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A comparative study of three topologies of three-phase (5L) inverter for a PV system

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Abstract

In this paper, we present a comparative study in the Matlab/Simulink environment between three topologies of three-phase multilevel inverter MLI (five-level). We will consider the Flying Capacitor Multilevel Inverter (FCMLI), the Neutral Point Clamped Multilevel Inverter (NPCMLI), and the Cascaded H-Bridge Multilevel Inverter (H-bridge MLI). The comparison between these inverters is based on some criteria: the spectral quality of the output voltage, the complexity of the power circuits and the cost of implementation. Each inverter is controlled by the same type of control which is the multi-carrier sinusoidal pulse width modulation (SPWM). Voltage sources supplying the inverters cells are simulated by a DC voltage representing photovoltaic panels (PV). We have chosen the 5L inverter because it is the most widespread. In literature, there is works dealing on a single topology with several levels, or developing a new topologies, or achieving a sophisticated control dedicated to very specific topologies. This study focuses on a comparison of three topologies bases. These topologies are simpler and easily controlled in an analog or digital manner. This study shows, on the one hand, that the total harmonic distortion (THD) is approximately 32% for NPCMLI and PWM H-Bridge topologies, and it is about 36% for the FCMLI topology. Moreover, the distortion factor (DF) of the FCMLI is smaller (0.94) than the NPCMLI and H-bridge (0.951). In addition, the rays spectrum are concentrated on the switching frequency (2500Hz) for the three topologies. On the other hand, the H-bridge MLI topology has fewer components compared to the others. Our study confirms that the most promising topology for photovoltaic systems is the PWM H-bridge one in view of the spectral quality, the phase shift ($2\pi/3$) between voltages, the waveform of the composed output voltage and the cost.

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Keywords : Three-phase multilevel inverters, FCMLI, NPCMLI, H-Bridge MLI, THD, SPWM Multi-carrier ;

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1. Introduction

Electrical production from photovoltaic panels (PV) gives DC voltage. So the use of inverters is a compelling solution to convert output voltage to the alternative form. The increase of the electric power in industrial applications leads to an increase in the switched current. Although the increase in voltage is often privileged, to improve the performance of the installation, however, it's difficult to handle semiconductors who undergo deterioration of their dynamic and static performances [1] [8] [10]. However, a high level of power involves either a high voltage or high current, or even both at the same time. In addition, despite significant advances, the evolution of technological opportunities is slow at present compared to industrial application [3]. The appearance of the multilevel inverters since the beginning of the 1980s brought solutions by making power semiconductors in series. These topologies provide the distribution of the voltage stress on different switches while improving waveforms (harmonic spectrum) of the output quantities.

In the field of multilevel inverters, new topologies have emerged in recent years. They mainly include the technique of flying capacitor multilevel inverter FCMLI, the technique of neutral point clamped multilevel inverter NPCMLI, as well as the technique of cascaded H-Bridge multilevel inverter H-bridge MLI [4][15][16].

In this article, we will present a comparative study in the Matlab/Simulink environment of three different five-level inverter topologies (FCMLI, NPCMLI, and PWM H-BRIDGE) controlled by the same control law, i.e. multi-carrier SPWM sinusoidal pulse width modulation. Criteria of comparison are based on the quality of the output voltages (THD, DF, magnitude, phase,...), on the complexity of the power circuit, and on the cost of implementation.

2. Basic topologies:

We find in literature the descriptions of the three basic topologies considered in this paper, along with their merits and demerits [10] [12] [13] [16].

We give a brief description of these three multi-level inverter topologies, highlighting their main features:

- Flying capacitor multilevel inverter FCMLI: many capacitors are required which makes this topology heavy and cumbersome. In applications requiring non-zero voltage at capacitors terminals, it may be necessary to associate with the system control strategy, another strategy of capacitors pre-charging.
- Neutral point clamped multilevel inverter NPCMLI: it is the most commonly used topology in the industry for a number of levels equal to three. When the number of levels is greater than three, the voltage at capacitors terminals becomes very difficult if not impossible.
- Cascaded H-Bridge multilevel inverter PWM H-bridge: it has the huge advantage of being modular. However, this topology requires a galvanic separation.

Briefly, table 1 shows some characteristics of these basic topologies, for an inverter of m levels.

3. Inverters control:

Throughout this work, the control used for different topologies studied is multi-carrier sinusoidal pulse width modulation whose characteristics are:

- Sinusoidal PWM;
- Signal modulating: 50 Hz;
- Frequency: 2500Hz;

- Index modulation: 1.

Table 1. Main features of the three topologies of multilevel inverter based

Topology	Basic topologies of multilevel inverters		
	FCMLI	NPCMLI	H - Bridge MLI
Key features phase switch	2 (m-1)	2 (m-1)	2 (m-1)
Antiparallel diode by phase	2 (m-1)	2 (m-1)	2 (m-1)
Close phase-diode	0	(m-1)(m-2)	0
The DC bus capacitor	(m-1)	(m-1)	(m-1) / 2
Capacitor balance	(m-1)(m-2) / 2	0	0
Cost	0.85	1	0.85

4. Flying capacitor multilevel inverter (FCMLI):

4.1. Topology:

Fig. 1 below shows the pattern of simulation by Matlab/Simulink of a three-phase inverter 5L type FCMLI. 220V DC voltage source represents the PV generator.

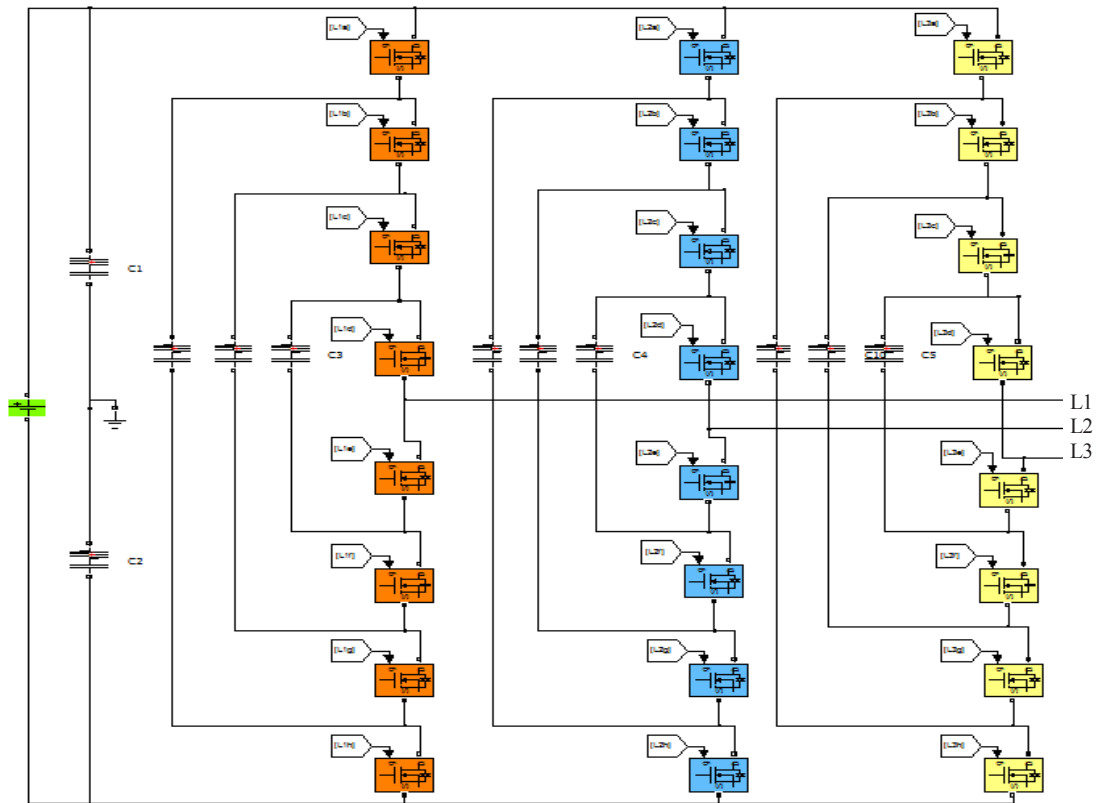


Fig. 1: Schema of simulation of inverter FCMLI (5L)

4.2. SPWM control:

The SPWM control principle is to compare the reference signal V_{ref} , modulating, with the 2500 Hz frequency carrier. Fig. 2 shows the waveform of signals: modulating and surrogate generating the power switches control pulses.

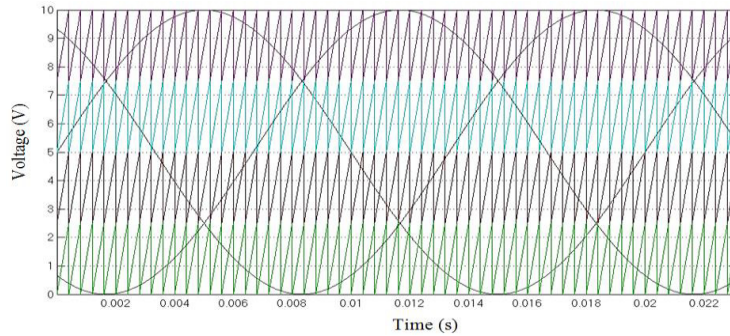


Fig. 2: The signals generating the control pulses

- Modulating signals for phases A, B and C:
 - ✓ $V_{Aref}(t) = A * m * \sin(\omega * t)$
 - ✓ $V_{Bref}(t) = A * m * \sin\left(\omega * t - \frac{2\pi}{3}\right)$
 - ✓ $V_{Cref}(t) = A * m * \sin\left(\omega * t - \frac{4\pi}{3}\right)$
 - Magnitude: $A = 10V$
 - Modulation index: $m = 1$
 - Frequency: $f = \omega/2\pi = 50 \text{ Hz}$
- Carriers:
 - ✓ Number: 4 carriers for each alternation of the modulating signal,
 - ✓ Form: a carrier sawtooth moved to the right;
 - ✓ Frequency: 2500Hz.

4.3. Output composed voltage waveforms:

Waveforms of compound voltages of three-phase FCMLI 5L inverter are illustrated in Fig. 3.

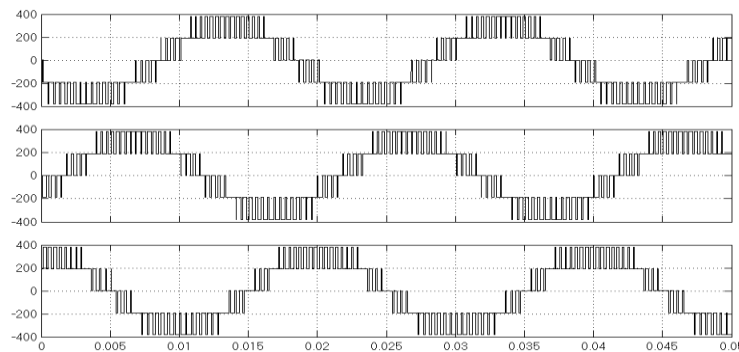


Fig. 3: Waveforms of voltage to the output of the inverter (5L) FCMLI

The given result of simulation in Fig. 3 shows that compound voltages with a maximum value of 380V and a phase angle of $2\pi/3$.

4.4. Total Harmonic Distortion (THD) and Distortion Factor (DF):

The spectral analysis of compound voltages shown in Fig. 4, shows that these voltages are very rich in harmonics, and are concentrated in the vicinity of the switching frequency $f = 2500\text{Hz}$. The amplitude of the voltage consisting of 324.1V, THD is 36% and DF is 0.94.

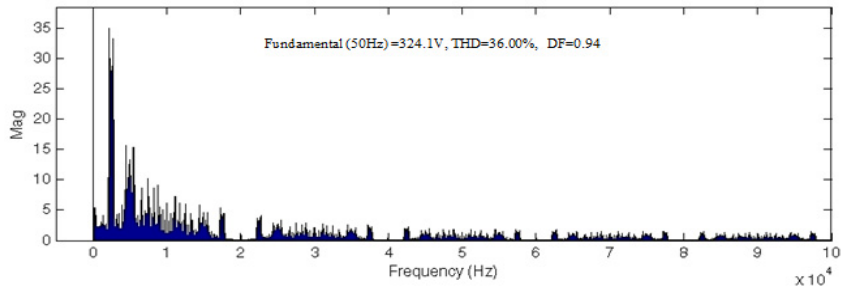


Fig. 4: The spectrum of harmonics of voltage of inverter FCMLI (5L)

5. Neutral point clamped multilevel inverter (NPCMLI):

5.1. Topology:

In this topology, four power switches are used in every 'subsystem' Matlab/Simulink block, PV panels of the inverter power supply are represented by DC generators whose value is 100V each.

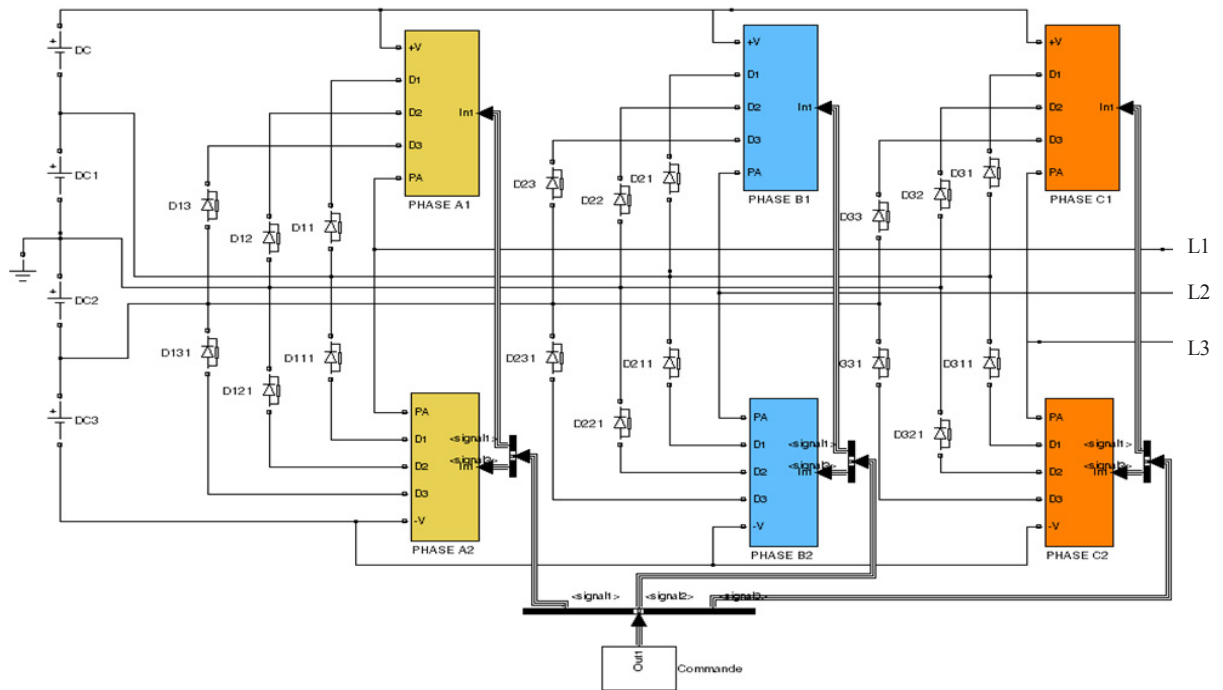


Fig. 5: The NPCMLI (5L) inverter topology

5.2. SPWM control:

We represent, in Fig. 6, the simulation of a phase of the inverter control schema. This is the law of SPWM control with four carriers.

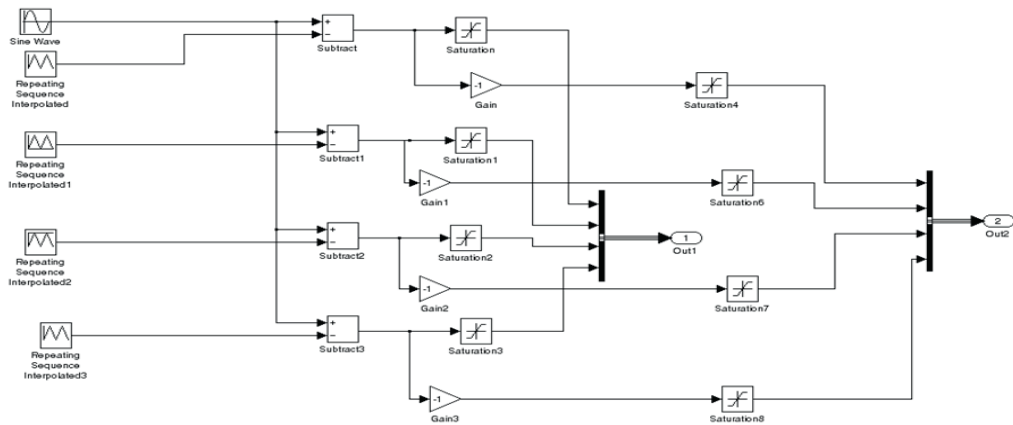


Fig. 6: Schematic of simulation of a phase of the NPCMLI (5L) Inverter control

5.3. Output composed voltage waveforms:

The waveforms of compound voltages, in the output of the inverter three-phase NPCMLI (5L), are illustrated in Fig. 7.

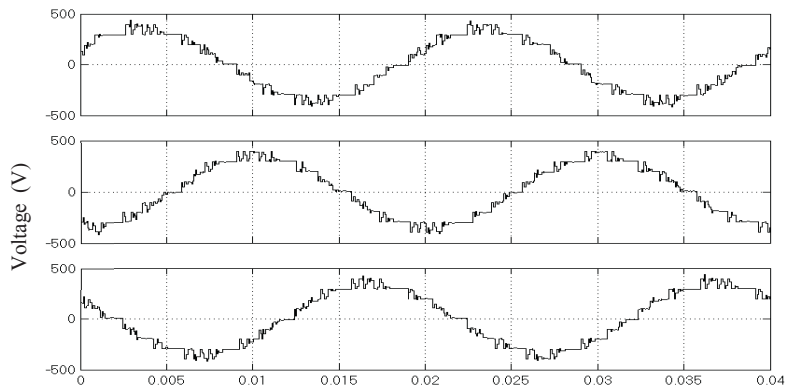


Fig. 7: Waveforms consisting of a NPCMLI (5L) inverter voltages.

The simulation result given in Fig. 7 shows that compound voltages have a maximum value of 391.5V and may have peaks that exceed 438.5V. These peaks are due to the non-stability of the voltages of this type of topology.

5.4. Total Harmonic Distortion (THD) and Distortion Factor (DF):

The spectral analysis of compound voltages (Fig. 8) shows that these voltages are very rich in harmonics, and concentrated in the vicinity of the switching frequency $f = 2500\text{Hz}$. The amplitude of the line voltage is 348.7V, the THD is 32.28% and DF is 0.951.

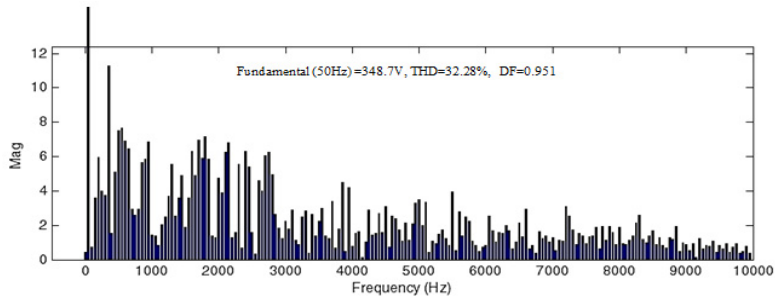


Fig. 8: The spectrum of harmonics voltage of the NPLMLI (5L) inverter

6. Cascaded H-Bridge multilevel inverter (H-bridge MLI):

6.1. Topology:

This type of topology is based on a classic H-bridge cell. Each block 'subsystem' Matlab/Simulink, has H-bridge and a DC voltage source = 100V which represents a PV Panel.

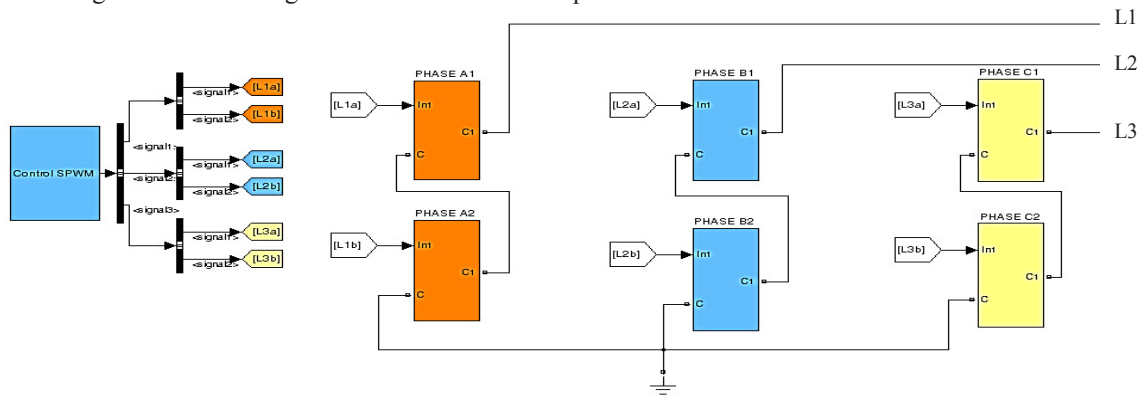


Fig. 9: The (5L) H-Bridge inverter topology

6.2. SPWM control:

We give in Fig. 10 the synthesis of control SPWM by Matlab/Simulink, for each phase of the inverter.

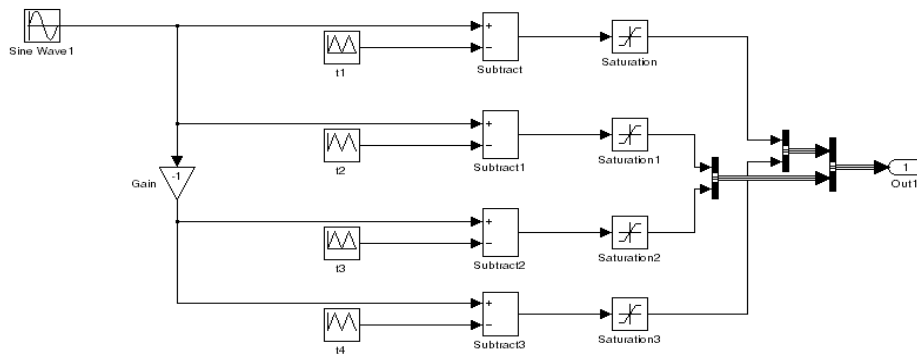


Fig. 10: Schema of simulation of a phase of the H-Bridge MLI (5L) Inverter control

6.3. Output composed voltage waveforms:

The forms of compound voltage, to the inverter H-Bridge MLI (5L) exit are illustrated in Fig. 11.

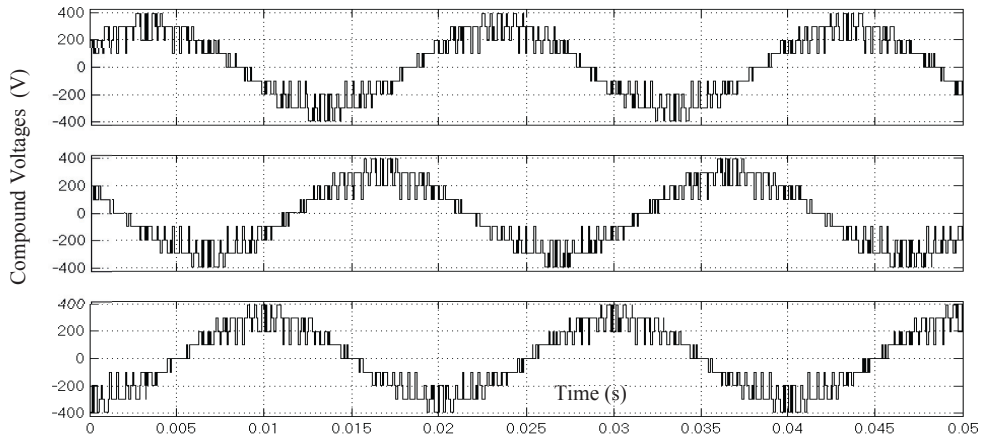


Fig. 11: The Waveforms consisting of the H-Bridge MLI (5L) inverter voltages

The simulation results given on Fig. 11 show voltages composed with a maximum value of 392V, and a phase shift of $2\pi/3$.

6.4. Total Harmonic Distortion (THD) and Distortion Factor (DF):

The spectral analysis of compound voltage, Fig. 12, shows that these voltages are very rich in harmonics, and their concentration is in the vicinity of the switching frequency $f = 2500\text{Hz}$. The fundamental of the line voltage is 293.5V, the THD is 32.4% and DF is 0.951.

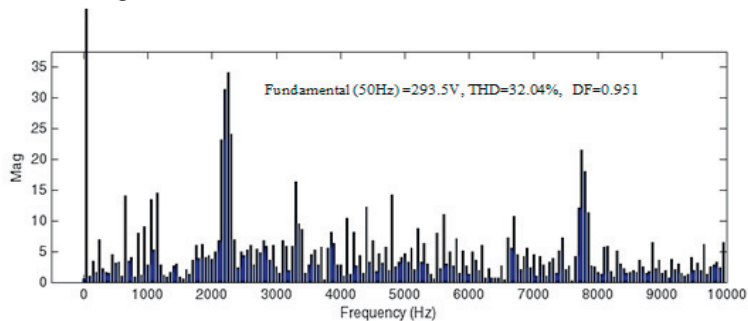


Fig. 12: The spectrum of harmonics of voltage of inverter H-Bridge MLI (5L)

7. Conclusion:

This paper presents a comparative study of three main different topologies of 5 levels three-phase inverters. Multi-carrier SPWM control is the control law applied to all types of inverters considered. The sources of DC voltages power supply of different inverters, used in the simulation, are the PV panels.

We gather in table 2, the number of components used in each structure inverter 5L and the simulation results, i.e. the maximum value of the compound voltage, the THD, and the phase angle between the compound voltages.

Table 2. The results of simulation of the three topologies

Topology	FCMLI	NPCMLI	H - Bridge MLI
Key features of switching			
By phase	8	8	8
Antiparallel diode by phase	8	8	8
Close phase-diode	0	12	0
The DC bus capacitor	4	4	2
Capacitor balance	6	0	0
Composed of output voltages(V)	380	391.5	392
THD %	36	32.47	32.04
DF	0.940	0.951	0.951
Phase shift between consecutive compound voltage	$2\pi/3$	$2\pi/3$	$2\pi/3$

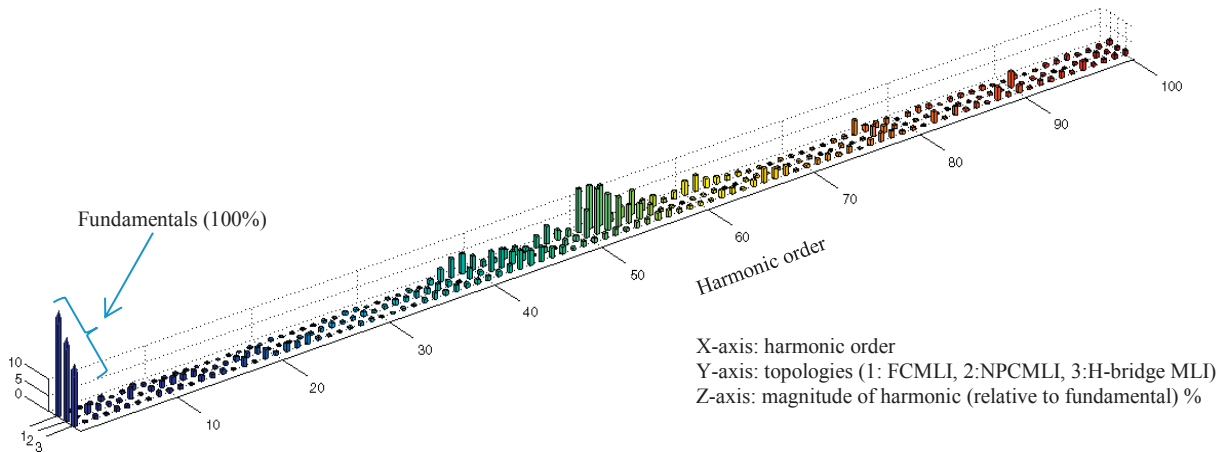


Fig. 13: The spectrum harmonic of output voltages of different topologies

We find that:

- The NPCMLI has the highest cost of implementation among the three studied inverters. The implementation of the FCMLI and H-Bridge MLI costs are almost the same, but less than 15% relative to NPCMLI.
- Up to the 35th harmonic of the three topologies with almost the same spectrum.
- The spectrum of the three topologies is rich in harmonics in the vicinity of the 50th harmonic (switching frequency of the switches).
- The THD of the NPCMLI and PWM H-Bridge topologies is almost the same (32%). On the other hand, the THD for FCMLI is 36%.
- The THD of NPCMLI and PWM H-Bridge is almost the same (32%). and is smaller compared to that of FCMLI (36%).

- The DF of NPCMLI and H-Bridge MLI is close to 1 relative to that of the topology FCMLI.
- The phase shift between compound voltages is $2\pi/3$.

We deduce that the PWM H-bridge is the most promising topology for PV systems because it has the following advantages:

- This topology is modular and allows very high voltage levels.
- The number of components is less than in other multilevel topologies for the same voltage levels. This topology doesn't use loopback diodes and capacitors float.
- Switches support the same blocking voltage.
- It is possible to feed a high or medium voltage load from one or more low voltage supplies (the case of PV panels).
- Another benefit of this topology is its ability to operate even if a cell (H-bridge) is short-circuited.

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