule topology, the switches have to operate in complementary way in order to short circuit the capacitor. By controlling the number of the submodules inserted and bypassed, a staircase output voltage can be obtained at the AC terminals of the converter. Number of submodules inserted depends on the voltage required. The switching can be done by using PWM techniques.

The direction of the arm current affects the capacitor voltage. Figure 3 shows the current flow in the submodule in different states. The positive direction of the arm current is represented in red colour and the negative in blue. When the submodule is inserted, the positive current will charge the capacitor, passing through the upper diode, whereas the negative current will discharge the capacitor. When the sub-module is bypassed the capacitor voltage remains constant.

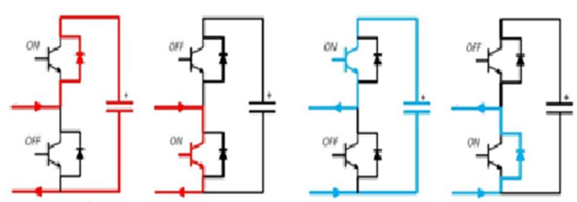

Fig 3. On-Off condition of switches

III. MODULATION TECHNIQUES

Modulation at high switching frequencies modulations based on triangular wave carrier signals with phase shifting and level shifting can be used as in Modular Multilevel Converters. Here we consider only the level shifting modulation to compare with the staircase modulation technique. The Carrier-based Pulse-Width Modulation concept is based on comparison of a reference signal with a high frequency triangular waveform (the carrier). The carrier can have a periodic bipolar or unipolar waveform. The switching instants are determined by the intersections of the modulating and carrier signals. Carrier based modulation are well-known techniques, but they have the disadvantage of high switching losses, compared to fundamental frequency modulation.

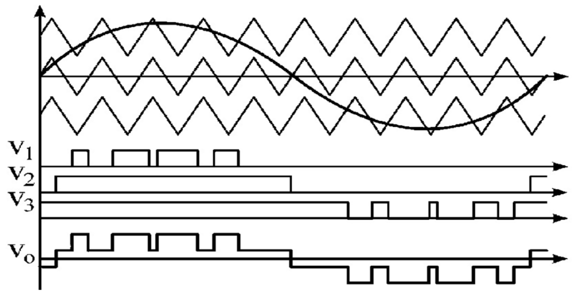

Fig 4. Level shift modulation

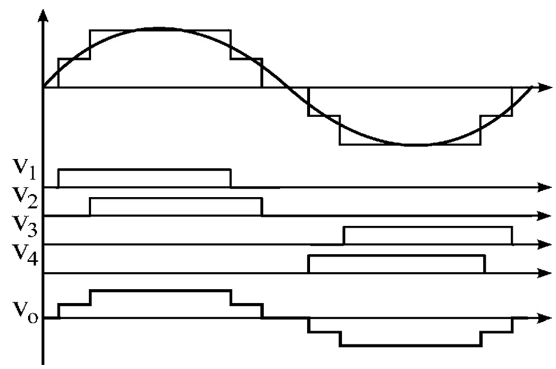

Fig 5. Staircase modulation

In staircase Pulse Width Modulation the modulated wave eliminates harmonics [7]. In order to obtain desired quality of output voltage, the modulation frequency ratio mf and the number of steps are chosen. If the number of pulses is less than 15 per half cycle this is optimized pulse width modulation [8] [9].

IV. Simulation Results

Simulation result of level shift modulation technique and staircase modulation technique in modular multilevel converter is shown below. As discussed Modular Multilevel Converter has its main application in HVDC system. Here Number of submodules used are 7. The input is given as 9kV. The arm inductance to limit the transient current is given as 1μF. The resistive load is given to the system as 20Ω. Here the values are considered on the basis of application in HVDC systems. The value of load resistance is taken by expected output power as 4050kW and the input voltage as 9kV thus value of current obtained as 450A.

The level shift modulation and staircase modulation is compared by calculating the Total Harmonic Distortion.

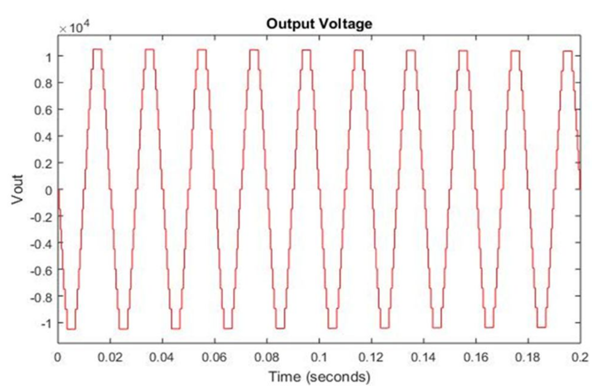

Fig 6. Output waveform of modular multilevel converter

The modulation technique in multilevel converter is compared by Total Harmonic Distortion. The total harmonic distortion in both modulation techniques is calculated.

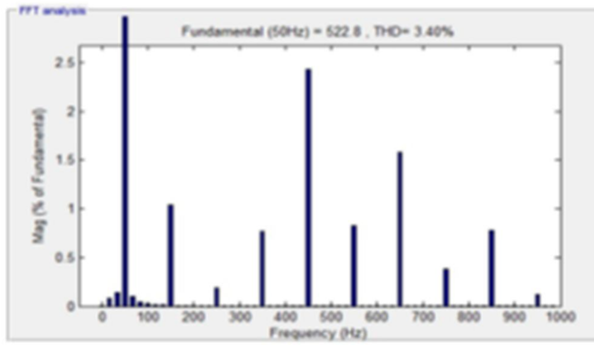

Fig 7. Total Harmonic Distortion in level shift modulation technique

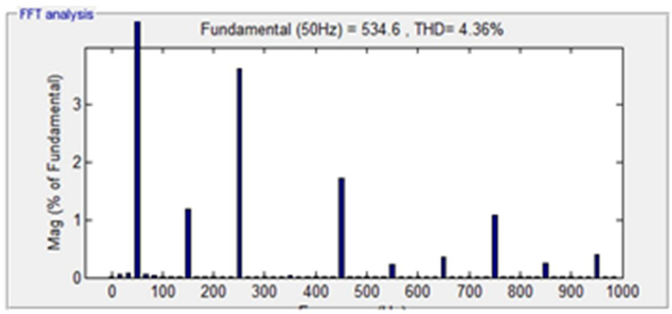

Fig 8. Total Harmonic Distortion in staircase modulation technique

Comparing the total harmonic distortion in both modulation techniques the level shift modulation has lesser percentage, that is for level shift modulation technique the THD is 3.4% and for staircase modulation technique the THD is 4.36%.

V. CONCLUSION

The comparison of different modulation technique in modular multilevel converter is studied. Level shift and staircase modulation technique is applied to Modular Multilevel Converter using MATLAB/SIMULINK. Simultion results of level shift and staircase case modulation technique are compared by calculating the total harmonic distortion. By comparing THD of both modulation technique Level Shift modulation technique have better performance. Deep study and analysis of operation limits of modulation strategies. Real implementation of control and modulation strategies based on either FPGA/DSP or on a real time platform. Precise study of impact of modulation on the individual devices can be done.

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