Performance Analysis of Eleven Level Modular Multilevel Converter Using Nearest Level Control Technique

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Abstract—**This paper focuses on the design and analysis of different levels of Modular Multilevel Converter (MMC) topology for reducing Total Harmonic Distortion (THD) losses, through the use of the Nearest Level Modulation (NLM) control technique, especially when dealing with larger number of submodules. Furthermore, the MMC has been designed for greater scalability with high voltage and power capacity. By implementing the NLM approach, it was demonstrated in this study that MMC offers simplicity and strong controllability in the decrease of THD up to 13 levels. In this work, the reduction of THD by increasing the voltage levels in MMC is comprehensively analyzed. The MATLAB/Simulink simulation results are used to examine the performance of the nearest level control strategy in reducing total harmonic distortion of MMC for its HVDC applications.**

Index Terms—**Modular multilevel converter (MMC); Nearest Level Modulation (NLM); Total Harmonic Distortion (THD); MATLAB/Simulink**

I. INTRODUCTION

Multilevel converter topologies have become more popular and are progressively replacing two-level converters due to their high impacted advantages on reducing the size of harmonic filters, increased nominal power capability and component voltage stress reduction[1].Cascaded full bridge, flying Capacitor (FC), neutral point clamped (NPC) and active neutral point clamped (ANPC) are the popular and classic topologies of multilevel converters that have been commercialized in recent years, replacing conventional converters in several industrial applications[2], [3]. Multilevel converters have recently been used in medium-voltage and high-voltage applications, such as medium-voltage drives, the connection of solar and wind turbine plants to the main grid, and high-voltage direct current (HVDC) and flexible AC transmission systems[4], [5].

The modular multilevel converter (MMC) was proposed in 2001 in a German patent by Prof. Marquardt[6] and is further extended to other applications such as medium-voltage motor drives and power quality improvement[7]. Modular multilevel converter (MMC) has gained significant popularity in high and medium voltage applications due to its several advantages. It is scalable, modular and can produce a nearly sinusoidal output voltage[8] and also can eliminate the need for bulky inductors and transformers due to its superior harmonic performance[9].The MMC circuit topology is depicted in Figure 1. Power electronic converters that convert direct current (DC) power supplies to alternating current (AC) waveforms are known as inverters. The output of the inverter is determined by the type of inverter used. Inverters can be square wave, quasi-square wave, or sine wave. Even when a sine-wave inverter is used, the output is not purely sinusoidal because it contains harmonics. These harmonics are periodic wave components that are multiples of the fundamental frequency and cause distortion in the output[10].These harmonic distortions can be reduced by using the appropriate modulation technique or converter topology. Modular Multilevel Converters have a large number of levels that are more efficient and have lower harmonic distortions[10], [11].They are capable of handling high voltage operations without the use of series-connecting switching devices. They offer lower common-mode voltages as well as higher power quality. They have several advantages, including high modularity and scalability, transformer-free operation, lower switching losses, and lower filtering costs[12].
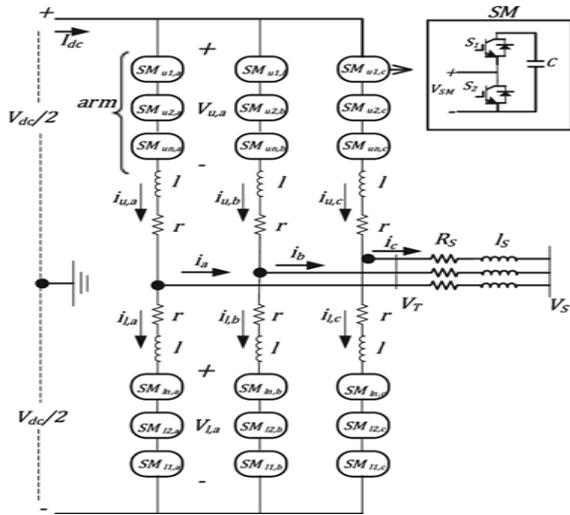
Fig.1 MMC Circuit topology

II. MODULAR MULTILEVEL CONVERTER

It includes arms that include both the upper and lower arm. Each arm contains submodules (SM). Submodule is the basic building block of MMC, shown in Figure 2. The modularity of modular multilevel converter comes from this basic
building block. Each submodule has a well-known half-bridge structure, which consists of one submodule capacitor and two power semiconductors,IGBT.
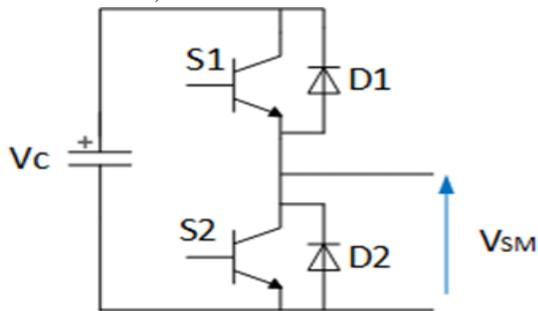

Fig .2 Half-bridge submodule structure

The capacitor acts as the DC-link capacitor of two-level (2L) converter, but it is evenly distributed in the structure of MMC. It behaves as a voltage source and energy buffer. The half-bridge IGBTs chop the capacitor voltage according to PWM commands. The transistors T1 and T2 in the submodule work in an opposite way. When T1 is turned on, T2 has to be turned off to prevent shoot-through. When T1 is turned on, the capacitor voltage appears at the submodule terminals. In this condition, the submodule is said to be "inserted". Otherwise, it is said to be "bypassed".

III. MODULATION TECHNIQUE

The nearest level control (NLC), also known as the round method, uses the nearest voltage level that can be generated by converting to the desired output voltage reference[17].The three phases are controlled separately using an independent comparison process. Figure4 shows the block diagram and the working of NLM. The block diagram shows that at first the reference voltage is normalized with the capacitor voltage of the submodule in the gain block then the round-function generates the closest integer number of the submodules to insert to approximate the reference voltage with the nearest voltage level [18].
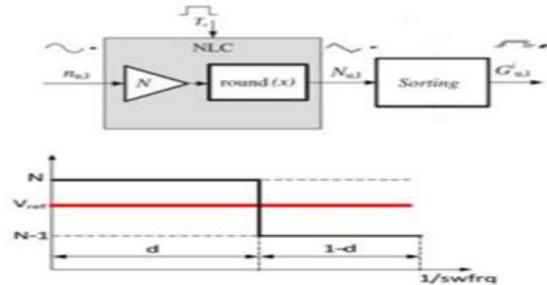

Fig .3 Block Diagram & working Principle of NLM

IV. SIMULATION AND RESULTS

Eleven Level Modular Multilevel Converter has been simulated using MATLAB/SIMULINK R2021a to verify its performance with RL-load. In all five cases of MATLAB/SIMULINK models, nearest level modulation is given to the gate pin of IGBT. The simulation specification of parameters is given in Table1.

Table1

Simulation Step Size	Ts=4e-2 s
Supply Voltage	V=1000V
Fundamental Frequency	f=50Hz
Submodule Capacitor	C=5pF
R-L Load	R=70Ω, L=20e-3H
Switching Element	IGBT

SIMULATION OF 11 LEVEL CONVERTER

Fig 4. MATLAB/ SIMULINK model of 3 phase Eleven-level MMC

Fig5. Nearest Level Control of one phase for 11 level MMC in Simulink

In the proposed Simulink model of eleven level MMC shown in Figure 4, the individual converter legs consist of a series connection of ten Sub-Modules (SMs) connected in series with one converter reactor. It has two voltage sources each of 2000 volts**.**The gate pulses and the switching sequence is implemented through nearest level control block as shown in Figure5. From the output voltage waveform, it is observed that there are ELEVEN different levels of voltages i.e., 0V, +1000V, +2000V, +3000V, +4000V, +5000V and -1000V, -2000V,-3000V,-4000V,-5000V. From the Fast Fourier Transform (FFT) window, the Total Harmonic Distortion analysis was carried out and the results are observed in the Harmonic Spectrum as shown in Figure 6 & Figure 7.

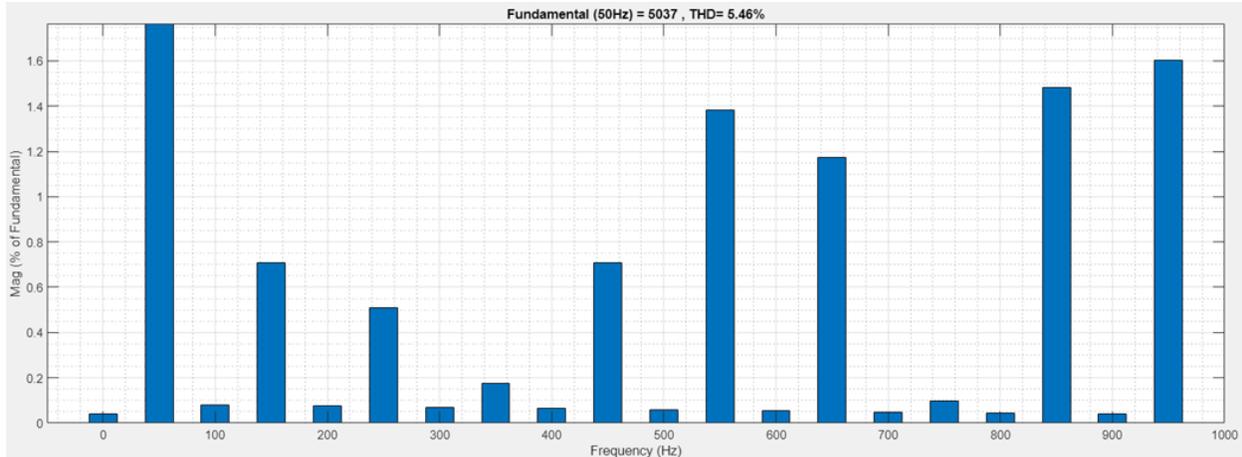Fig 6. Three-Phase Output Voltage for 11-Level MMC

Fig 7. Harmonic spectrum for phase voltage of 11-level MMC

V. CONCLUSION

Modular Multilevel Converter with H-bridge SM configuration requires at least twelve submodules per arm to produce Total Harmonics Distortion (THD) within the IEEE standards using Nearest Level Modulation (NLM) control technique. It is further, analyzed that (MMC) through the NLM Modulation technique is found better in achieving very minimum THD as compared to the conventional converters. However, in this work, the THD is reduced by 68% approximately with increased levels from 5 to 13, which results in mitigation of harmonics distortion and improved voltage waveform at the output side. This also fulfils IEEE 519 standard about harmonics Voltage limits. MMC leads to various applications where the proposed MMC-based HVDC structure can be used to replace conventional power networks, particularly for HVDC systems.

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