I J C T A, 9(14) 2016, pp. 6775-6785

Simulation and Analysis of Different Topologies of Multi Level Inverter

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ABSTRACT

Cascaded H-bridge multilevel converters can generate voltage waveforms with negligible waveform distortion. For high level multilevel inverters, the number of isolated sources and switching devices used by the cascaded H-bridge multilevel inverter is very high. This paper proposes an advanced cascaded H-bridge multilevel inverter which differs from the conventional one based on the number of isolated power sources and power switching devices used for high level inverter. The proposed twenty seven level and eighty one level asymmetrical cascaded H bridge multilevel inverters have minimum number of isolated sources and switching devices when compared to conventional cascaded H-bridge multilevel inverters. The circuit is simulated by using MATLAB/simulink software and the THD is analysed.

Keywords: Cascaded H-Bridge (CHB) multilevel inverter, Asymmetrical Cascaded H-Bridge (ACHB) multilevel inverter, THD.

1. INTRODUCTION

Power rating of the equipments used in modern industries have become in the range of megawatt level, corresponding to medium-voltage (2.3–13.8 KV) network. Now, the commercially available power semiconductor switches are not sufficient to connect directly to the medium-voltage grids. The arrival of multilevel converters can accommodate the commercially available semiconductor devices for the high-power applications [1].

The three level inverter is the basic level of multilevel inverter [2]. Now several multilevel inverter topologies have been developed. The topologies are categorized into three types as diode clamped multilevel inverter (neutral point clamped multilevel inverter), capacitor clamped multilevel inverter (flying capacitor multilevel inverter), cascaded h-bridge multilevel inverter (isolated series H-bridges) [3]. The fundamental concept of a multilevel inverter is to achieve higher power by using the series of power semiconductor switches with several lower voltage dc sources which perform the power conversion by synthesizing a staircase voltage waveform (near sinusoidal waveform). As more steps are added to the waveform, the harmonic distortion of the output wave decrease and almost approaching zero as the number of levels increases [4]. Capacitors, batteries and renewable energy voltage sources like wind, solar can be used as the dc voltage sources [1].

For medium-voltage high-power applications, multilevel converters have become an attractive solution. The diode clamped multilevel inverter is used in many conventional high-power ac motor drive applications like conveyors, pumps, fans and mills. It is also used in industries like oil and gas, metals, power, mining, water and marine. Flying capacitor multilevel inverters have been introduced and used successfully in high bandwidth–high switching frequency applications such as medium-voltage traction drives. Finally, the cascaded H-bridge multilevel inverters have got remarkable place in very high-power and power-quality demanding applications (up to a range of 31 MVA), because of its series expansion capability. This topology

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is implemented for active filter and reactive power compensation applications, electric and hybrid vehicles, photovoltaic power conversion, uninterruptible power supplies and magnetic resonance imaging [5].

The multilevel inverter is mainly used in two areas, i.e. large motor drives and power system applications. In large motor drives, it deals with a wide range of high power loads e.g. pumps in the petrochemical industry, fans in cement industry, traction in transportation industry, steel rolling mills in cement industry, blowers, compressors and conveyers, downhill conveyor system etc. In power system applications it is used in STATCOM, UPFC, power quality, power conditioners, reactive power compensators and grid connected systems [6].

The disadvantages of diode clamped multilevel inverter are the requirement of high speed clamping diodes which are subjected to severe reverse recovery stress, excessive numbers of diodes are required for high level inverter and difficult to do real power flow control because of capacitor voltage unbalance [7].

The disadvantages of flying capacitor multilevel inverter are the control of the whole circuit becomes complex because of the addition of DC link capacitor charge controller, for high level multilevel inverters more number of capacitors are needed which increases the complexity of total circuit [8].

The main advantages of cascaded H-bridge are the series structure allows a scalable, modularized circuit layout and packaging due to the identical structure of each H-bridge, no extra clamping diodes or voltage balancing capacitors are needed. Unfortunately, it has the disadvantage of requiring large number of isolated DC sources and switching devices for high level multilevel inverters [9], [10].

The disadvantage of cascaded H-bridge is overcome by using asymmetrical cascaded H-bridge inverter which can generate same number of levels with fewer power supplies. ACHB consists of a number of cascaded basic cells fed with DC voltages of different magnitudes. It can synthesize voltage waveforms with reduced harmonic content without increasing the number of switching devices and isolated sources. Hence, it is possible to reduce or even to eliminate output filters [11].

2. CASCADED H-BRIDGE MULTILEVEL INVERTER

The cascaded H-bridge multilevel inverter significantly increases the level of output voltage waveforms. Therefore the harmonic contents are reduced much while keeping low switching frequency and switching losses. As the number of voltage levels on the DC side increases, the synthesized output waveform adds more steps, producing a staircase wave which approaches the sinusoidal wave with minimum harmonic distortion [4]. This topology is efficient for small number of levels. For high level multilevel inverter the number of series connected H-bridges become more. Therefore, the required number of isolated DC sources and power switching devices are also high. So the generation of gating signals and control of the circuit becomes tedious and not cost effective. The cascaded H-bridge multilevel inverter circuit and associated waveform is given in Figure 1.

To construct single phase m-level cascaded H-bridge multilevel inverter the required number of sources and switches are given as,

No of main switching devices= 2(m-1)

No of main diodes= 2(m-1)

No of bridges = (m-1)/2

No of sources= No of bridges= No of DC bus capacitors

Where m= no. of levels

For single phase 27 levels CHB multilevel inverter,

No of main switching devices = 2(27-1) =52

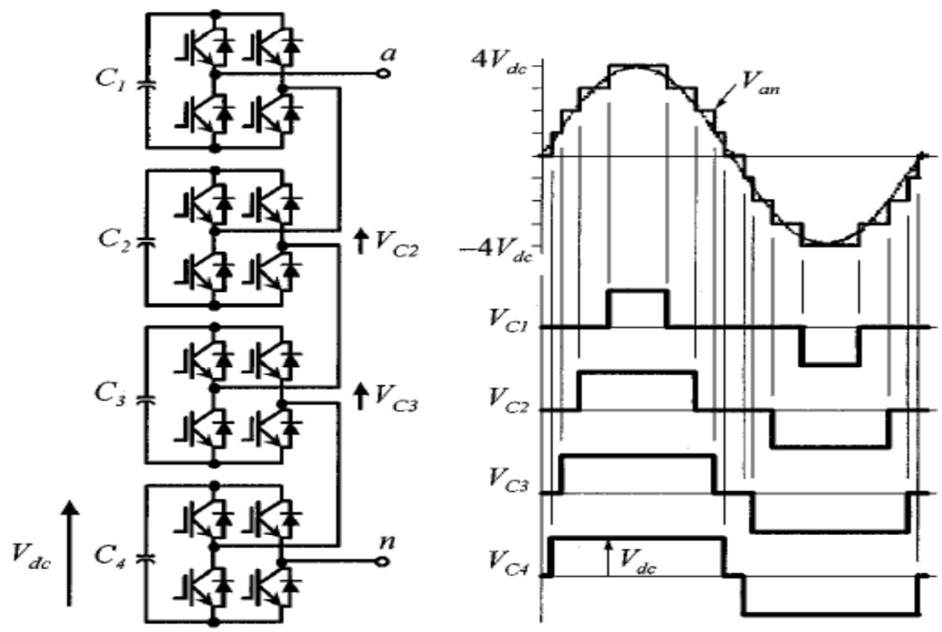

Figure 1: Cascaded H-bridge Multilevel Inverter Circuit and Associated Waveform

No of main diodes = 52

No of bridges= (27-1)/2 =13

No of sources = 13

No of DC bus capacitors= 13

For single phase 81 levels CHB multilevel inverter,

No of main switching devices = 2(81-1) =160

No of main diodes = 160

No of bridges= (81-1)/2 =40

No of sources= 40

No of DC bus capacitors= 40

By using high number of power switching devices and isolated DC sources will lead to more switching losses. Therefore, the output voltage waveform distortion becomes high i.e. THD becomes high. Each switching device needs separate snubber circuit for protection which makes the circuit more complex. The generation of gating signals for 160 power switching devices will be too complicate. By using large number of capacitors the circuit becomes large. Then the capacitors have to handle single phase pulsating power too [1].

3. PROPOSED TOPOLOGY

Advanced cascaded H-bridge multilevel inverter is known as asymmetrical cascaded H-bridge multilevel inverter. ACHB uses H-bridges fed with dc voltages of different magnitudes. ACHB which uses the larger dc source is called the MAIN bridge. When the dc voltages are scaled in powers of three, the MAIN bridge carries more than 80% of the total power and works at fundamental frequency. This will remarkably reduces the switching losses, improving the efficiency of the system. The rest of the H-bridges called Aux-bridges (auxiliary bridges) allows the generation of several voltage levels, reducing the total harmonic distortion

(THD) and common-mode voltages. Some advantages of these converters are the following: optimized number of levels, very low THD, reduced *dv/dt*, almost negligible common-mode voltage, smaller output filter, reduced volume and cost, better reliability and lower switching losses [9].

The main components of asymmetrical 27 level multilevel inverter (one phase) is shown in Figure 2. It has three H-bridges with different DC voltage sources in the range of 1:3:9. The drivers are used to control the semiconductor switches by using the signals from the controller. Similarly, for 81 levels multilevel inverter has four H-bridges with the DC voltage sources in the range of 1: 3: 9: 27.

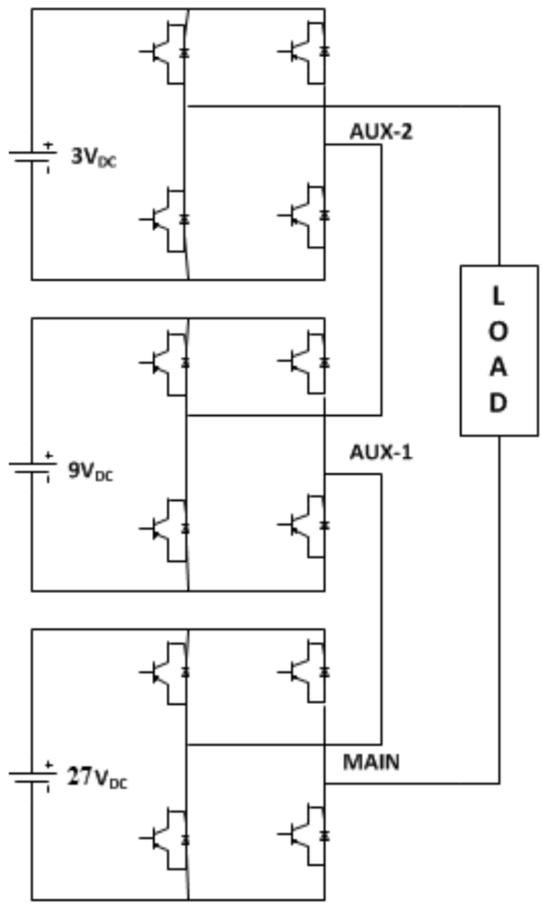

Figure 2: Main components of Asymmetrical 27 level Multilevel Inverter (one phase)

To construct single phase m-level asymmetrical cascaded H-bridge multilevel inverter,

No of levels = 3^{N+1}

Where N= No of Aux bridges.

To construct single phase 27-level asymmetrical cascaded H-bridge multilevel inverter,

No of bridges = 3

No of levels = 3^3 =27

No of sources =3

No of switching devices =12

Similarly, to construct single phase 81-level asymmetrical cascaded H-bridge multilevel inverter,

No of bridges = 4

No of levels = 3^4 =81

No of sources = 4

No of switching devices =16

To produce the same 27 level output and 81 level output the asymmetrical cascaded H-bridge multilevel inverter needs only 12 switching devices with three DC sources and 16 switching devices with four DC sources respectively. But by using cascaded H-bridge multilevel inverter, to produce 27 level output and 81 level output needs 52 switching devices with 13 DC sources and 160 switching devices with 40 DC sources respectively. So the complexity of the circuit and switching losses are reduced by implementing asymmetrical cascaded H-bridge multilevel inverter when compared to cascaded H-bridge multilevel inverter. In this paper the gating signals of the switches are given by using pulse generator. The switching state is given in Table 1. By using this switching states, the switching pattern for all switches have been drawn. It has many pulses. For each pulse separate pulse generator is used. From this the gating signals for each switch is obtained and given to the switches.

Consider in each cell the upper switches are positive and the lower switches are negative. Switching state N denotes the negative state voltage, P denotes the positive state voltage and 0 denotes the zero state voltage. The zero voltage occurs in a cell when either both the upper switches or both the lower switches are in ON condition.

Table 1
Switching states of Multilevel Inverter for 27 level

VOLTAGE LEVEL	$V_1(3V_{DC})$	$V_2(9V_{DC})$	$V_3(27V_{DC})$	*VOLTAGE LEVEL*	$V_1(3V_{DC})$	$V_2(9V_{DC})$	$V_3(27V_{DC})$
$-13V_{DC}$	N	N	N	$+13V_{DC}$	P	0	0
$-12V_{DC}$	0	N	N	$+12V_{DC}$	N	P	0
$-11V_{DC}$	P	N	N	$+11V_{DC}$	0	P	0
$-10V_{DC}$	N	0	N	$+10V_{DC}$	P	P	0
$-9V_{DC}$	0	0	N	$+9V_{DC}$	N	N	P
$-8V_{DC}$	P	0	N	$+8V_{DC}$	0	N	P
$-7V_{DC}$	N	P	N	$+7V_{DC}$	P	N	P
$-6V_{DC}$	0	P	N	$+6V_{DC}$	N	0	P
$-5V_{DC}$	P	P	N	$+5V_{DC}$	0	0	P
$-4V_{DC}$	N	N	0	$+4V_{DC}$	P	0	P
$-3V_{DC}$	0	N	0	$+3V_{DC}$	N	P	P
$-2V_{DC}$	P	N	0	$+2V_{DC}$	0	P	P
$-1V_{DC}$	N	0	0	$+1V_{DC}$	P	P	P
$0V_{DC}$	0	0	0				

4. SIMULATION AND RESULTS

The simulation is done by using MATLAB/SIMULINK. The simulation of single phase 27 level asymmetrical cascaded H-bridge inverter is shown in Figure 3. It needs 12 main switching devices, 12 main diodes, 3 DC sources which makes the circuit too simple. The output of Aux-2 bridge in 27 level ACHB multilevel inverter is given in Figure 4. The output of Aux-1 bridge in 27 level ACHB multilevel inverter is given in Figure 5. The output of MAIN bridge in 27 level ACHB multilevel inverter is given in Figure 6. The output of 27 level ACHB multilevel inverter without filter is given in Figure 7. The output of 27 level ACHB multilevel inverter with filter is given in Figure 8.

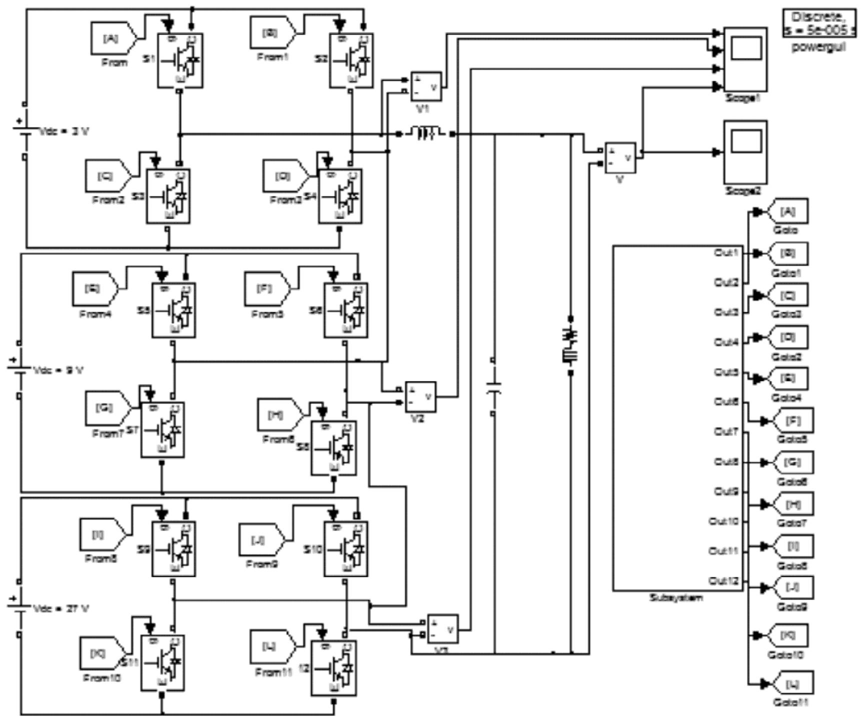

Figure 3: Simulation of single phase 27 level asymmetrical cascaded H-bridge multilevel inverter

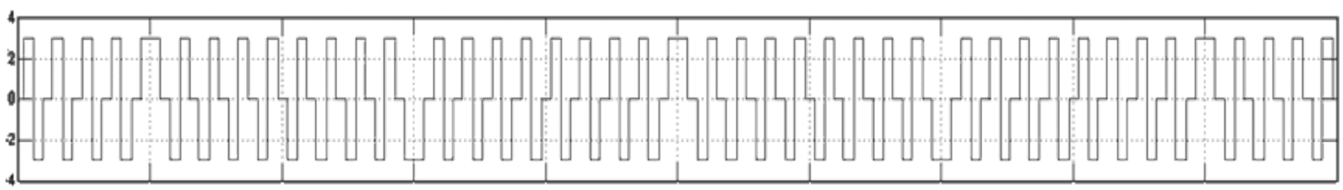

Figure 4: Output Voltage of *Aux-2* Bridge in 27 level asymmetrical cascaded H-bridge multilevel inverter

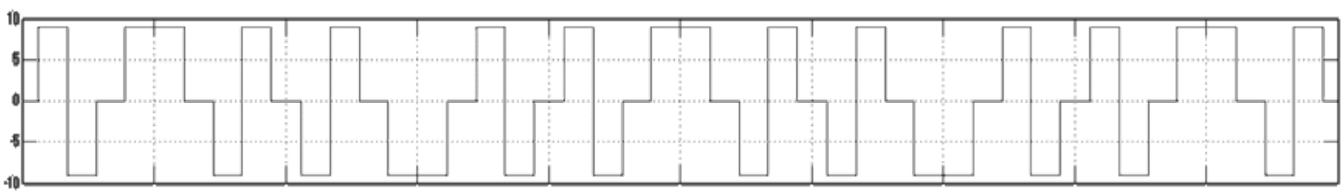

Figure 5: Output Voltage of *Aux-1* Bridge in 27 level asymmetrical cascaded H-bridge multilevel inverter

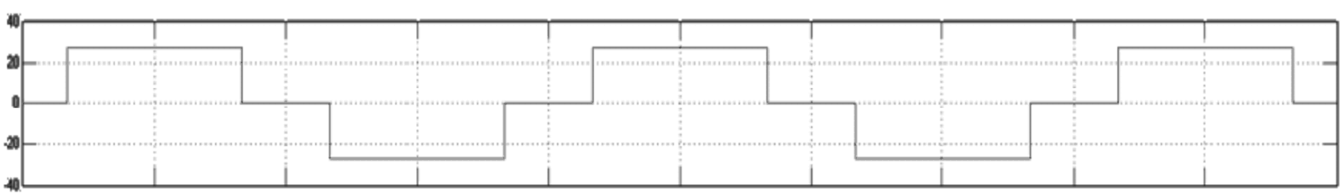

Figure 6: Output Voltage of *Main* Bridge in 27 level asymmetrical cascaded H-bridge multilevel inverter

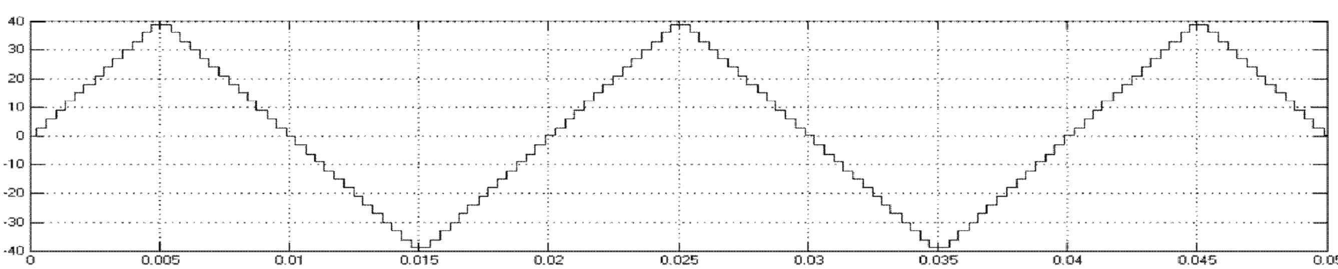

Figure 7: Output Voltage 27 level asymmetrical cascaded H-bridge multilevel inverter without filter

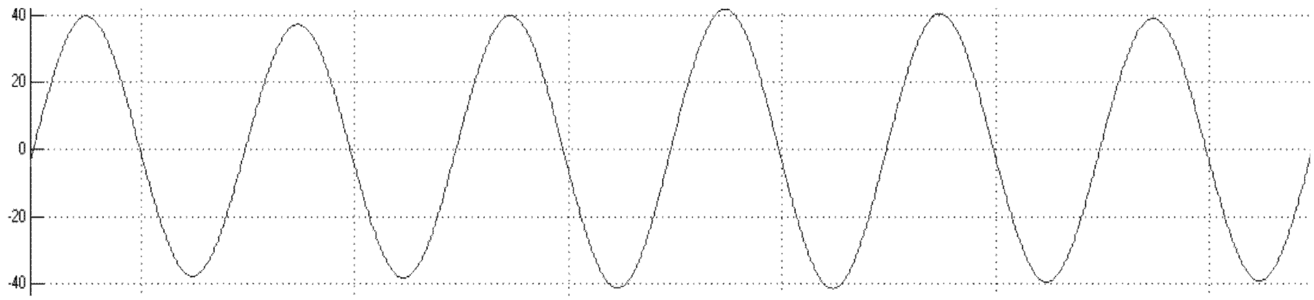

Figure 8: Output Voltage 27 level asymmetrical cascaded H-bridge multilevel inverter with filter

The simulation of single phase 81 level asymmetrical cascaded H-bridge inverter is shown in Figure 9. The simulation of single phase 81 level asymmetrical cascaded H-bridge inverter needs 16 main switching devices, 16 main diodes, 4 DC sources which makes the circuit too simple. The output of Aux-3 bridge in 81 level ACHB multilevel inverter is given in Figure 10. The output of Aux-2 bridge in 81 level ACHB multilevel inverter is given in Figure 11. The output of Aux-1 bridge in 81 level ACHB multilevel inverter is given in Figure 12. The output of MAIN bridge in 81 level ACHB multilevel inverter is given in the Figure 13. The output of 81 level ACHB multilevel inverter without filter is given in Figure 14. The output of 81 level ACHB multilevel inverter with filter is given in Figure 15.

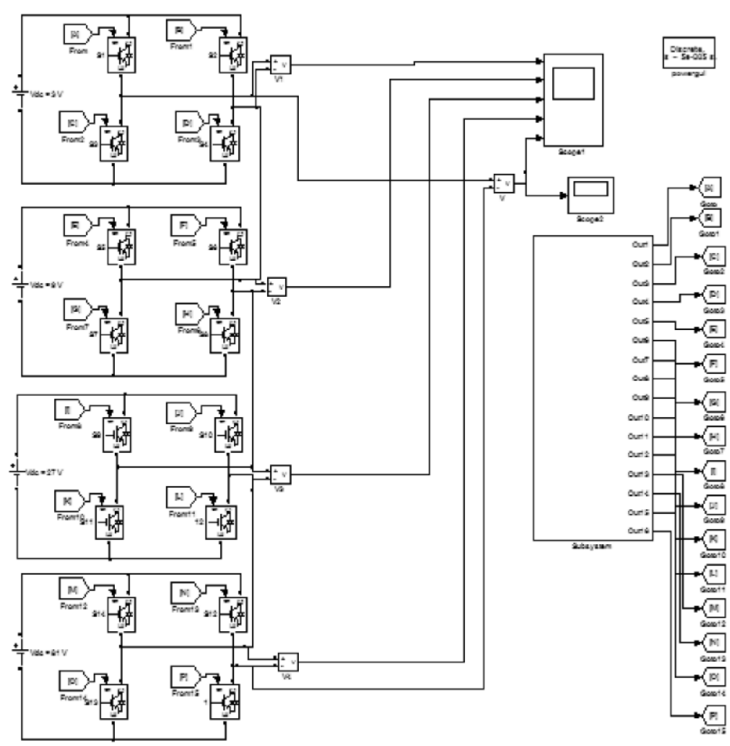

Figure 9: Simulation of single phase 81 level asymmetrical cascaded H-bridge multilevel inverter

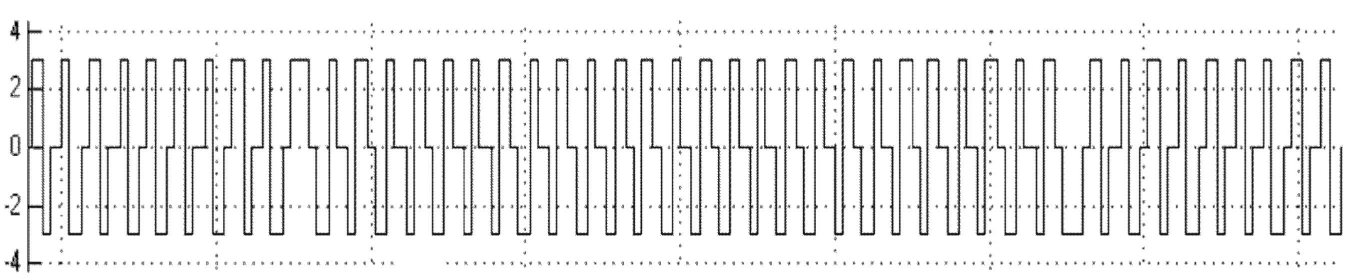

Figure 10: Output Voltage of *Aux-3* Bridge in 81 level asymmetrical cascaded H-bridge multilevel inverter

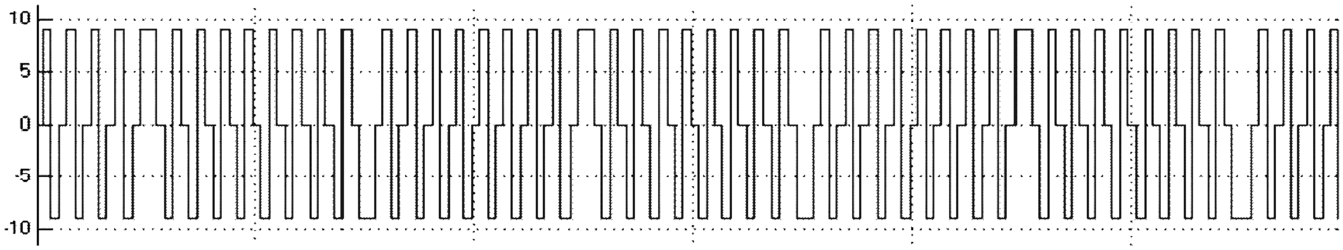

Figure 11: Output Voltage of *Aux-2* Bridge in 81 level asymmetrical cascaded H-bridge multilevel inverter

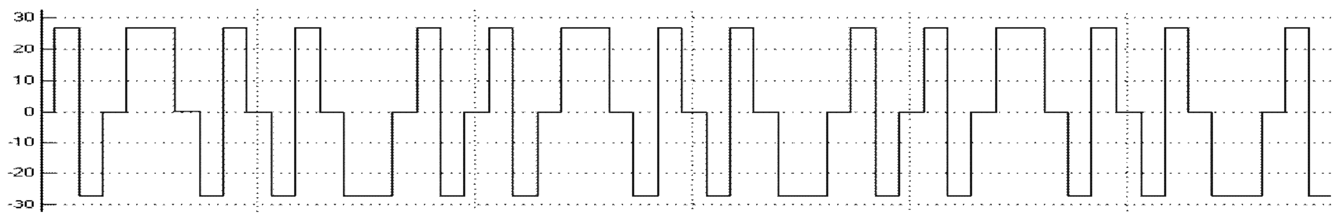

Figure 12: Output Voltage of *Aux-1* Bridge in 81 level asymmetrical cascaded H-bridge multilevel inverter

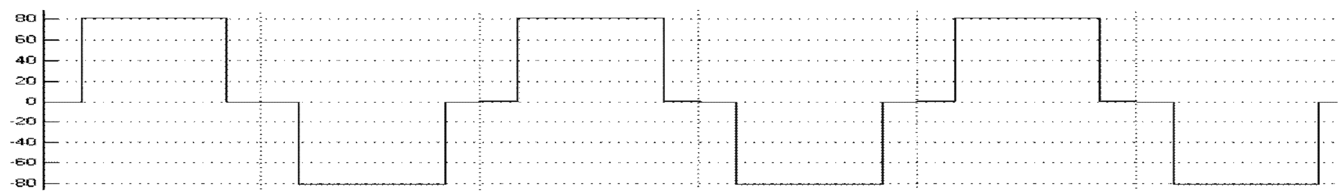

Figure 13: Output Voltage of MAIN Bridge in 81 level asymmetrical cascaded H-bridge multilevel inverter

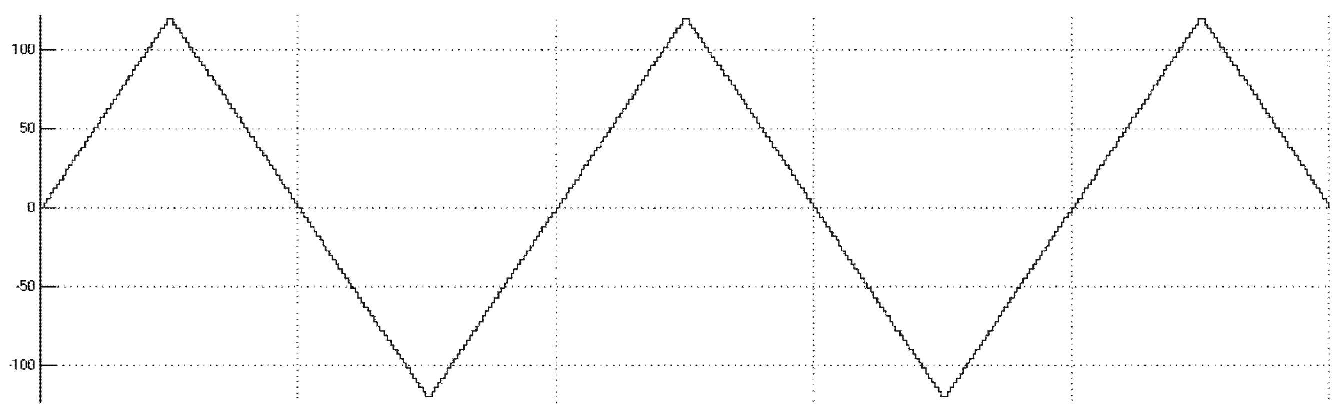

Figure 14: Output Voltage 81 level asymmetrical cascaded H-bridge multilevel inverter without filter

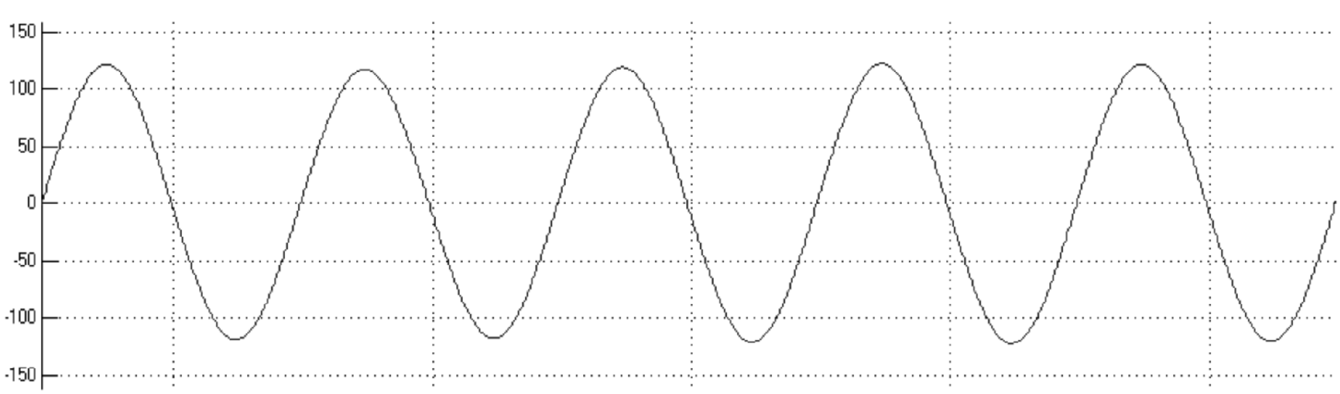

Figure 15: Output Voltage 81 level asymmetrical cascaded H-bridge multilevel inverter with filter

5. THD ANALYSIS

THD analysis is carried out for both the levels. For 27 level ACHB multilevel inverter the THD obtained is 8.98%. The THD for 81 level ACHB multilevel inverter is 6.07%. The THD is reduced when we go to higher level in multilevel inverter.

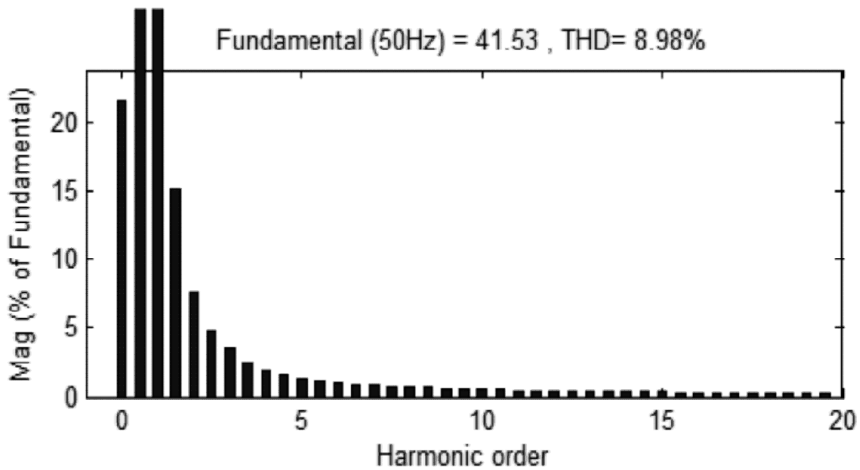

Figure 16: THD analysis of 27 level asymmetrical cascaded H-bridge multilevel inverter

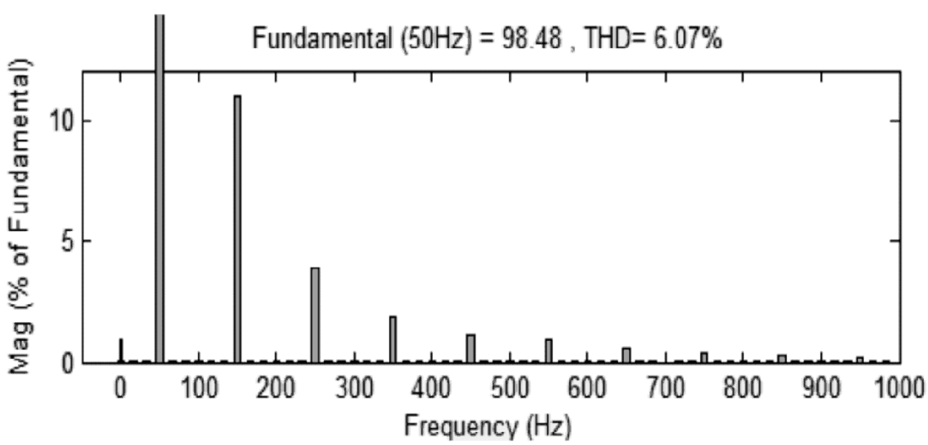

Figure 17: THD analysis of 81 level asymmetrical cascaded H-bridge multilevel inverter

6. COMPARISON

The comparison of CHB & ACHB multilevel inverter for 27 level & 81 level is carried out in Table 2. From this table we may conclude that the switching devices, DC sources and THD are very low in ACHB multilevel inverter for higher level when compared to CHB.

Table 2
Comparison of CHB & ACHB multilevel for 27 level & 81 level

Items	*27 Level CHB Multi Level Inverter*	*27 Level ACHB Multi Level Inverter*	*81 Level CHB Multi Level Inverter*	*81 Level ACHB Multi Level Inverter*
Switching Devices	52	12	160	16
Main Diode	52	12	160	16
DC Sources	13	3	40	4
THD	12.54%	8.98%	8.54%	6.07%

From the Figure 18 it is showed that the switching devices used for 27 level ACHB multilevel inverter is almost 77% reduced and for 81 level ACHB multilevel inverter is almost 90% reduced when compared to CHB multilevel inverter. This reduces the losses and cost efficient when compared to CHB multilevel inverter.

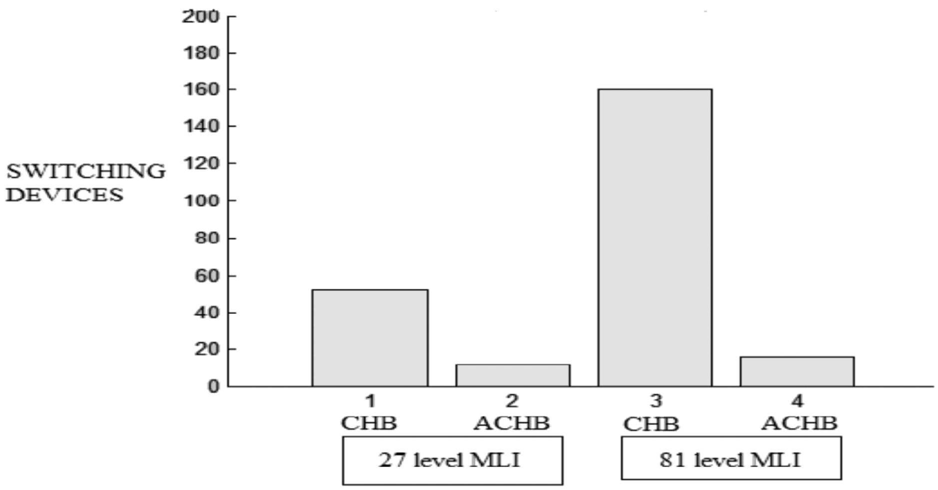

Figure 18: Comparison of switching devices for various MLI topologies

The DC sources used in the proposed system are reduced immensely than the conventional system which is shown in Figure 19. So the necessity of large number of sources is drastically reduced.

Figure 20 shows the THD of CHB & ACHB multilevel inverter for 27 level and 81 level. THD is reduced preferably by using ACHB multilevel inverter.

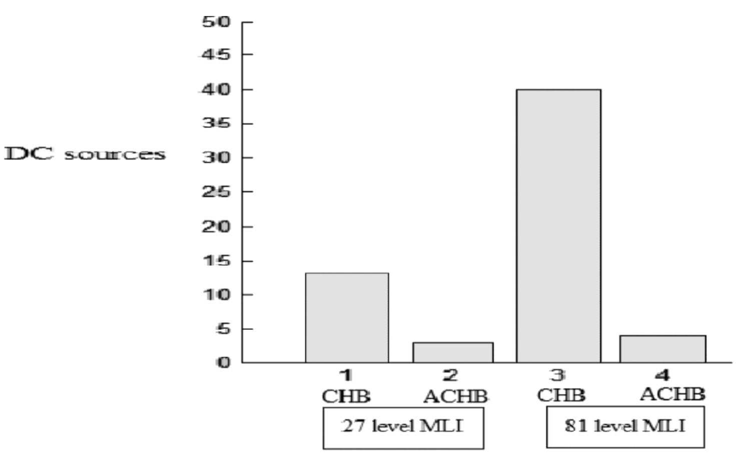

Figure 19: Comparison of DC sources used for various MLI topologies

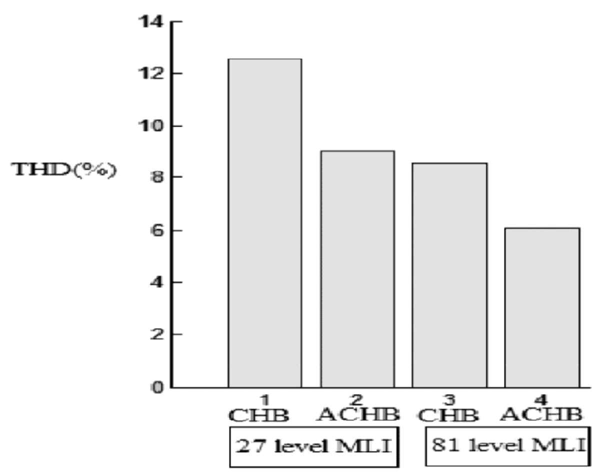

Figure 20: Comparison of THD for various MLI topologies

7. CONCLUSION

The main advantage of asymmetrical multilevel inverter is the optimization of levels with a minimum number of power supplies and switching devices. An asymmetric cascaded multilevel inverter topology based on less number of isolated sources and switching devices for 27 level and 81 level has been proposed, implemented and proven. The proposed solution allows a reduction in large number of power supplies and switching devices needed by the CHB inverter to produce the same voltage level. The single phase 27 level CHB inverter needs 13 H-bridges and 52 switching devices which makes the circuit more complex and not cost effective. But the single phase 27 level ACHB inverter needs only 3 H-bridges and 12 switches which reduces the complexity. Similarly, the single phase 81 level CHB inverter needs 40 H-bridges and 160 switching devices which makes the circuit more complex and not cost effective. But the single phase 81 level ACHB inverter reduces the complexity by using only 4 DC sources and 16 switches. By using ACHB multilevel inverter the number of isolated sources and switches are reduced when compared to CHB multilevel inverter. THD is also reduced by using ACHB multilevel inverter when compared to CHB multilevel inverter.

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