An Efficient Cascade H-Bridge Multilevel Inverter for Power Applications

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Abstract: Multilevel inverter as compared to single level inverters have advantages like minimum harmonic distortion, reduced Electro Magnetic Interference (EMI/RFI) generation and can operate on several voltage levels. In this paper a new topology of cascaded multilevel inverter using reduced number of switches, resulting in higher output voltage levels is proposed. There are five series connected H-bridges and the DC voltage is given in the ratio n^0: n: n^3: $2n^3$: 10n. The output voltage having 123 levels is obtained (61 positive voltage levels, 61 negative voltage levels and zero voltage level). The reduced Total Harmonic Distortion (THD) makes them useful for electric vehicle, flexible AC transmission and has the potential for various power applications. The proposed topology results in reduction of installation area, cost and has simplicity of control system.

Key words: *Cascaded H- Bridge Multilevel Inverter (CMLI), Total Harmonic Distortion (THD), Power Quality, Switching Losses*

I. INTRODUCTION

Multilevel inverters have attracted much research interest, particularly in high power applications. The advantages of using multilevel inverters are twofold. Firstly the voltage stress across each converter will get reduced because of its series connection of power semiconductor modules, making the inverters suitable for high voltage applications. Secondly the quality of the generated voltage increases with the number of voltage levels. Therefore the resolution of the waveform will get increased and the filtering efforts can be reduced as a result of   the improved resolution in the voltage harmonic content.

Several multilevel inverter topologies have been proposed in the literature and the most popular among them are diode clamped[5], flying capacitor[6] and cascaded H-bridge structure[7]. Diode clamped inverter needs more complex PWM controls because more capacitors and diodes are necessary for generating output levels and adjusting the balance of each DC-link voltage of the capacitor. When the flying capacitor multilevel inverter is applied, the circuit can consist of relatively less elements. However, the volume of the system is enlarged for the necessity of more capacitors.

In the case of the cascaded H-bridge multilevel inverter, each low voltage H-bridge module has an independent DC-link voltage source. Control and operation of this inverter are simple and and have robust structure than mentioned inverters. The number of output phase voltage levels is defined by n = 2N+1, where N is the number of DC sources. The CHB needs several independent DC sources which may be obtained from batteries, fuel cells or solar cells. Through different combinations of the four switches of each cell, each converter module can generate three different voltage outputs $+V_{dc}$, 0, $-V_{dc}$. The AC output from the cascaded multilevel inverter is the sum of the individual converter outputs.

The standard eleven level inverter consists of five H-bridges connected in series and the DC voltage is supplied in symmetrical ratio. In the proposed paper, an improved cascade multilevel inverter with same number of switches with separate DC voltage sources is examined. The voltage ratio given to the inverter module is n^0: n: n^3: $2n^3$: 10n,(n=3) and 123 output voltage levels is obtained, therefore the proposed system presents higher output voltage levels with reduced number of switches. This efficient cascaded multilevel inverter is developed to reduce the total harmonic distortion in power applications.

In the proposed system the output voltage level is increased with reduced number of switches. Since each bridge has the same structure, the series structure allows a scalable, modularized circuit layout and packaging. Therefore it can reduce the installation area and the cost. Also switching redundancy in inner voltage level is possible because the phase voltage output is the sum of each bridges output. Potential of electrical shock is reduced due to separate DC sources and requires less number of components when compared to other two topologies.

Section II deals with the operation of new hybrid cascaded multilevel inverter. Section III discusses about the modulation scheme needed to get the 123 output voltage levels. Section IV focuses on the triggering

pulses given to the circuit and the simulation results. Simulation is done based on the MATLAB/SIMULINK software. Section V deals with the conclusion part.

II.   NEW HYBRID CASCADED H-BRIDGE MULTILEVEL INVERTER

In this figure 1, it shows the inverter leg of a 11-level cascade inverter. Five identical inverter modules are connected in series to form a single-phase 11-level inverter. All modules are fed by DC voltage sources of the same magnitude. The output voltage has 11 voltage levels from -5 Vp.u. to +5 Vp.u.. By using DC voltage sources with a magnitude ratio of n^0: n: n^3: $2n^3$: 10n, the traditional eleven-level inverter can be evolved as a 123-level inverter.
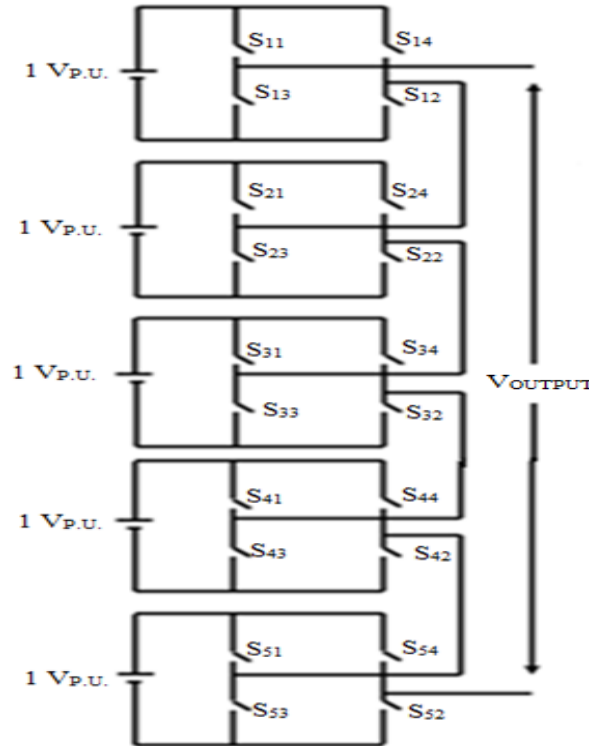

Fig. 1 Schematic of a single-phase cascaded eleven level inverter

Figure 2 shows the schematic of the new proposed 123-level inverter for a single-phase system. This circuit topology is identical to that of a traditional eleven-level inverter, except that unequal separate voltages are employed. By using the separate DC voltage sources with the ratio of n^0: n: n^3: $2n^3$: 10n and by controlling the switching of the cascade inverter modules, 123 discrete voltage levels (from 61Vp.u to -61 Vp.u.) can be generated.

For positive and negative voltage generation, switches SN1, SN2 and SN3, SN4 respectively are turned on in each inverter module, where subscript denotes the Nth inverter module. The inverter consists of twenty IGBT switches and five separate DC sources with a load. By switching the IGBT's at appropriate firing angles, it can obtain the 123 level output voltage. The improved characteristics of IGBT have resulted in higher switching speed and lower energy losses. One important thing which sets the cascaded H-bridge apart from other multilevel inverters is the capability of utilizing separate DC sources on the individual H-bridge cells which results in splitting the power conversion among higher- voltage lower frequency and lower-voltage higher frequency inverters[4].

Application of IGBTs in high power converters subjects them to big transient electrical stress such as short circuit and turn-off under clamped inductive load and therefore robustness of IGBTs under stress conditions is an important requirement. If the time duration of simultaneous high voltage and high current is long enough, the IGBT failure will occur because of thermal breakdown. But if this time duration is short, the temperature rise due to power dissipation will not be enough to cause thermal breakdown. This 123 level inverter is suitable for the applications where separate DC sources are available, such as photovoltaic generators, fuel cells and batteries. This technology can be applicable for motor drive systems, power distribution, power quality and power conditioning applications.
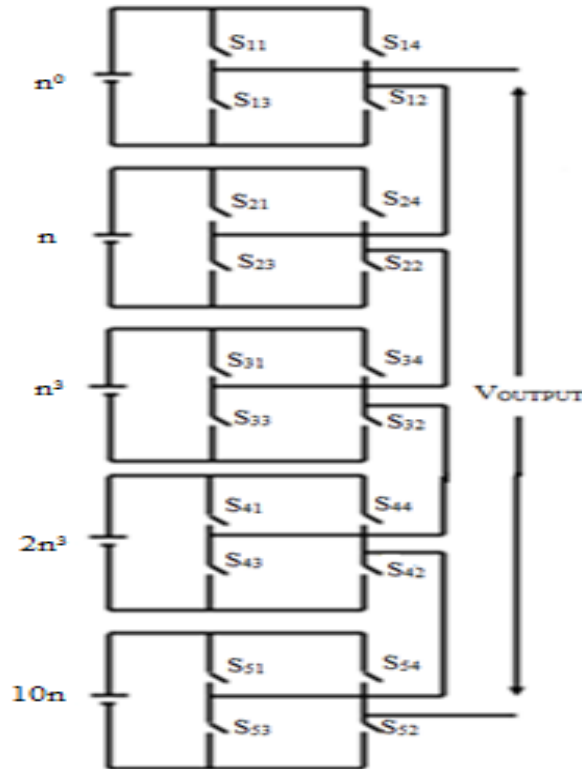
Fig. 2 Proposed 123-level inverter (same structure as a eleven-level inverter, except that the DC voltage sources are separated).

III.   MODULATION SCHEME

Table 1 illustrates the switching patterns of all 123 discrete levels (+61 Vp.u to -61 Vp.u.). This topology of firing reduces the switching losses which can be implemented without using PWM technique and also brings down the Total Harmonic Distortion (THD). The separate DC voltage sources are usually provided by voltages across large electrolytic capacitors, the switching pattern shows an important point that all electrolytic capacitors should connected in the same polarity in all cases. In the proposed circuit, inverter modules fed by higher voltage sources do not need any PWM control, thus minimizing the switching losses.

Table 1   Switching Patterns for the 123 Voltage Levels

Voltage (p.u.)	Switching Pattern	Voltage (p.u.)	Switching pattern
61	30+18+9+3+1	-61	-30-18-9-3-1
60	30+18+9+3	-60	-30-18-9-3
59	30+18+9+3-1	-59	-30-18-9-3+1
58	30+18+9+1	-58	-30-18-9-1
57	30+18+9	-57	-30-18-9
56	30+18+9-1	-56	-30-18-9+1
55	30+18+9-3+1	-55	-30-18-9+3-1
54	30+18+9-3	-54	-30-18-9+3
53	30+18+9-3-1	-53	-30-18-9+3+1
52	30+18+3+1	-52	-30-18-3-1
51	30+18+3	-51	-30-18-3
50	30+18+3-1	-50	-30-18-3+1
-	-	-	-
-	-	-	-
3	3	-3	-3
2	3-1	-2	-3+1
1	1	-1	-1
0	0	0	0

For getting the positive first level, S11 and S12 of H-bridge 1 (1 Vp.u.) will conduct and the remaining H-bridges will be in the short circuited condition. To maintain short circuit for the positive half cycle of the output waveform SN1 and SN3 will get turn on, likewise for the negative half cycle switches SN2 and SN4 will turn on. For getting the second level output voltage H-bridge 1 will conduct in the positive direction and the H-bridge 2 (3 Vp.u.) will conduct in the negative direction by turn on the switches S22 and S24.

IV.   SIMULATION MODEL

In order to validate the proposed concept, the inverter of Fig. 3 was constructed and tested in MATLAB/Simulink. For the 123 level model, a single phase resistive load with parameter R= 10Ω was connected to the output voltage. The DC voltage for each bridge is supplied by the battery source and had high output voltage. Transformer, rectifier and capacitors for each bridge are different ratings which is determined according to the frequency and voltage ratio given.

This feature highlights the advantage of the proposed system because the higher the inverter module voltage, the lower is the switching frequency. Relatively high-voltage devices with slower switching speed can be used for the relatively high-voltage module while relatively low-voltage power devices with faster switching speed can be used for the relatively low-voltage modules.In this simulation diagram of 123 level cascaded multilevel inverter, there are five H-bridges connected in series. Each H-bridge having four IGBT switches.
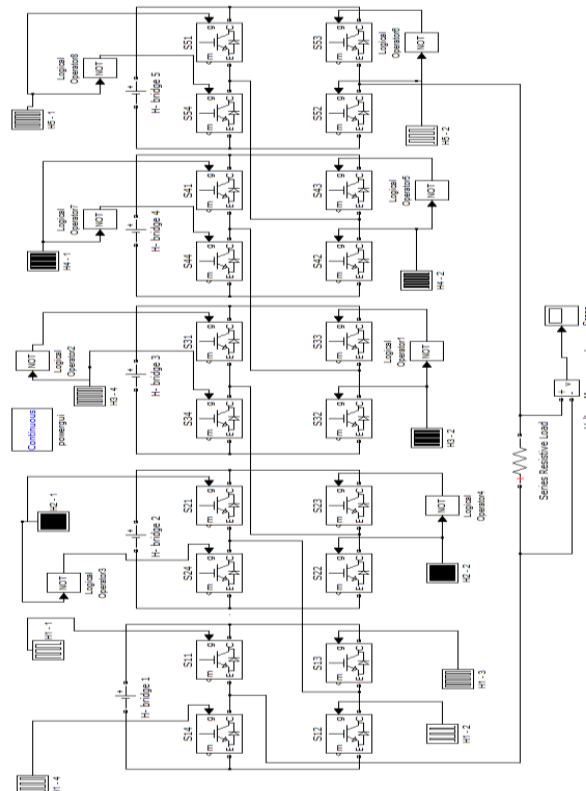

Fig. 3 Simulation model of the proposed system

To estimate the output voltage level a simple resistance load is connected across the terminals. Each switches carrying triggering pulses and the switches carrying opposite triggering pulses is given by a NOT gate. The triggering pulses of each bridges are of different frequencies. Switching losses of IGBT will get increased by increase in switching frequency. The series structure allows a scalable, modularized circuit layout and packaging since each bridge has the same structure.

The proposed inverter consist of less number of switches when compared to the other familiar topologies. The initial cost reduces because of the switch reduction. So it looks attractive and an apt one for industrial applications as well as power applications. Totally there are five H-bridges, each consists of four switches, therefore the whole system carrying sixteen switches. The proposed inverter can also be used as a power amplifier. It is envisaged that this proposal will be useful in many power conversion applications, such as FACTS, UPS, and audio amplifier systems. MOSFET or IGBT can be used as the power devices. Each H-bridge carrying individual DC sources, it can be taken from photovoltaic batteries, wind energy conversion systems can be used. For controlling the operation of power switches, each carrying firing control and protection circuits.

V. SIMULATION RESULTS

MATLAB/Simulink is utilized to create the simulation model and the control signals. Simulation results comprises of the triggering pulses given to each bridges and the resulting 123 output voltage levels. From this it can be seen that the frequency of triggering pulses is entirely different for each H-bridges and these asynchronous pulses can be made from microprocessor for the hardware implementation. It is found that the proposed system offer lower THD compared to the conventional one.
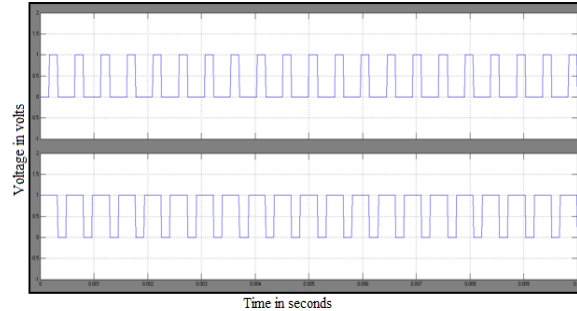
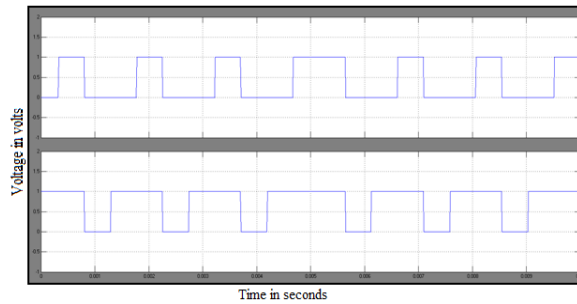Fig. 4 Triggering pulse for first H- bridge

Fig. 5 Triggering pulse for second H-bridge

In figure 7 it is shown the quarter waveform which is simulated in Matlab and it consists of the 61 output voltage levels. These experimental results shown that modification made in CMLI are able to acheive higher output voltage levels with reduced number of switches and have better harmonic performance. By maintaining these higher levels the output voltage taken from the cascaded inverter will have smoother sine wave.
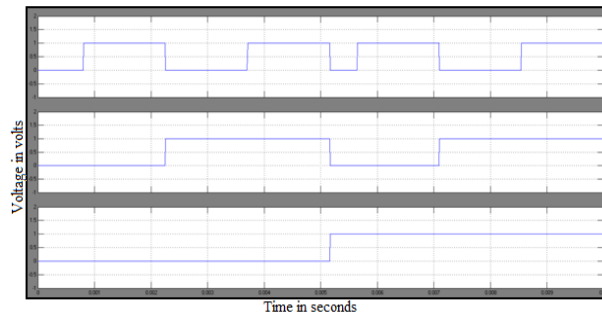

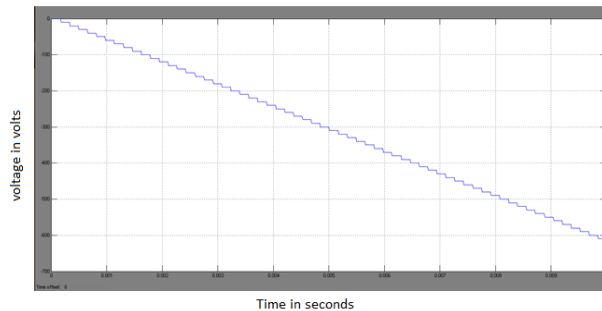Fig. 6 Triggering pulse for third, fourth and fifth bridge

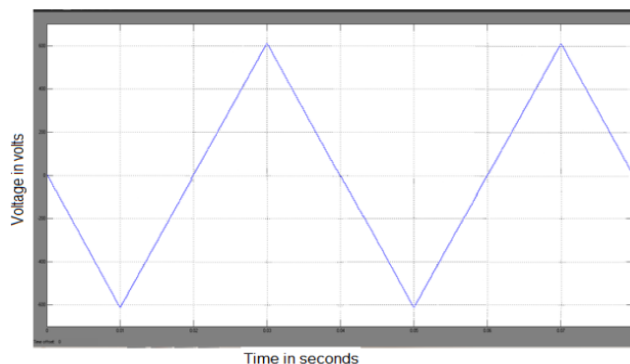Fig. 7 Simulation result of quarter waveform

Fig. 8 Simulation result of full waveform

VI. CONCLUSION

An efficient cascaded multilevel inverter with 123 output voltage levels is obtained. Simulation has been done in MATLAB /SIMULINK. From the simulation it is noted that new multilevel topology works well and shows hope to reduce the initial cost and complexity. When the output voltage levels get increased, the number of switches used is very less compared to other topology. By the increase in output voltage levels the total harmonic distortion get reduced, so that it can be used in many power applications. The basic idea is to take advantage of the different power rates among the cells to reduce switching losses and improve the converter efficiency.

VII. REFERENCE

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