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CASCADED H-BRIDGE THREE-PHASE MULTILEVEL INVERTERS CONTROLLED BY MULTI-CARRIER SPWM DEDICATED TO PV

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ABSTRACT

Generally, electrics devices need alternating current. But PV generators provide direct current. So, it is necessary to use inverters. Multilevel inverters seem very suitable for this task. In this paper, we present a comparative study between three multilevel inverters: 3 levels, 5 levels and 15 levels. These inverters have the same topology and are controlled by the same law: Sinusoidal Pulse Width Modulation multi-carrier (SPWM). Our interest concerns the magnitude and the quality of generated voltage. The 15L multilevel inverter supplied by 36V PV gives a 230V AC voltage. So it's the most suitable for supplying normal electric equipments. Simulation with Matlab/Simulink of the inverters operation shows that: THD is independent of the value of PV voltage; the greater the number of levels is, the less THD becomes.

Keywords: *Three-Phase Multilevel inverters, H-Bridge, SPWM Multi-Carrier, THD.*

1. INTRODUCTION

Voltage generated by a photovoltaic panel (PV) is a DC. Low voltage source requires inverters for assuring alternative form for several applications. On another hand, power demand of the industry has increased dramatically in recent years. For both low and medium voltage, PV has marked seen an increasing development.

The use of so-called conventional inverters with two levels and high switching frequencies is limited due to the large lass switching in the devices. In addition, the inverter AC voltage quality has a significant distortion. This requires a harmonic filtering. To overcome this problem, the use of multilevel inverters in applications of medium and high powers is suggested by several studies [1],[2],[3].

Some works comparing between different multilevel inverters topologies have shown that H-bridge inverter is the most suitable for photovoltaic systems [4],[5],[6].

This work presents a comparative study from quality standpoint of voltages generated (simple and compound) by three multilevel inverters. The basic component of these inverters is a cell called H-bridge. These inverters are controlled by the PWM control law and have different levels (3L, 5L and 15L). The goal is to reduce the total harmonic distortion (THD) of the generated voltage. SPWM control is chosen given its advantages: simplicity of implementation. This control is programmed in cards (DSP, FPGA and microcontroller cards) [7],[8],[9],[10].

2. BASIC CELL

2.1 Topology

Figure below illustrates the basic cell structure of multilevel inverters.

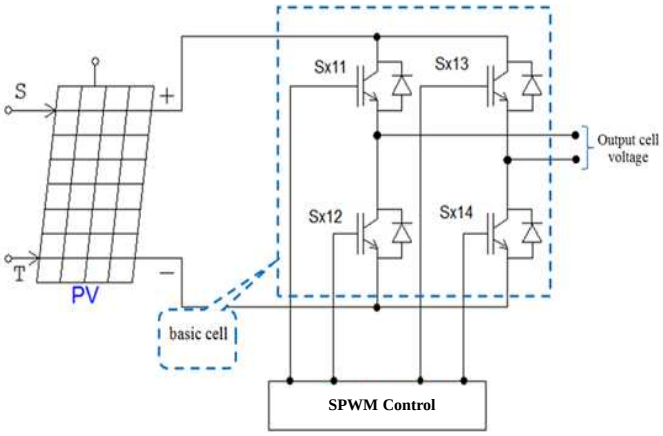

Figure 1: Structure of a basic cell with its control connected to a PV panel

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- Each bridge has four power switches.
- The cell supply is provided by a photovoltaic panel with a rated voltage of 48V. In this study, we will not consider any stage between the PV panel and the H-bridge.
- Switches (S_{X11}, S_{X14}) and (S_{X13}, S_{X12}) (x = A, B, C) operate in a complementary manner according the PWM control.
- For topologies with multiple cells in this document
  - Star connection three-phase system is used to increase the output voltage of the inverters.
  - The number of levels of the output voltage depends on the number of cells:

$$N = 2C + 1 \quad (1)$$

Where N: number of levels
C: number of cells

1.2 SPWM Control

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

The reference voltages for a three-phase topology form a balanced three-phase system which will give the output voltages of the inverter.

- ✓ $V_{Aref}(t)=A*m*\sin(\omega.t)$
- ✓ $V_{Bref}(t)=A*m*\sin(\omega.t-2\pi/3)$
- ✓ $V_{Cref}(t)=A*m*\sin(\omega.t-4\pi/3)$ (2)

Magnitude: A = 21V
Modulation index: m = 1
Frequency: f = ω/2π = 50 Hz

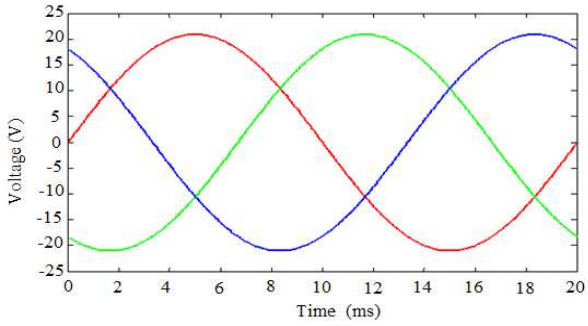

Figure 2: Reference voltages of a balanced three-phase (A = 21V, m = 1, ω = 314 rad / s)

3. H-BRIDGE MULTILEVEL INVERTER (3 LEVELS)

3.1 Topology

The structure of a 3L inverter is shown in Figure 3.

3.2 Waveforms

Waveforms of simple voltage and of compound voltage, plotted by Matlab / Simulink, are given respectively in figure 4 and figure 5.

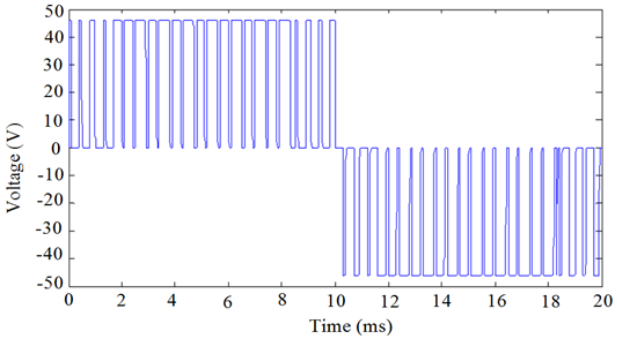

Figure 4: Simple voltage

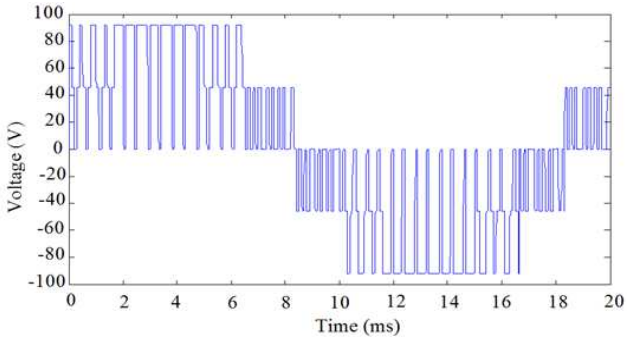

Figure 5: Compound voltage

According to figures 4 and 5, the maximum voltage is 46V and 92V for respectively simple and compound voltage.

3.3 Total Harmonic Distortion (THD)

Spectral analyses of the simple and compound voltages, performed by Matlab / Simulink, are shown in Figures 6 and 7.

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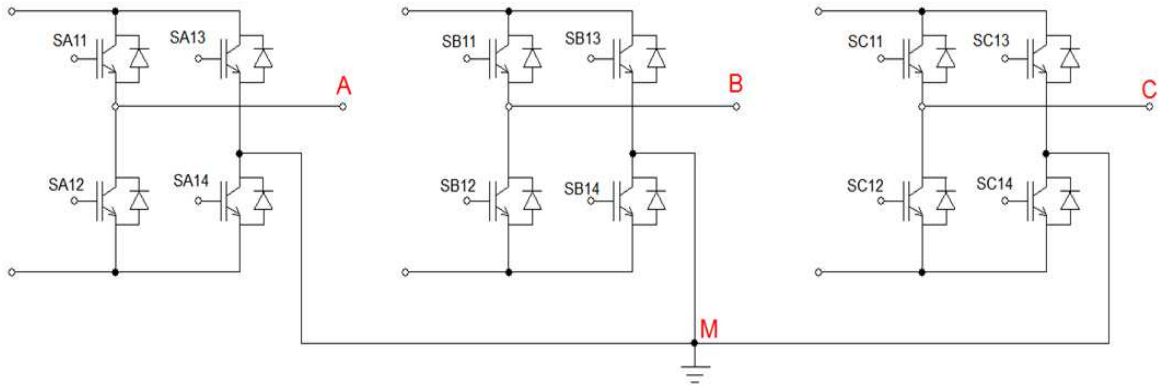

Figure 3: Three-phase multilevel inerter (3 levels)

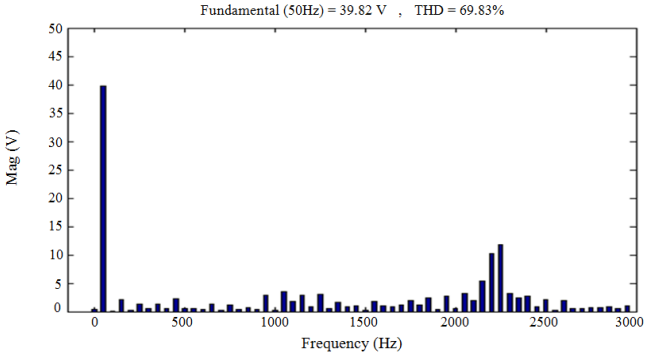

Figure 6: Spectral analysis of simple voltage

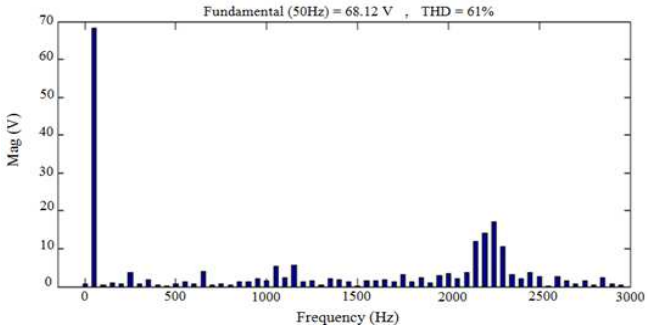

Figure 7: Spectral analysis of compound voltage

According to figures 6 and 7, fundamental voltage is 39.82V and 68.12V for simple and compound voltage. The rate harmonic is then calculated 68.83% for simple voltage and 61.95% for compound voltage.

4. H-BRIDGE MULTILEVEL INVERTER (5 LEVELS)

4.1 Topology

The structure of a 5L inverter is shown in figure 8.

4.2 Waveforms

Waveforms of simple and compound voltages, plotted by Matlab / Simulink, are shown in figures 9 and 10.

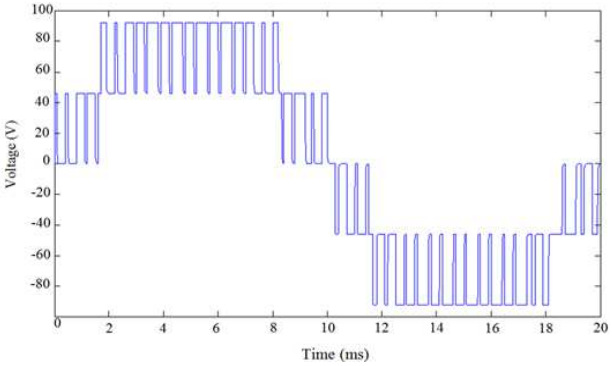

Figure 9: Simple voltage

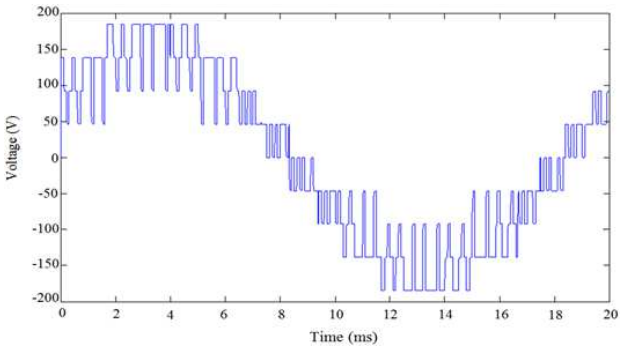

Figure 10: Compound voltage

According to figures 9 and 10 the maximum voltage is 92V and 184V for respectively simple and compound voltages.

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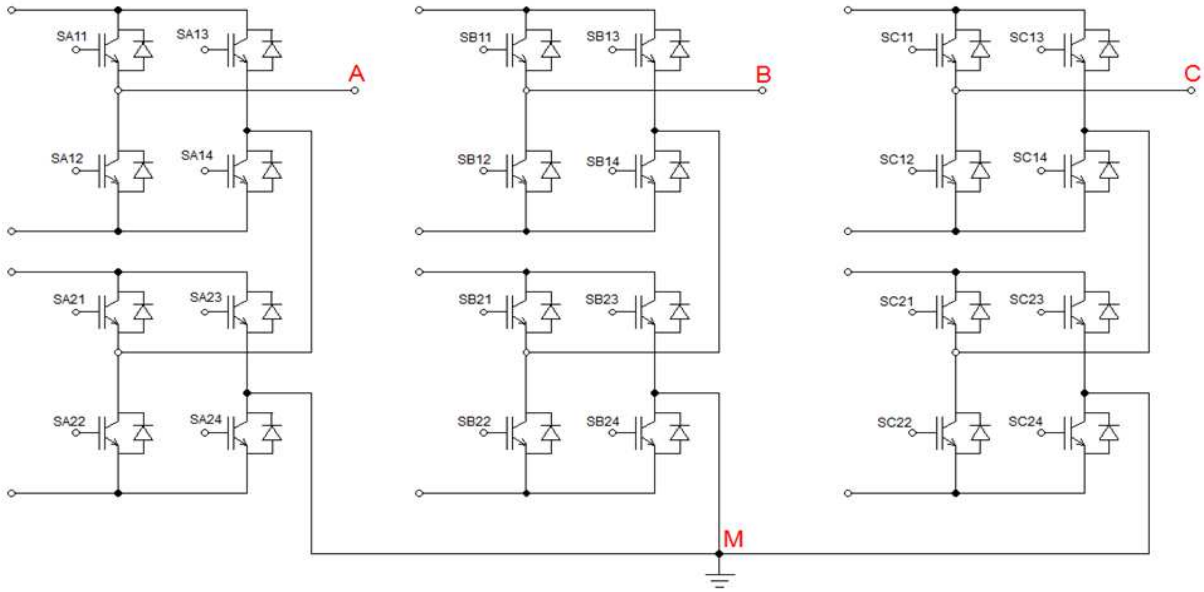

Figure 8: Three-phase multilevel inerter (5 levels)

4.3 Total Harmonic Distortion (THD)

Spectral analyses of the simple and compound voltages, performed by Matlab / Simulink are shown respectively in figures 11 and 12.

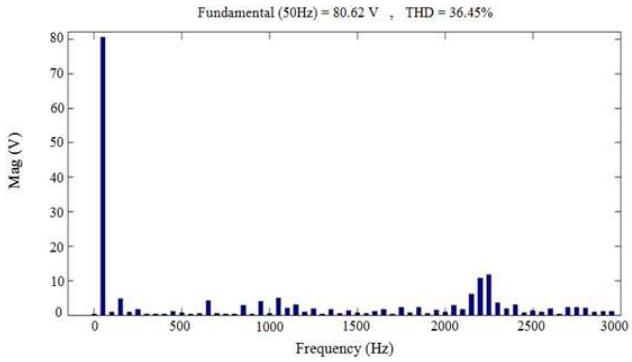

Figure 11: Spectral analysis of simple voltage

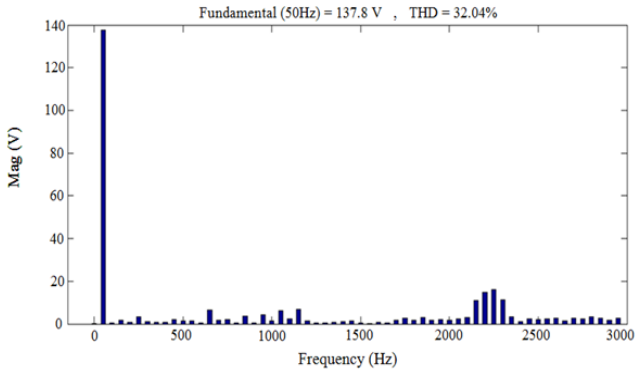

Figure 12: Spectral analysis of compound voltage

According to figures 11 and 12, fundamental of simple voltage is 80.62V and fundamental of compound voltage is 137.8V. The rate harmonic is then calculated 36.45% for simple voltage and 32.04% for compound voltage.

5. H-BRIDGE MULTILEVEL INVERTER (15 LEVELS)

5.1 Topology

The structure of a 15L inverter is shown in figure 13. C_{ij} is a cell H bridge with (i= A, B, C) and (j=1, 2,…, 7).

5.2 Waveforms

Waveforms of simple and compound voltages, plotted by Matlab / Simulink, are shown in figures 14 and 15.

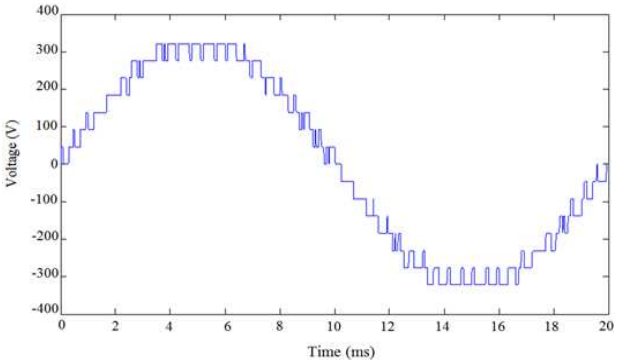

Figure 1: Simple voltage

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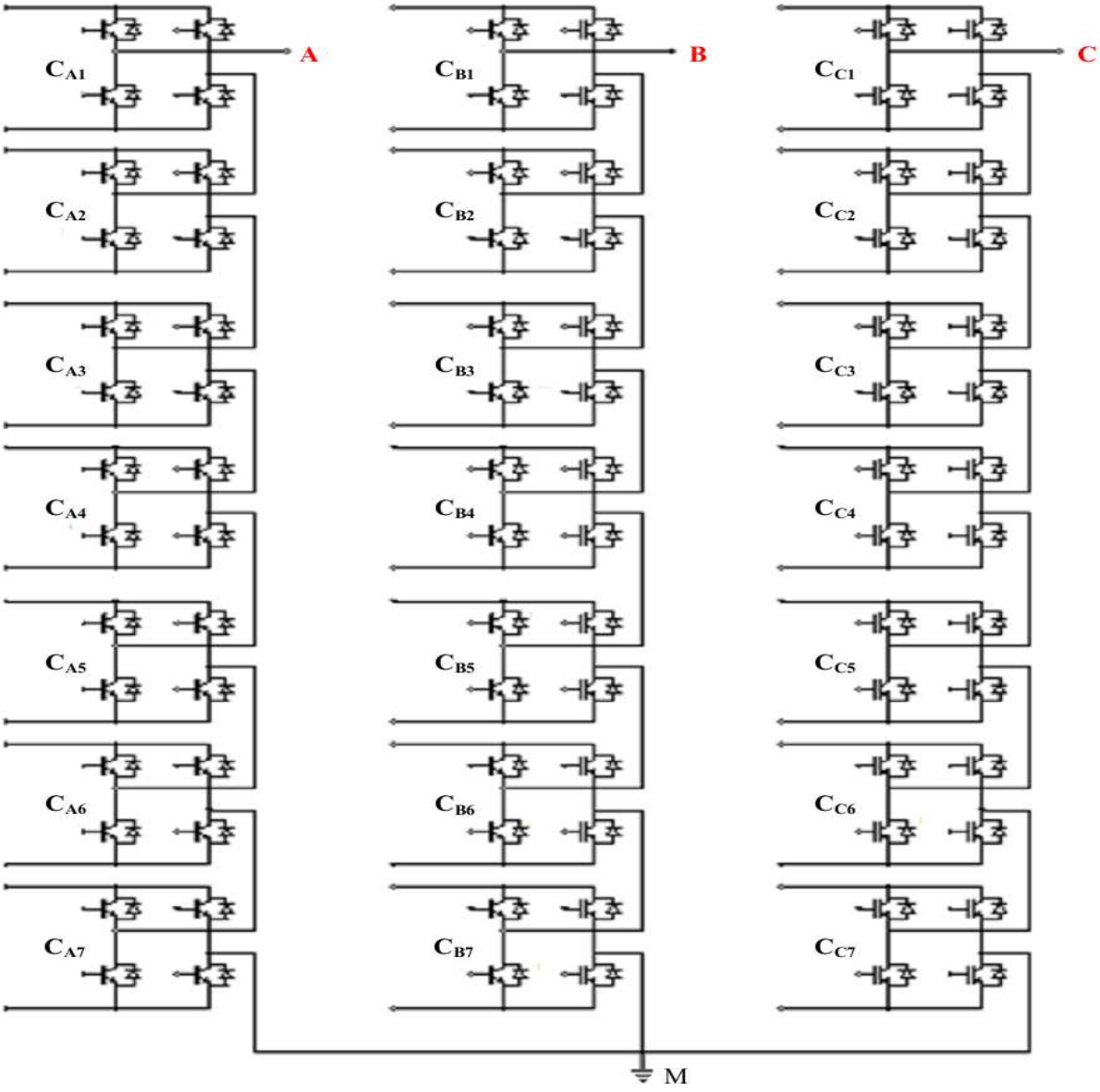

Figure13. Three-phase multilevel inerter (15 levels)

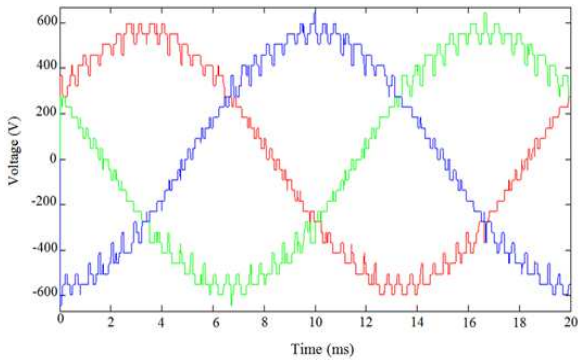

Figure 15: Compound voltage

According to figures 14 and 15, the maximum voltage is 322V and 598V, for respectively simple and compound voltages. Voltages are 2π / 3 phase shifted successively.

5.3 Total Harmonic Distortion (THD)

Spectral analyses of the simple voltage and the compound voltage, performed by Matlab/Simulink, are shown respectively in figures 16 and 17.

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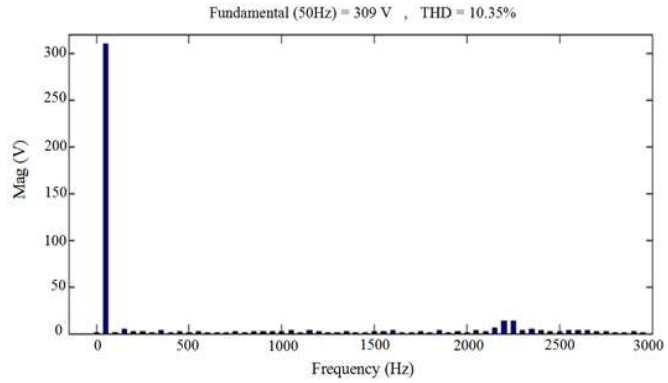

Figure 16: Spectral analysis of simple voltage

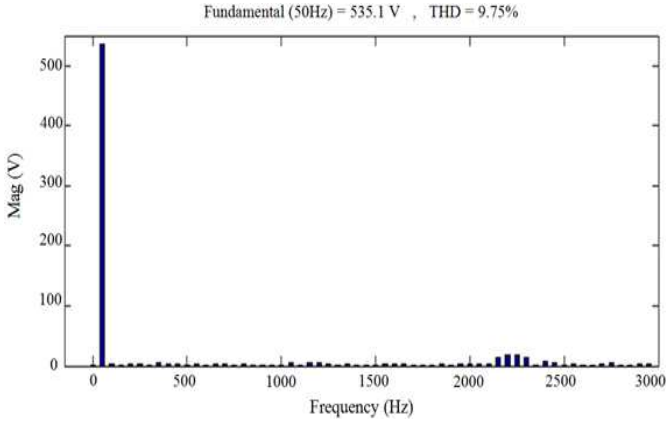

Figure 17: Spectral analysis of phase voltage

According to figures 16 and 17, fundamental of simple voltage is 309V and fundamental of compound voltage is 535.1V. The rate harmonic is then 10.35% for simple voltage and 9.75% for compound voltage.

6. RESULTS

The table below summarizes the simulation results for the three multilevel inverter controlled by SPWM. Each inverter is powered by various PV sources. It gives the amplitude of the fundamental and the value of harmonic distortion output voltages.

Table 1: Results

Level of inverter	Number of cells by phase	supply of cells (V)	Magnitude of fundamental (V)		THD %	
			Simple voltage	*Compound voltage*	*Simple voltage*	*Compound voltage*
3L	1	12	8.65	14.81	69.83	61.95
		24	19.04	32.58		
		36	29.43	50.35		
		48	39.82	68.12		
5L	2	12	17.53	29.95	36.45	32.04
		24	38.56	65.89		
		36	59.95	101.8		
		48	80.63	137.8		
15L	7	12	67.18	116.3	10.35	9.75
		24	147.8	255.9		
		36	228.4	395.5		
		48	309	535.1		

It was found that:

- Regardless of the value of the voltage of the solar panel, the THD is the same for a given inverter;
- The THD is considerably weakened by increasing the number of levels of the inverter;
- The fundamental is ready bit equal to the voltage supplied by the panel when the number of cells;
- The report of the fundamental compound voltage and simple voltage is almost equal to $\sqrt{3}$ (checking the withers coupling topology).

7. CONCLUSION

Multilevel inverters are very suitable for PV generation. H-bridge cell with PWM control is very promising solution. Not only for having medium and high voltages. But, for improving the quality of this voltage (reduction of THD).

This study shows that, for any of those supply voltage of the inverter, the harmonic distortion decreases with increasing of the number of levels (68.83% to 10.35% for 3L and 15L). The most significant harmonic is rejected to the high frequency inverter for 15L (near the fundamental switching frequency).

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