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Reduction in Total Harmonic Distortion using Cascaded H-Bridge Multilevel Inverter using Amplitude Modulation Technique

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Abstract — *In high power applications nowadays multilevel voltage source inverter provides alternative to the conventional two level voltage source inverter. Using this multilevel technique, switching devices losses and stress is reduced, the output voltage amplitude is increased and improved overall harmonic profile can be achieved. This advantages helps to reduce the size of passive filters. This paper focuses on cascaded h-bridge multilevel inverter using amplitude modulation technique which minimizes number of sources and power semiconductor devices. Simulation of 13 level inverter is done using MATLAB Simulink software with and without amplitude modulation technique and results are compared. Further a 41 level inverters is also simulated using amplitude modulation technique and Fourier analysis is done for total harmonic distortion.*

Keywords*-Amplitude Modulation (AM), Cascaded H-bridge Inverter, Multilevel Inverter (MLI), Power Converters, Total Harmonic Distortion (THD)*

I. INTRODUCTION

Nowadays it is a prime requirement to enhance the performance of the power electronics systems to improve the quality of the waveforms generated. To supply the demand multilevel inverters have been used to improve the performance and increase the power ratings. In medium voltage and high power applications multilevel inverters are the first choice in industry. Improving the output voltage waveform of the multilevel inverter reduces its respective harmonic content and so, the size of filter used and the level of electromagnetic interference (EMI) generated because of switching operation [1]. Multilevel inverter not only achieves high power ratings, but also enables the use of low power application in renewable energy sources such as photovoltaic, wind, and fuel cells which can be easily interfaced to a multilevel converter system for a high power application [8]. Multilevel inverter consist of an array of power electronics devices with capacitor voltage sources [3]. It generates output voltages with stepped waveforms. The commutation of power semiconductor switches permits the addition of capacitor voltages, which reaches high voltage at the output, while power semiconductor switches has to withstand reduced voltage.

The cascaded multilevel inverter has drawn great interest because of its applications and various control strategy can be applied to it. These control strategy includes Pulse Width Modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM), Space vector Pulse Width Modulation (SVPWM) and Amplitude Modulation (AM). Literature of multilevel converter proposes mainly four number of converter topologies i.e. Diode clamped converter, Capacitor clamped converter, transistor clamped converter and cascaded converter [5].

II. CASCADED H-BRIDGE MULTILEVEL INVERTER

Cascaded multilevel inverter of series H-bridge inverter is a new topology which can avoid the use of extra clamping diodes and voltage balancing capacitors. In cascaded H-bridge multilevel inverter separate DC sources configuration is used to avoid short circuit of DC sources. Because of this structure of separate DC sources, cascade multilevel inverter is best suited for solar photovoltaic cells and fuel cells. It is best suitable for active power conversion from AC to DC and then DC to AC. With its modularity and flexibility, the cascaded multilevel inverter shows superiority in high-power applications, because by connecting the H-bridge in series one can get required output voltage as well as power. Fig.1 shows the various configurations of cascaded h-bridge multilevel inverter [6].

Using H-bridge inverter there arises few problems like high electrical stress on devices, higher total harmonic distortion (THD) and Radio Interference. Because of high THD large, costly and complex filter circuit is required and because of high rating cost of power switches is also high. Above problems can be eliminated or minimized using a new topology i.e. Cascaded multilevel inverter. In this topology more than one semiconductor converter in series is used, hence electrical stress divide across all the semiconductor switches. Also low voltages appears across each device that results in lower harmonics due to switching. In this topology comparatively low voltage and current is chopped so radio interference is low and as THD is reduced simple filter circuits are required. As power rating of devices is low, cost is comparatively less. The proposed topology offers advantages like reduced number of power switches, optimization layout is possible because of same structure for all levels, simple control circuit etc [7]. Only disadvantage of this topology is that it requires separate DC sources [4].

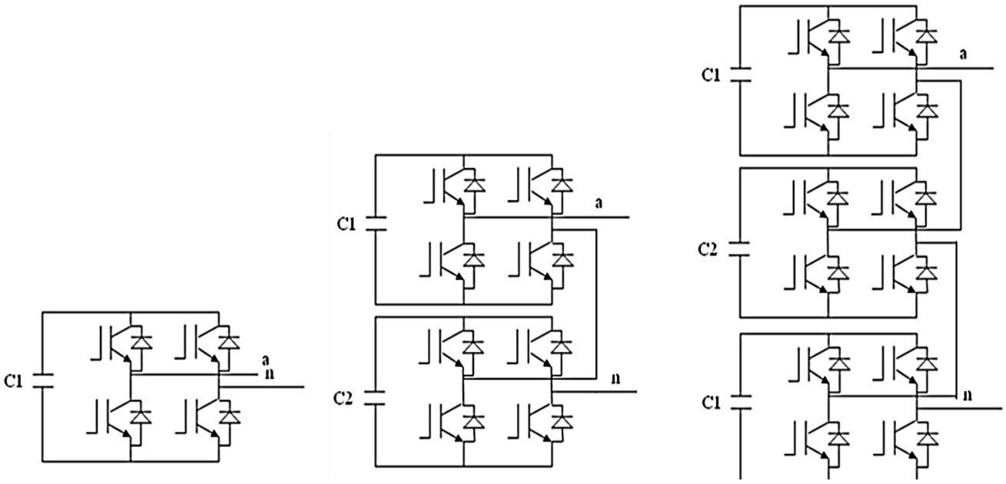

Figure 1. Various configurations of Cascaded H-bridge multilevel inverter

III. SIMULATION RESULTS

Simulation using MATLAB Simulink software is carried out for different output voltage levels [2]. In this paper simulation is done for 13-level inverter without amplitude modulation technique and with amplitude modulation technique with its Fourier analysis to find out total harmonic distortion and results are compared. Furthermore simulation of a 41-level inverter with proposed topology is also done and results are compared with 13-level cascaded h-bridge multilevel inverter.

3.1. 13-level h-bridge inverter without amplitude modulation technique

The model of single phase 13-level H-bridge multilevel inverter is shown in Figure 2. Simulation is done using three DC sources of 1 V, 3 V and 9 V. Maximum output voltage is 13V (zero to peak). The proposed topology is having one main converter and two auxiliary converters fed with unequal DC voltage sources. Switching sequence and output voltage is shown in Table 1.

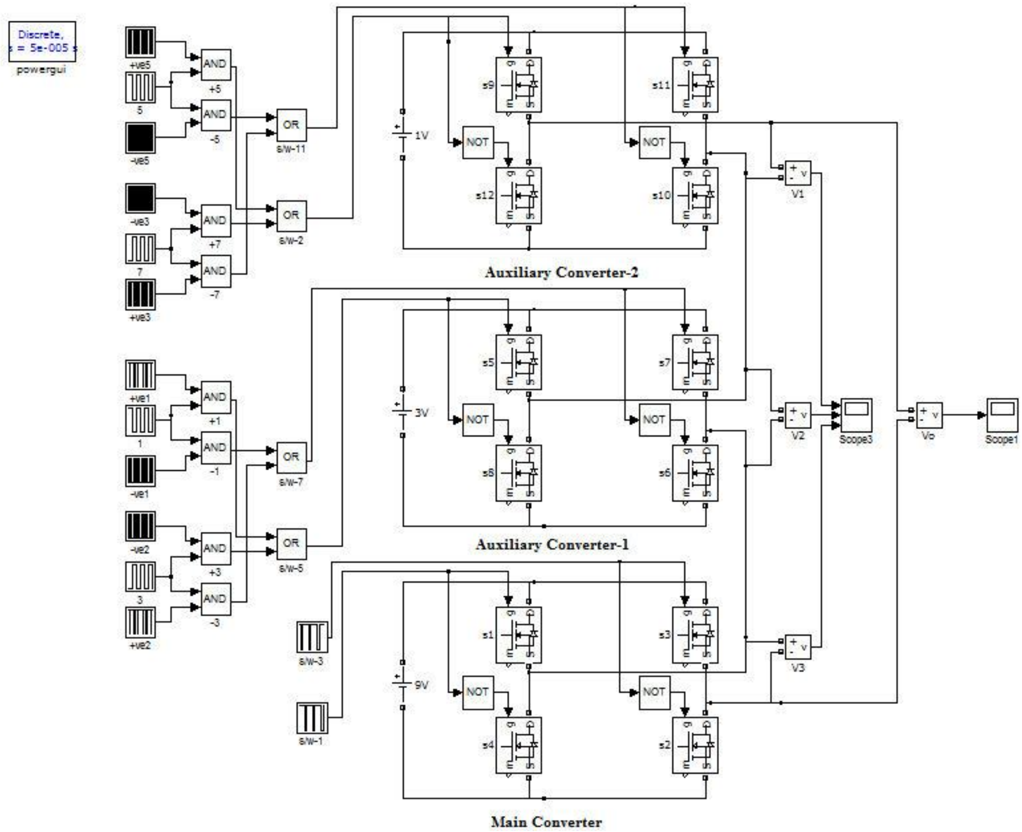

Figure 2. Simulink model of proposed topology (13-level inverter)

Table 1. Switching logic for 13-level inverter

Output Voltage(Vo)	Switching Status											
	S9	**S10**	**S11**	**S12**	**S5**	**S6**	**S7**	**S8**	**S1**	**S2**	**S3**	**S4**
0	1	0	1	0	1	0	1	0	1	0	1	0
1	1	1	0	0	1	0	1	0	1	0	1	0
2	0	0	1	1	1	1	0	0	1	0	1	0
3	1	0	1	0	1	1	0	0	1	0	1	0
4	1	1	0	0	1	1	0	0	1	0	1	0
5	0	0	1	1	0	0	1	1	1	1	0	0
6	1	0	1	0	0	0	1	1	1	1	0	0
7	1	1	0	0	0	0	1	1	1	1	0	0
8	0	0	1	1	1	0	1	0	1	1	0	0
9	1	0	1	0	1	0	1	0	1	1	0	0
10	1	1	0	0	1	0	1	0	1	1	0	0
11	0	0	1	1	1	1	0	0	1	1	0	0
12	1	0	1	0	1	1	0	0	1	1	0	0
13	1	1	0	0	1	1	0	0	1	1	0	0

In Table 1, condition 1 means switch is ON, and 0 means the switch is OFF. Figure 3 below shows the output voltage waveforms of one main converter, two auxiliary converter and final output voltage waveform of 13-level. Observing the output voltage wave form it can be stated that output voltage wave is in triangular shape. It does not follow sinusoidal wave shape.

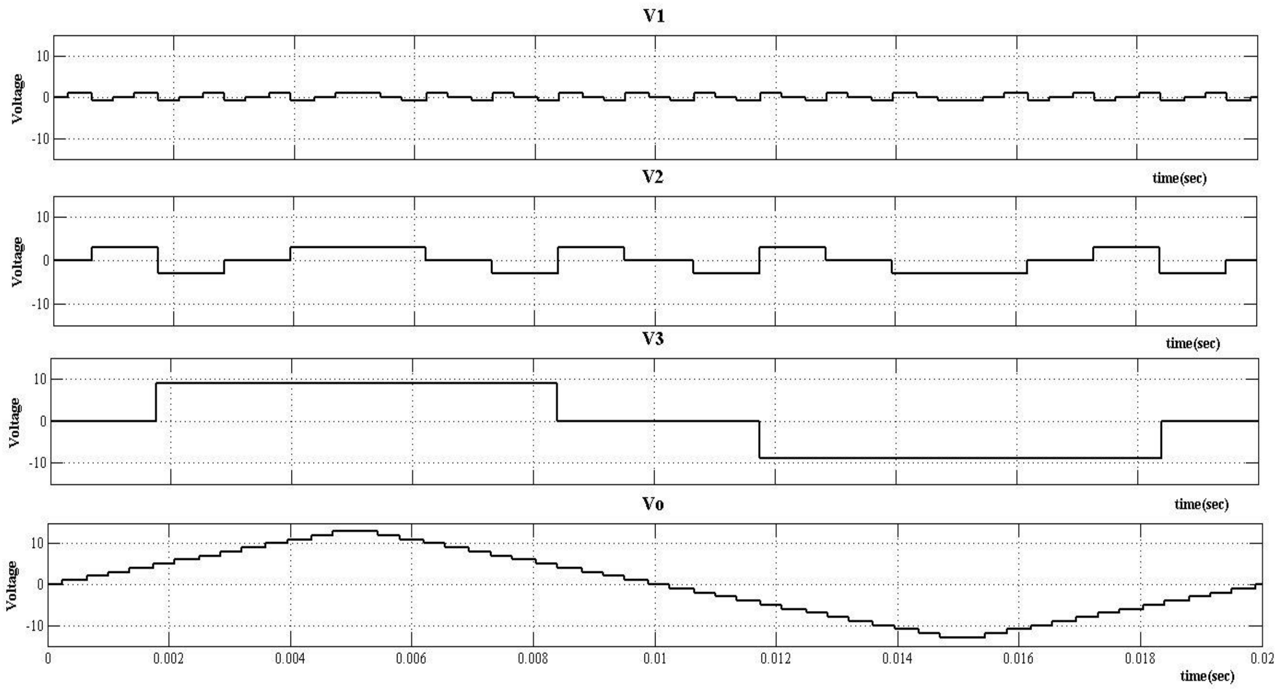

Figure 3. Output voltage waveform of all converters and final output voltage waveform

The Fast Fourier Transform (FFT) analysis of 13-level output voltage waveform is shown in Fig. 4 along with Fourier analysis in Figure 5. It can be shown that using amplitude modulation technique, there is a reduction in total harmonic distortion (%THD) compared 2 level and 5 level inverter [2].

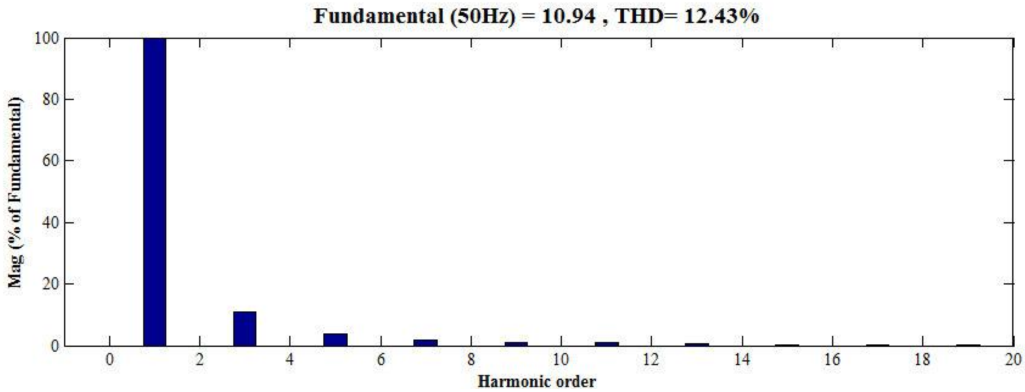

Figure. 4 FFT analysis of 13-level inverter without AM.

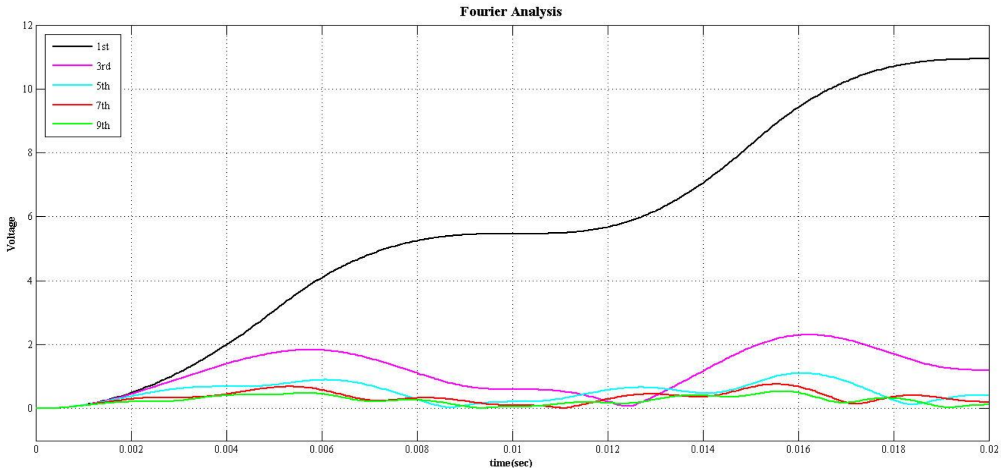

Figure. 5 Fourier analysis of 13-level inverter without AM.

It is clear from the above results that 13-level inverter without amplitude modulation (AM) technique is having 12.43 % THD in output voltage waveform, which is quite less compared to conventional 2-level inverter (usually 48% THD).

3.2. 13-level h-bridge inverter using amplitude modulation technique.

The same model as shown in Figure 1 is simulated using amplitude modulation technique. The output voltage waveforms of one main converter, two auxiliary converter and 13-level output voltage is shown in Figure 6. The FFT analysis of 13-level output voltage waveform using amplitude modulation technique is shown in Figure 7 along with Fourier analysis in Figure 8.

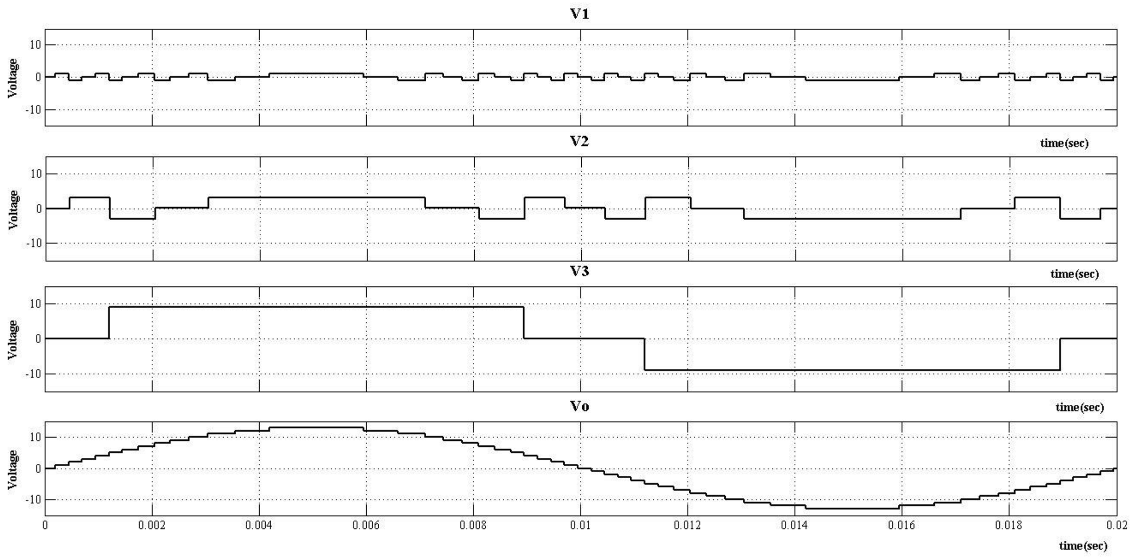

Figure 6. Output voltage waveform of 13-level inverter with AM

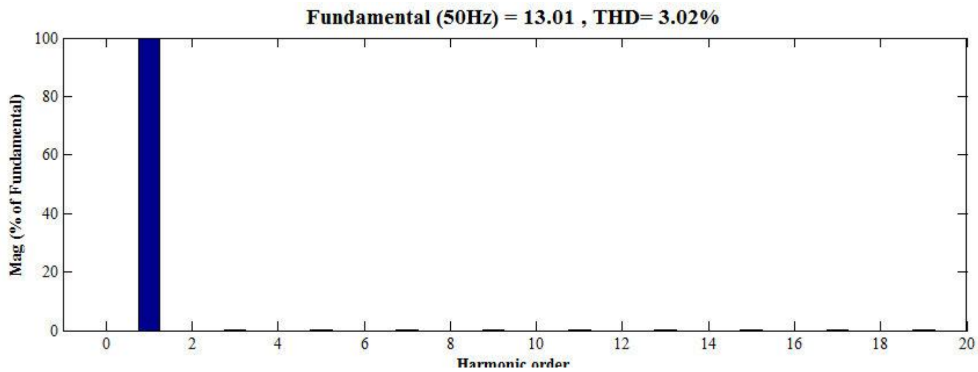

Figure 7. FFT analysis of 13-level inverter with AM.

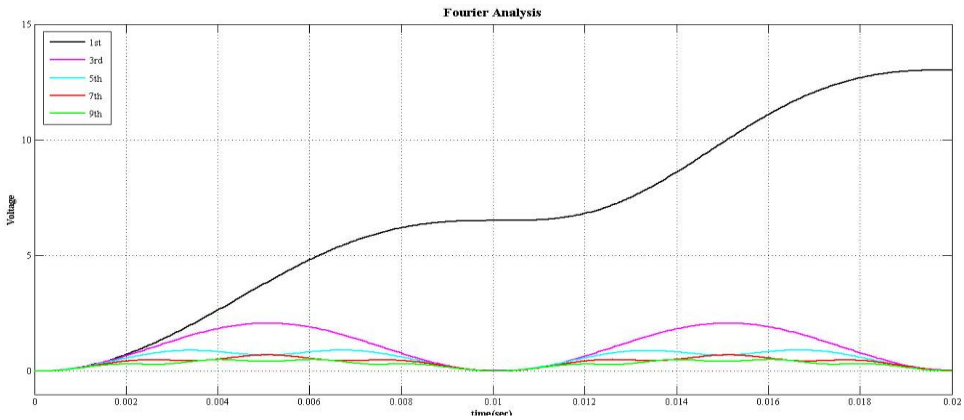

Figure. 8 Fourier analysis of 13-level inverter with AM.

From the above results it is clear that when inverter is used without amplitude modulation, output voltage waveform is having 12.43 % THD and when amplitude modulation technique is employed in the same inverter THD is reduced to 3.02 %. Here harmonic content reduced to a great extent when amplitude modulation technique is used.

3.3. 41-level h-bridge inverter using amplitude modulation technique.

MATLAB Simulink model for a 41-level cascaded H-bridge inverter with AM is shown in Figure 9. In this topology one main converters and three auxiliary converters are used. Simulation is done using four DC sources of 27 V, 9 V, 3 V and 1 V.

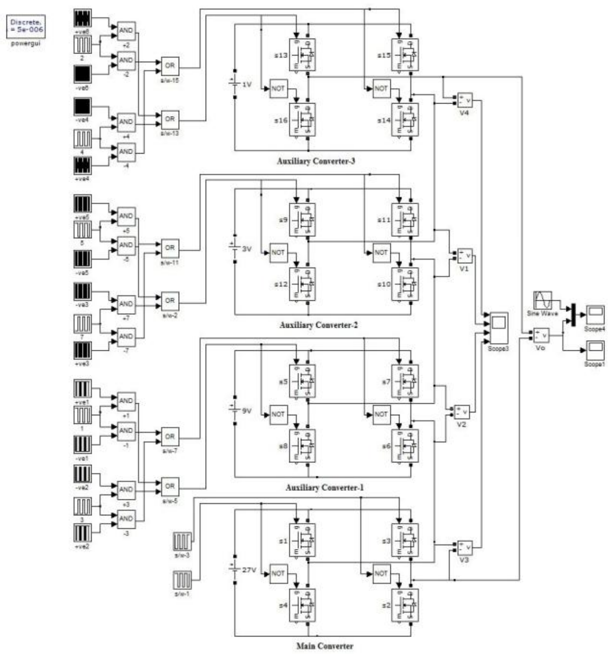

Figure 9. 41-level cascaded H-bridge multilevel inverter using AM.

The output voltage waveforms of all the converters is show in Figure 10 and final 41-level output voltage waveforms is shown in Figure 11. The FFT analysis & Fourier analysis of 41-level output voltage waveform using amplitude modulation technique is shown in Figure 12 and Figure 13 respectively.

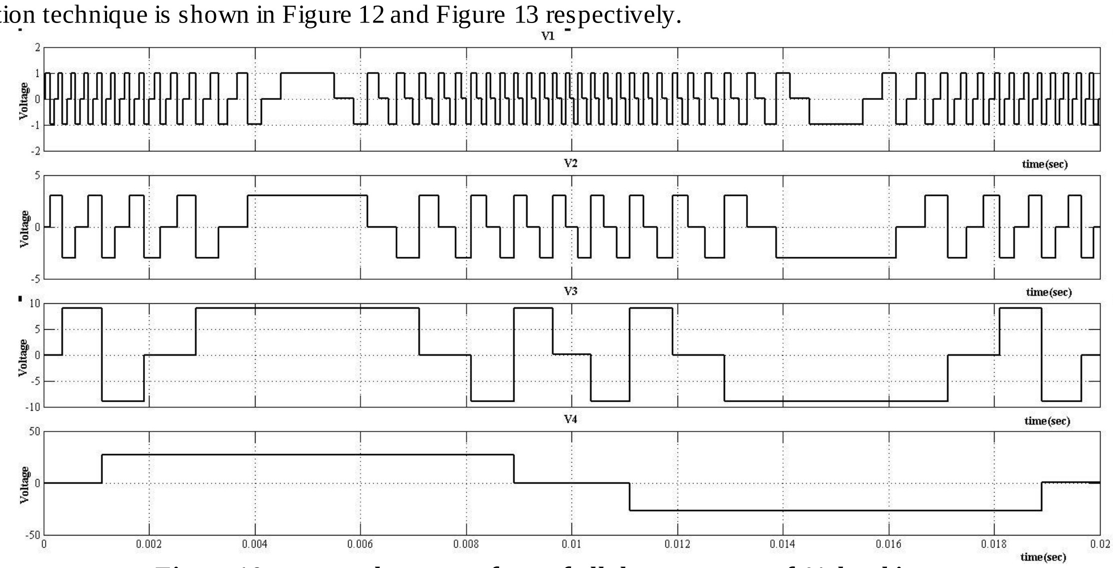

Figure 10 output voltage waveform of all the converters of 41-level inverter

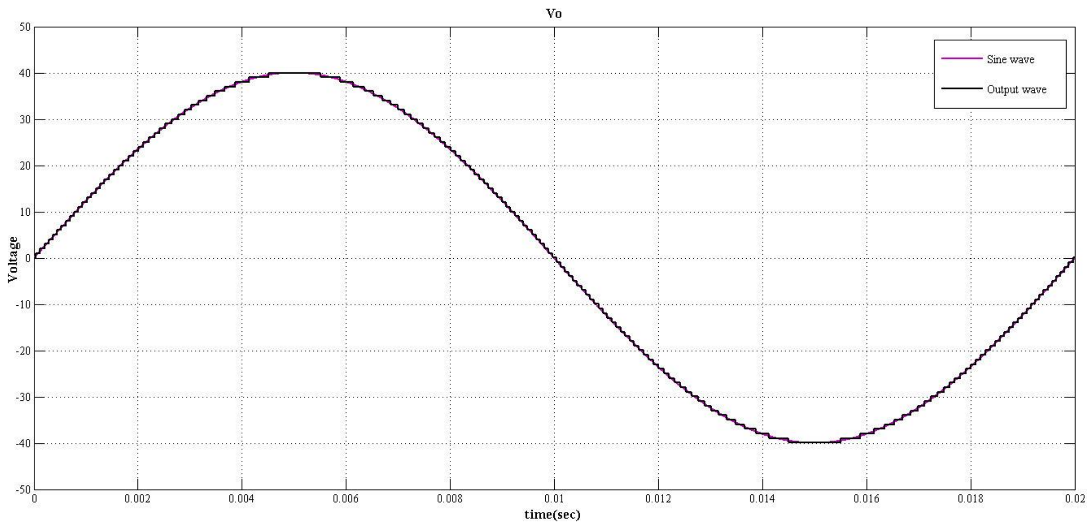

Figure 11 41-level output voltage waveform with AM

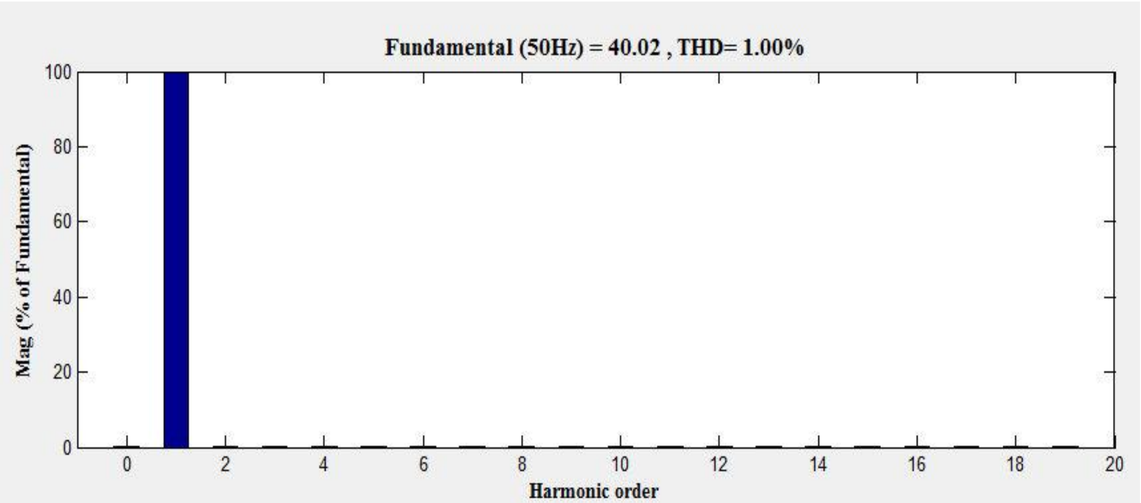

Figure 12 FFT analysis of 41-level inverter with AM.

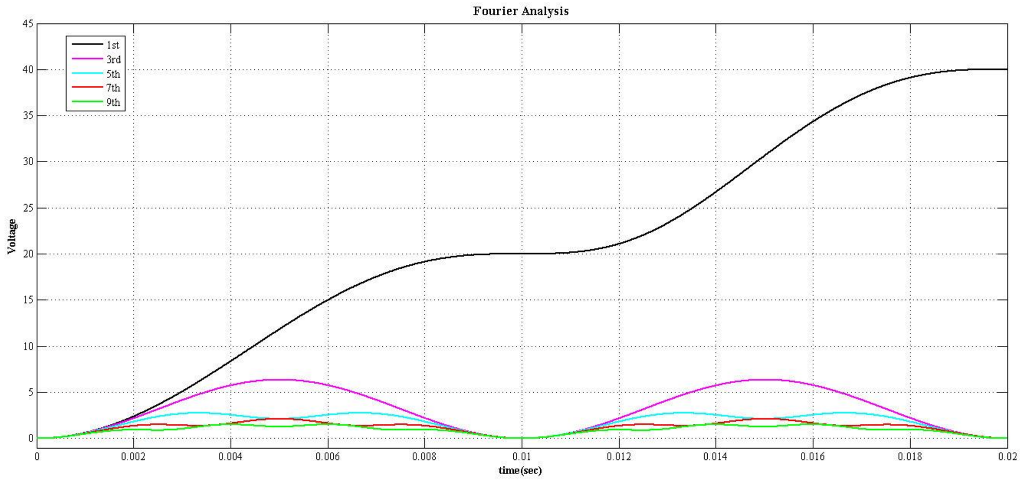

Figure. 13 Fourier analysis of 41-level inverter with AM.

From the above result is it can be concluded that as number of output voltage level is increased value of THD is reduced. In 41-level inverter THD is less than 1%. Percentage Total Harmonic Distortion analysis of cascaded H-Bridge multilevel inverter with different levels is shown in Table 2 below.

Table 2. % THD analysis with different levels of inverter

Cascaded H-bridge inverter (Levels)	% THD without using amplitude modulation	% THD using amplitude modulation technique
2 level	48.34	29.02
5 level	15.22	9.29
13 level	12.43	3.02
41 level	1	< 1

IV. CONCLUSION

In this paper multilevel inverters using amplitude modulation technique have been studied. The THD for different modulation strategy have been simulated and presented for different level inverters. The simulated results are presented in this paper and it is concluded that amplitude modulation technique gives good fundamental spectrum and reduced total harmonic distortion. As number of output voltage level increases, THD decreases. Conduction losses will be less as number of power semiconductor switches reduces. Overall cost is reduced as number of switches and power supplies are reduced. The application can be AC drives, Photovoltaic, Fuel Cells etc.

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