

Nine Level Cascaded H-Bridge Inverter with Boost Converter

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Abstract—The concept of utilizing multiple small voltage levels to perform power conversion was patented by an MIT researcher over twenty years ago. Advantages of this multilevel approach include good power quality, good electromagnetic compatibility (EMC), low switching losses, and high voltage capability. They typically synthesize the stair –case voltage waveform (from several dc sources) which has better harmonic spectrum. This paper targets to outspread the information about the working of nine level Cascaded H-Bridge MLI topology with DC/DC Boost Converter for constant DC Source. The output voltage is the sum of the voltage that is generated by each bridge. The switching angle employs Sinusoidal Pulse Width Modulation technique. With this method THD is curtailed. This configuration incorporates Boost Converter in the input side which augments the fundamental output voltage. It also has output filter and thus resultant wave is nearer to the sine wave. Outcomes are verified and observed that yields efficiency around 85%. The analysis of proposed topology has premeditated successfully by using MATLAB/Simulink.

Index Terms— Multi level Inverter (MLI), Pulse Width Modulation (PWM), Cascaded H-Bridge (CHB), Total Harmonic Distortion (THD).

I. INTRODUCTION

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilization. It has found an important place in modern technology being core of power and energy control. It is the technology associated with efficient conversion, control and conditioning of electric power from its available input into the desired output form.

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for a high power application.

The concept of multilevel converters has been introduced since 1975 [4]. The term multilevel began with the three-level converter [5]. Subsequently, several multilevel converter topologies have been developed [6-13]. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a

staircase voltage waveform The simplest dc voltage source for a VSI may be a battery bank, which may consist of several cells in series-parallel combination. Solar photovoltaic cells can be another dc voltage source. A voltage source is called stiff if the source voltage magnitude does not depend on load connected to it. All voltage source inverters assume stiff voltage supply at the input. In fact, the concept is so advantageous that several major drive manufacturers have obtained recent patents on multilevel power converters and associated switching techniques. It is evident that the multilevel concept will be a prominent choice for power electronic systems in future years. Moreover, abundant modulation techniques and control paradigms have been developed for multilevel converters such as sinusoidal pulse width modulation (SPWM), selective harmonic elimination (SHE-PWM), space vector modulation (SVM), and others. In addition, many multilevel converter applications focus on industrial medium-voltage motor drives [7], utility interface for renewable energy systems [8], Universal Power Conditioner [9] and traction drive systems [10]

II. STUDY OF CASCADED H BRIDGE MULTILEVEL INVERTER

Numerous industrial applications have begun to require higher power apparatus in recent years. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed [6-13]. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform.

The attractive features of a multilevel converter can be briefly summarized as follows.

- Harmonic content decreases as the number of levels increases thus reducing the filtering requirements
- The switching disservices do not encounter any voltage sharing problems. Thus MLI can easily applied for high power applications such as large motor drivers and utility supplies.
- They have higher efficiency because the devices can be switched at Low frequency.
- **Staircase waveform quality:**

Multilevel converters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt .

- **Absence of Capacitor:** It does not need any capacitors or diodes for clamping stresses .

III . NINE LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER STRUCTURE

Conventional cascaded multilevel inverters are one of the most important topologies in the family of multilevel and multi-pulse inverters. The cascade topology allows the use of several levels of DC voltages to synthesize a desired AC voltage. The DC levels are considered to be identical since all of them are fuel cells or photovoltaics, batteries, etc. [20]. It requires least number of components compared to diode-clamped and flying capacitors type multilevel inverters and no specially designed transformer is needed as compared to multi pulse inverter.

Since this topology consist of series power conversion cells, the voltage and power level may be easily scaled. The concept of this inverter is based on connecting H-bridge inverters in series to get a sinusoidal voltage output. The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are $2n+1$, where n is the number of cells. The switching angles can be chosen in such a way that the total harmonic distortion is minimized.

An n level cascaded H-bridge multilevel inverter needs $2(n-1)$ switching devices where n is the number of the output voltage level.

Cascade topology proposed in [21] uses multiple dc levels, which instead of being identical in value are multiples of each other. It also uses a combination of fundamental frequency switching for some of the levels and PWM switching for part of the levels to achieve the output voltage waveform. This approach enables a wider diversity of output voltage magnitudes; however, it also results in unequal voltage and current ratings for each of the levels and loses the advantage of being able to use identical, modular units for each level.

IV. THE PROPOSED MULTILEVEL INVERTER

The single phase cascaded nine level inverter topology [22] has been proposed in Fig.1 .The circuit consists of sixteen main switches in four series connected H-bridge configuration S1~S4, S5~S8, S9~S12 and S13~S16. The

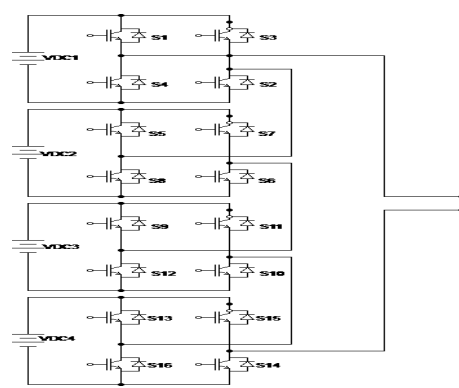


Fig.1 Nine level CHB inverter

number of dc sources are four so the output voltage of the cascaded multilevel inverter is $V_o = V_1 + V_2 + V_3 + V_4$. The output waveforms of multilevel inverters are in a stepped waveform therefore they have reduced harmonics compared to a square wave inverter.

Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H- bridge inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1 , S_2 , S_3 , and S_4 . To obtain $+V_{dc}$, switches S_1 and S_2 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_3 and S_4 . By turning on S_1 and S_2 or S_3 and S_4 , the output voltage is 0. Similarly S_5 and S_6 for $+V_{dc}$, switches S_7 and S_8 are turned on for $-V_{dc}$. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. As given below

TABLE I. THE SWITCHING STATES OF NINE LEVEL CHB

Switches Turn On	Voltage Level
S_1, S_2	$+V_{dc}$
S_1, S_2, S_5, S_6	$+2V_{dc}$
$S_1, S_2, S_5, S_6, S_9, S_{10}$	$+3V_{dc}$
$S_1, S_2, S_5, S_6, S_9, S_{10}, S_{13}, S_{14}$	$+4V_{dc}$
$S_4, S_3, S_8, S_7, S_{12}, S_{11}, S_{16}, S_{15}$	0
S_3, S_4	$-V_{dc}$
S_3, S_4, S_7, S_8	$-2V_{dc}$
$S_3, S_4, S_7, S_8, S_{11}, S_{12}$	$-3V_{dc}$
$S_3, S_4, S_7, S_8, S_{11}, S_{12}, S_{15}, S_{16}$	$-4V_{dc}$

A single-phase structure of a nine level cascaded inverter with DC/DC boost converter is illustrated in Figure 3. The operation of this topology is as same as conventional 9-level CHB, difference lies in the voltage level which is due to presence of DC/DC boost converter which boost the input voltage to the designed value.

V. DESIGN OF PROPOSED TOPOLOGY

A. DC/DC Boost converter

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer [23]. The main components of a boost converter are an inductor, a diode and a high frequency switch as shown in fig 3. These in a coordinated manner supply power to the load at a voltage greater than the input voltage magnitude.

Inductor Selection

Often data sheets give a range of recommended inductor values. If this is the case, it is recommended to choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current. The lower the inductor value, the smaller is the solution size.

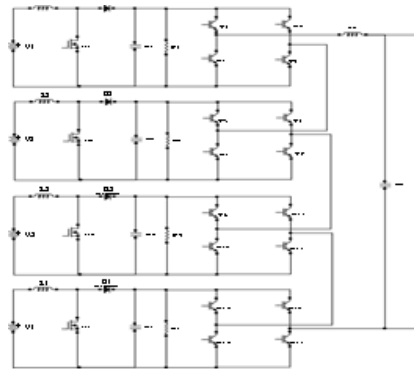
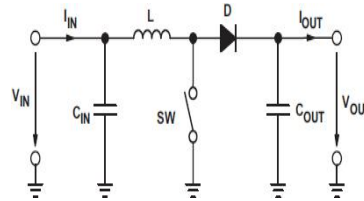


Fig.2 Nine-level CHB MLI with DC/DC Boost Converter



The following equation [36] is a good estimation for the right inductor:

$$L = \frac{V_i \cdot (V_o - V_i)}{F_s \cdot V_o \cdot \Delta I_L} \quad \dots\dots\dots (1)$$

Rectifier Diode Selection

To reduce losses, Schottky diodes should be used. The forward current rating needed is equal to the maximum output current.

$$I_F = I_{OUT(max)} \quad \dots\dots\dots (2)$$

I_F = average forward current of the rectifier diode

$I_{OUT(max)}$ = maximum output current necessary in the application

Output Capacitor Selection

Best practice is to use low ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice.

$$C_b = \frac{P_o}{\omega V_o} \quad \dots\dots (3)$$

P_o = output power; C_b = input capacitor

For a good practice choose C_f = 4-5% of C_b

Here input voltage is $12+12+12+12=48V$. Due to the presence of DC/DC boost Converter voltage will increase to $48+48+48+48=192V$.

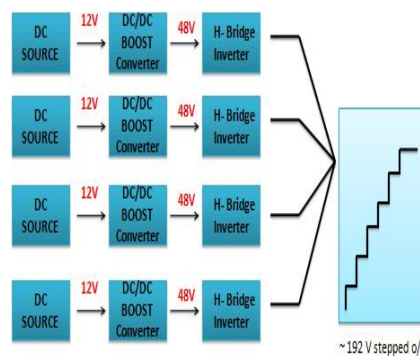


Fig.4 Nine level CHB MLI – with DC/DC Boost Configuration and Filter

B. Measured parameters

TABLE II. DC/DC BOOSTED 9 LEVEL INVERTER PARAMETERS

1.	Input voltage	48V
2.	Output voltage	165V
3.	Input current	13.3A
4.	Output current	3.25A
5.	Input power	$48 * 13.33 = 625W$
6.	Output power	$165 * 3.25 = 528W$

$$\% \eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{528}{625} = 85.50 \%$$

C. firing pulse analysis

Pulse-width modulation (PWM) is the basis for control in power electronics. The theoretically zero rise and fall time of an ideal PWM waveform represents a preferred way of driving modern semiconductor power devices. With the exception of some resonant converters, the vast majority of power electronic circuits are controlled by PWM signals of various forms. Although other considerations, such as parasitic ringing and electromagnetic interference (EMI) emission, may impose an upper limit on the turn-on and turn-off speed in practical situations, the resulting finite rise and fall time can be ignored in the analysis of PWM signals and processes in most cases. Here analysis is done by Sinusoidal PWM technique.

Specifications: Type; SPWM

Carrier frequency = 3KHz Operating Frequency = 50Hz, Gain = K = 6500

Phase delay = 0, $-\pi/3$

VI. SIMULATION RESULTS

A. Modeling of CHB MLI

Fig.5 shows the Matlab/Simulink Model of nine level Cascaded H-Bridge MLI with DC/DC Boost Converter. Each H-bridge DC voltage is 12 V. Hence total input is 48 volts

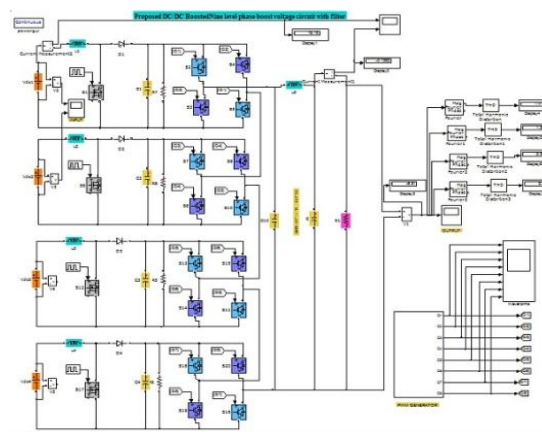


Fig.5 DC/DC Boosted Nine level Inverter with Filter

Fig.6 shows the Matlab/Simulink pulse generator model. The Switches are turned ON and turned OFF with a phase delay and respectively. Fig.6 shows Simulated Reference and Carrier Wave.

Fig.8 shows the Matlab/Simulink model Boosted 9-level CHB MLI output voltage without filter, having Magnitude of 192V in staircase (stepped) AC, to get pure sine wave an LC filter is added which is shown in figure 9

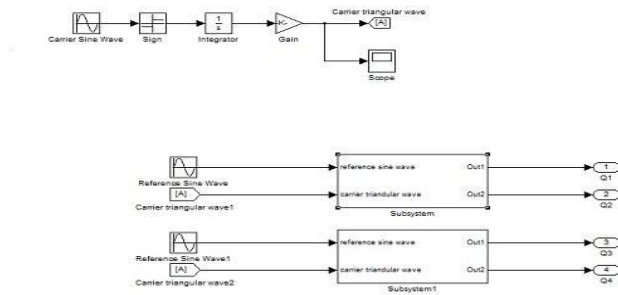


Fig. 6 Pulse Generator Model

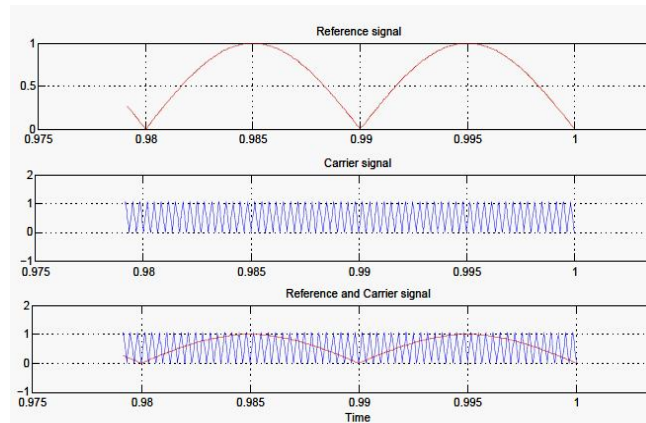


Fig.7 Simulated Reference and Carrier Wave

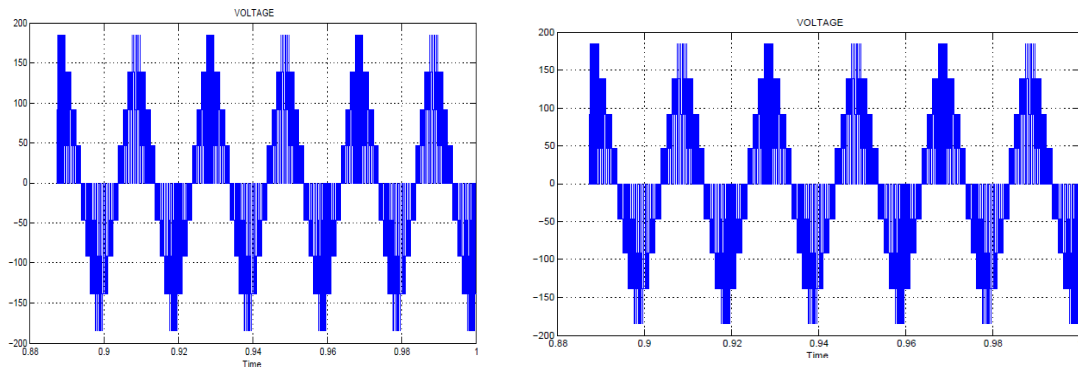


Fig. 8 Basic nine level CHB MLI output voltage

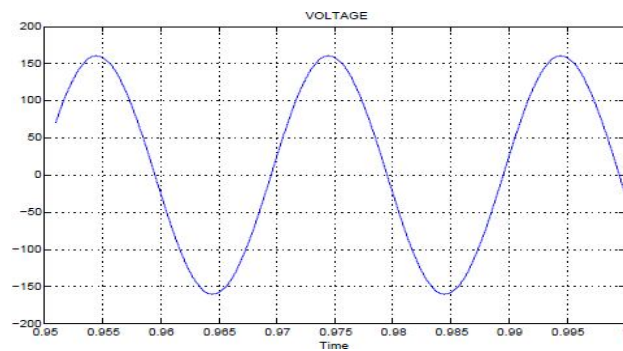


Fig. 9 Basic Nine level CHB MLI output voltage with DC/DC boost converter and filter

B. THD Analysis

Total harmonic distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave. In this method the switching angles for switches should be calculated in such a way that the dominant harmonics are eliminated (minimized). The THD will be decreased by increasing the number of levels. It is obvious that an output voltage with low THD is desirable, but increasing the number of levels needs more hardware, also the control will be more complicated.

It is a tradeoff between price, weight, complexity and a very good output voltage with lower THD.

$$\% THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + V_6^2 + \dots + V_n^2}}{V_1} * 100 \dots (4)$$

Where V_1 = Fundamental Voltage magnitude

V_2 = Magnitude of 2nd Harmonic

V_3 = Magnitude of 3rd Harmonic

V_n = Magnitude of nth Harmonic

The formula above shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

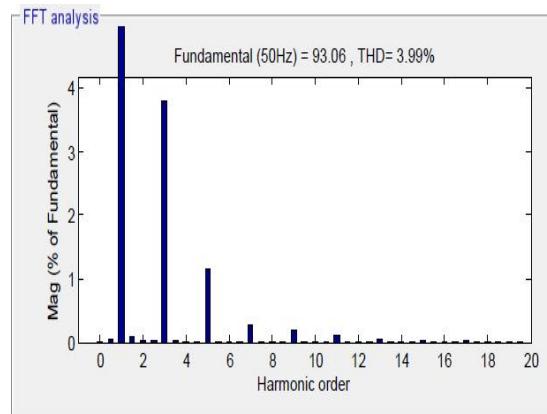


Fig.10 %THD of DC/DC Boosted Nine level Inverter with filter

VII. CONCLUSION

It has been observed from the simulation results that the overall efficiency of the developed nine level inverter is 85% which is more than the conventional DC to AC inverter. The two-level inverter has the lowest cost and weight in comparison with the other topologies. But it has very high THD and it is not practical to have an output voltage with high such THD. The design of the 9-level multilevel inverter seems to be better than the 13-level multilevel inverters. By increasing the number of levels, the cost and weight of the multilevel inverter will be increased. So this topology is well suited for industrial drives.

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