COMPREHENSIVE ANALYSIS AND SIMULATION OF MULTILEVEL POWER CONVERTERS TO CURTAIL TOTAL HARMONIC DISTORTION

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ABSTRACT

Present day industrial applications require higher power apparatus for power conversion. At medium voltage grid, to connect only one power semiconductor switch directly is a not practically successful concept. To overcome this multilevel power converter structure has been introduced and studied as an alternative in high power and medium voltage applications. Renewable energy sources like photovoltaic, wind, fuel cells can be conveniently interfaced to a multilevel converter system for high power applications. In this study it is discussed in detail for different levels of the multilevel converters using pulse width modulation technique (PWM) the harmonics contents decreases gradually. The simulated results are presented and compared thereafter. Total harmonic distortion decreases as the number of levels increased are tabulated accordingly. All the simulation results are carried out under MATLAB/Simulink environment.

KEYWORDS

Multilevel converter, Neutral Point Clamped, Cascade H Bridge, PWM

1. INTRODUCTION

The concept of multilevel converters has been introduced since 1975. The term multilevel started with the three-level converter which was the first basic upgrade from the conventional two level converters. Subsequently, numerous multilevel converter topologies have been developed since then. However, the elementary concept of a multilevel converter to achieve higher power uses series of power semiconductor switches with the several lower voltage DC sources to perform power conversion by synthesizing a staircase voltage waveform. Renewable energy voltage sources, Capacitors, batteries can be used as multiple DC voltage sources. The commutation of the power switches aggregates these multiple DC sources in order to achieve high voltage at the output. However, the rated voltage of the power semiconductor switches depends only upon the rating of the DC voltage sources to which they are connected [1-5]. The numerous advantages of multilevel converter over conventional two levels can be summarised as staircase waveform quality generated by multilevel converter itself proves to be a new achievement in the field of converters [2]. The multilevel converters are gradually being used in industrial applications in

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grid connected system and many more. On the outstanding advantages there are some disadvantages which like the number of power semiconductor switches increases as the levels are added.

2. MULTILEVEL CONVERTER

Since multilevel converters can synthesize the output voltages by increasing levels they overcome conventional two- and three-level inverters in terms of harmonic distortion. Single phase multilevel converters are roughly into following categories based on design.

Although, a number of topologies are proposed in literature, few main techniques are

- Diode clamped (neutral point clamped).
- Flying capacitors (capacitor clamped).
- Cascaded H-bridge converter.

2.1. Diode clamped (neutral point clamped)

The neutral point clamped converter proposed in 1981 by Nabae, Takahashi, and Akagi was essentially a three-level diode-clamped. Figure 1 shows Neutral point clamped three level circuit for multilevel converter fed from the 100V DC supply.

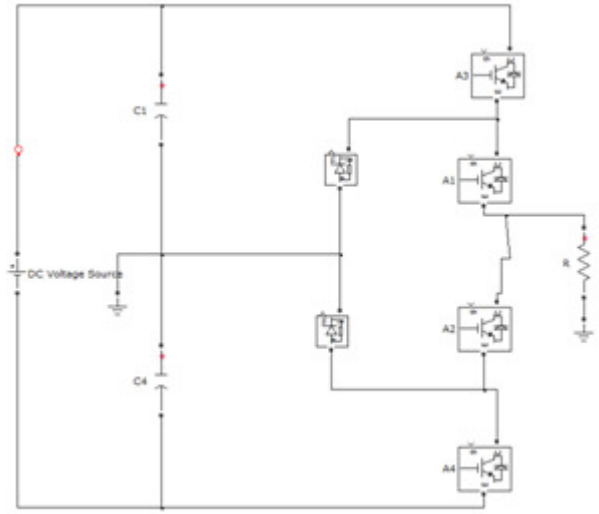

Figure 1.Neutral point clamped three level circuit for multilevel converter

2.2. Flying capacitor topology

The flying capacitor topology as shown in Fig. 3.involves series connection of capacitor clamped switching cells .Flying capacitor topology has few attractive and unique features comparably; one is that added clamping diodes are not needed [5]. It also has switching redundancy within the phase that can be used to balance the flying capacitors making use of only one dc source. This topology concept of operation is that each flying capacitor is charged to one-half of the dc voltage and can be connected in series with the phase to add or subtract this voltage [6-11]. In three-level

flying capacitor type of inverter the highest and lowest switching states, charge of the capacitors do not change.

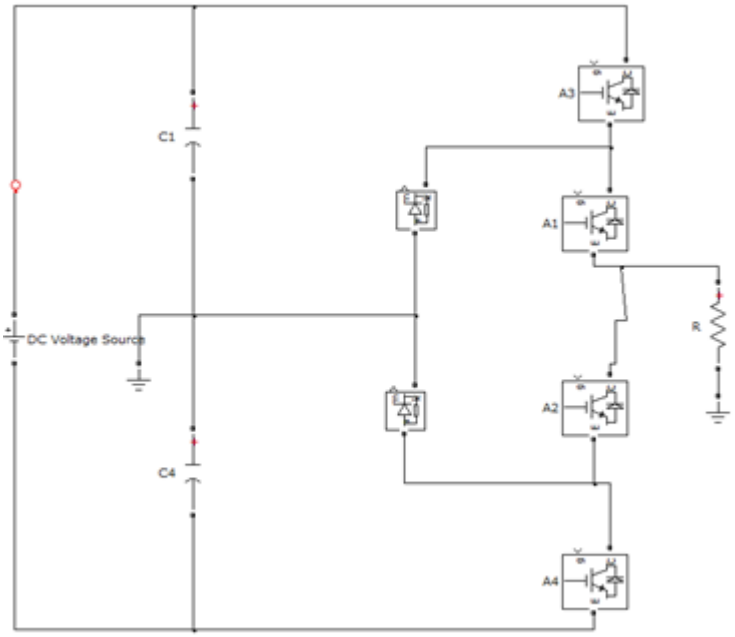

Figure 2.Three level flying capacitor topology

2.3. Cascaded H-bridges converter

A Cascade H-bridge converter is shown in Figure 3 consists of familiar H-bridge sometimes also referred to as full-bridge cells in a cascade connection. Since each cell can provide three voltage levels (zero, negative dc voltage, positive dc voltage), the cells are themselves multilevel converter [11]. Cascade H-bridge cells supply negative and positive voltages contributing to line to ground voltages.

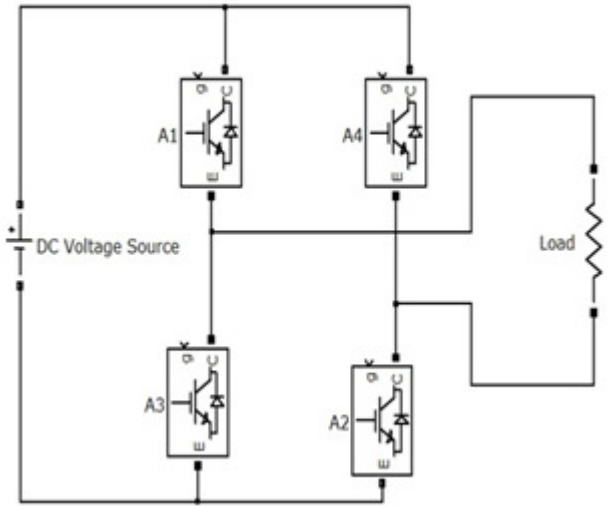

Figure 3.Cascade H-bridge for three level converter

3. MODULATION FUNDAMENTALS

Pulse width modulation (PWM) methodologies used in the multilevel converter modulation can be classified according to switching frequency. The three multilevel PWM methods most discussed in the literature have been multilevel carrier-based PWM, selective harmonic elimination, and multilevel space vector PWM; all are extensions of traditional two-level PWM strategies to several levels. Other multilevel PWM methods have been used to a much lesser extent by researchers [17].

Multilevel PWM methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave. To reduce harmonic distortions in the output signal phase-shifting techniques are used. There are several methods that change disposition of or shift multiple triangular carrier waves. The number of carrier waves used is dependent to the number of switches to be controlled in the inverter. In addition to the sinusoidal carrier wave modulation methods presented there are two alternative methods they are Position Opposition Disposition (APOD) and Phase Opposition Disposition (POD) [18][19][20].+
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In our study we will focus on the Phase Opposition Disposition (POD) technique in detail.

3.1. Phase Opposition Disposition PWM (PODPWM)

In Phase Opposition Disposition (POD), the carrier signal above the zero axes is in phase with each other having same frequency and same amplitude. Consecutively below the zero axis the carrier wave have phase shifted 180 degree with the same frequency and same amplitude as the above zero axis. The figure demonstrates the PODPWM. The three level multilevel converter simulation sine wave and the triangular carrier shown in Figure 4.

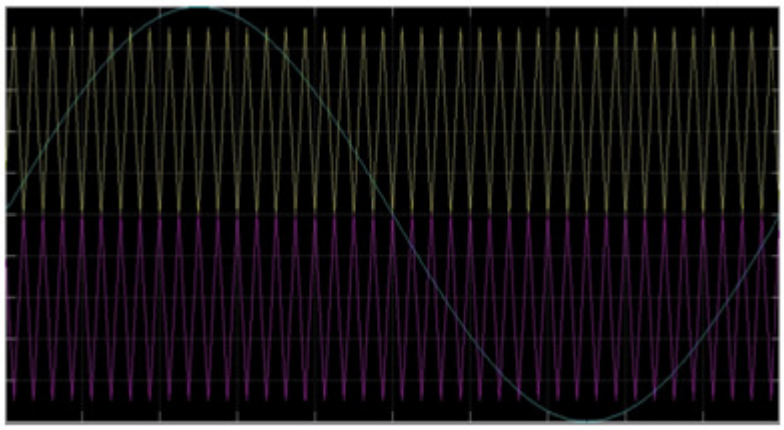

Figure 4.POD of three level multi level converter

4. ADVANTAGES OF MULTILEVEL CONVERTER

Multilevel converters attractive features over a conventional two-level converter by use of high switching frequency pulse width modulation (PWM).

- Staircase waveform quality
- Common-mode (CM) voltage
- Switching frequency
- Input current

Staircase waveform quality: Multilevel converters generate the output voltages with very low distortion, and also can reduce the dv/dt stresses; therefore problems of electromagnetic compatibility (EMC) can also be reduced.

Common-mode (CM) voltage: Multilevel converters generate smaller CM voltage which results in reduced stress in the bearings of a motor connected to a multilevel motor drive. Furthermore, by using the advanced mode technology the CM voltage can be reduced.

Switching frequency: Multilevel converters can operate at both fundamental switching frequency and high switching frequency Pulse width modulation (PWM). It should be noted that lower switching frequency usually means lower switching loss and higher efficiency.

Input current: Multilevel converters can draw input current with low distortion comparatively [5] [20-28].

Multilevel converters has few disadvantages like it require more devices which increases system cost comparatively hence probability of a device failure increases [26] [29-31].

5. MATLAB/SIMULATION AND RESULTS

5.1 For Neutral point clamped multilevel converter simulation results

Simulation results are shown in this section, for Neutral point clamped multilevel converter are displayed from Figure 5 to Figure 8. As shown in figure (1) in NPC topology the total voltage or input voltage V_{dc} divides across the capacitor after that the operation of switches decides the output voltage that is the three level converter voltage is divided in two parts across the two capacitor C_1 and C_2 i.e. $+\frac{Vdc}{2}$ and $-\frac{Vdc}{2}$. for simulation purpose the value of input voltage is equal to 100V and the output-voltage waveform is shown in Figure 5 ,similarly the simulated response for five level ,seven level and nine levels are displayed in Fig.6,7,and 8 respectively.

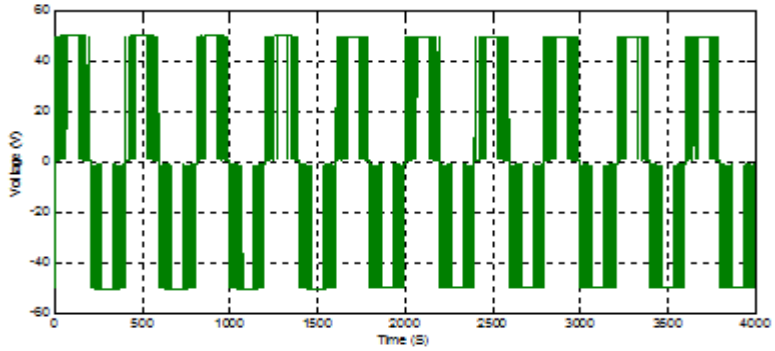

Figure 5.Waveform of output-voltage with respect to time of three level neutral point clamped multilevel converter

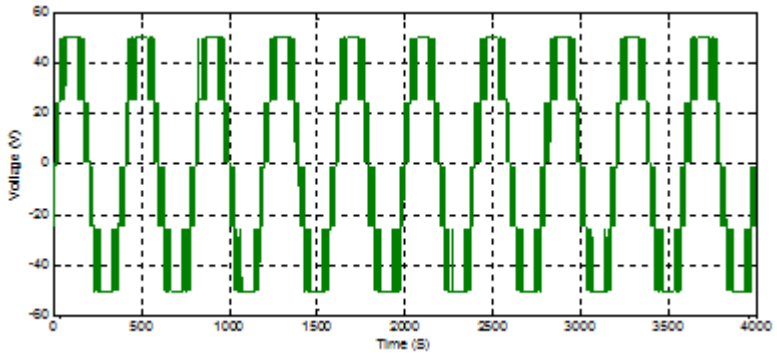

Figure 6.Waveform of output-voltage with respect to time of five level neutral point clamped multilevel converter

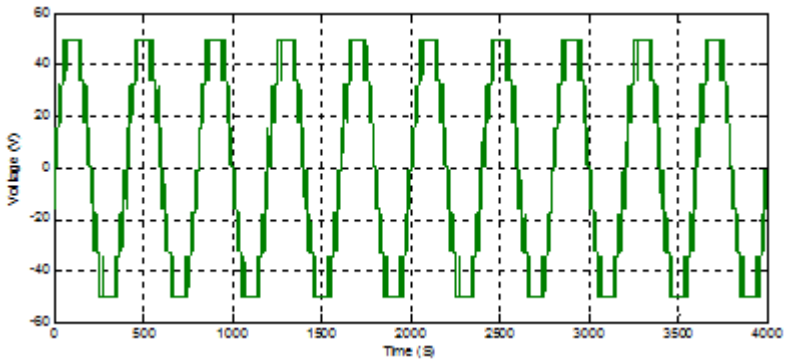

Figure 7.Waveform of output-voltage with respect to time of seven level neutral point clamped multilevel converter

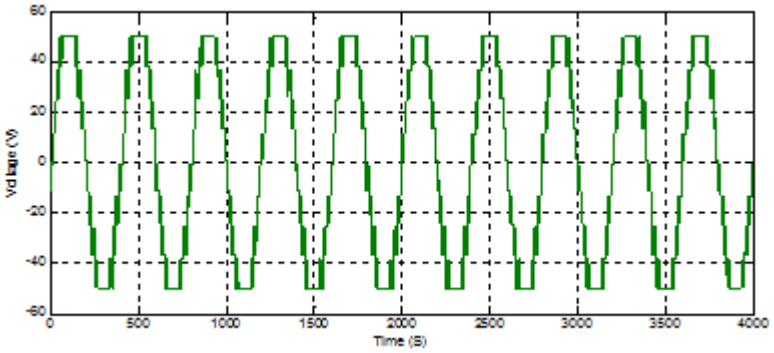

Figure 8.Waveform of output-voltage with respect to time of nine level neutral point clamped multilevel converter

5.2. For Cascade H-bridge multilevel converter simulation results

In cascade H bridge topology levels are achieved with the help of separate voltage sources. For example if considering three level inverter a voltage source say 100 V can produce three levels such as +100, 0 and -100 as shown in Figure 9. Two sources are required for five levels by which we can produce +200, +100, 0, -100 and -200.

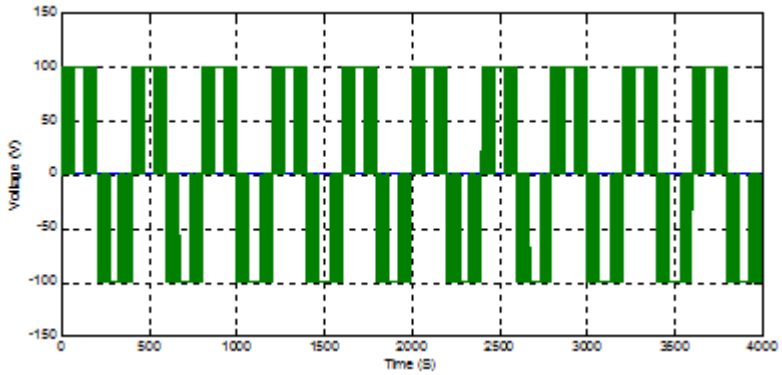

Figure 9.Waveform of output-voltage with respect to time of three level cascade H-bridge multilevel converter

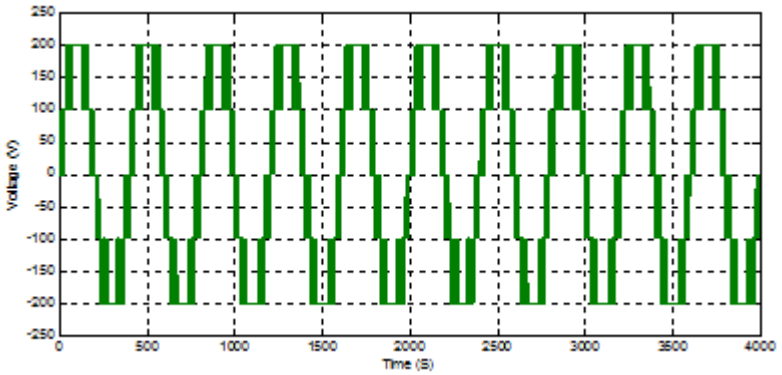

Figure 10.Waveform of output-voltage with respect to time of five level cascade H-bridge multilevel converter

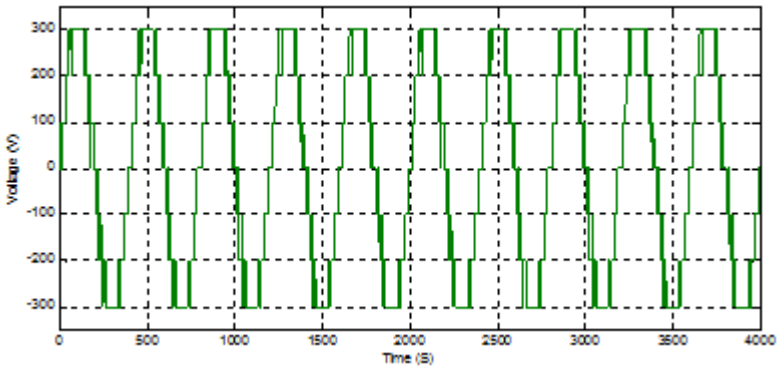

Figure 11.Waveform of output-voltage with respect to time of seven level cascade H-bridge multilevel converter

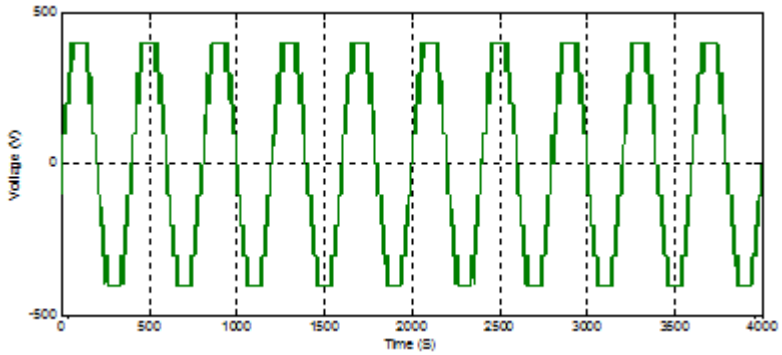

Figure 12.Waveform of output-voltage with respect to time of nine level cascade H-bridge multilevel converter

6. COMPARATIVE ANALYSIS OF MULTILEVEL CONVERTER TOPOLOGIES

Table 1 gives the total harmonic distortion of NPC and CHB topology of multilevel converter for three, five, seven and nine level. The percentage of total harmonic distortion reduces with increase in number of levels in both topologies NPC and CHB. Also results show CHB topology gives more efficient result as compared to NPC topology.

Table 1.Comparative analysis NPC and CHB topology of Multilevel converter in terms of THD

Levels of Multilevel converter	**Total harmonics distortion%**	
	Cascade H bridge	**Neutral point clamped**
3	53.41	42.99
5	25.69	22.40
7	15.09	14.85
9	12.36	11.22

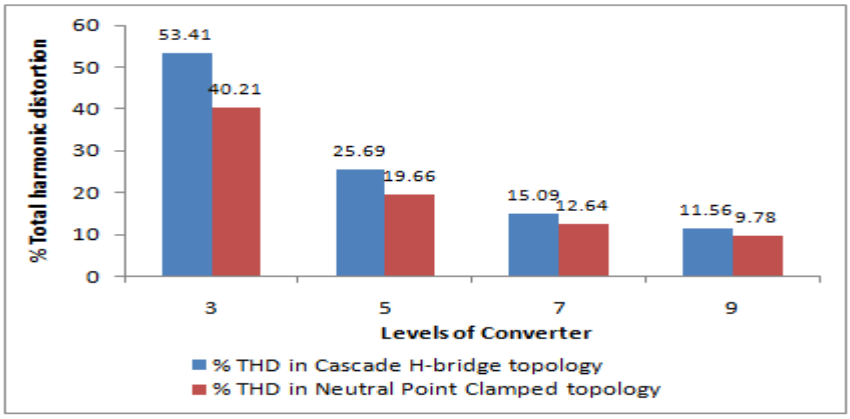

Figure 13.Graph showing percentage THD for three, five, seven and nine level converter

7. CONCLUSIONS

This paper presents a comprehensive review of multilevel converters and their control strategies. The increase in the voltage levels through NPC and Cascade H-bridge topology along, the performance gets better dimensions in the sense it facilitates more or less a sinusoidal output voltage. Increasing the number of levels by these topologies is easily possible to large extends which will be a new direction in this domain. This is very beneficial for drive applications and attractive for research and application Future research should be focused on developing optimal control for such topologies. A multilevel approach for converters guarantees a reduction of output harmonics due to sinusoidal output voltages thus grid filters are reduced, leading to system cost and complexity reduction. The aim of this study was to analysis the multilevel converter for different levels and to present their Total harmonics distortion (THD) behaviour.

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