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A New Topology for 81-Level Hybrid Multilevel Inverter with Reduced Number of Power Electronic Components and Voltage Boosting Capability

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ABSTRACT

In this paper, a new topology is implemented to get high number of levels at the output with reduced number of switches, gate driver circuits. The size, complexity and power consumption in the gate driver circuits is also reduced. In this, the Hybrid Bridge is used to get 81-level output voltage with the use of amplitude modulation. Multilevel inverters can operate not only with PWM techniques but also with amplitude modulation will improves significantly the quality of the output voltage waveform. With the use of amplitude modulation, low frequency voltage harmonics are perfectly eliminated. This paper presents a single-phase 81-level Hybrid multilevel inverter for a grid-connected system which is used for reactive power compensation. The proposed topology has the feature like boost output voltage capability along with capacitor voltage balancing. Simulation results obtained from Matlab/Simulink to simulate 81-levels of voltage with only four power supplies and sixteen transistors.

Keywords- Amplitude Modulation Technique, Capacitor voltage balancing capability, Matlab/Simulink, Reduction of switches, Voltage boosting capability.

I. Introduction

Multilevel inverters are finding increased attention in industry and academia as one of the preferred choices of electronic power conversion for high-power applications. They have successfully made their way into the industry and therefore can be considered a mature and proven technology. Currently, they are commercialized in standard and customized products that power a wide range of applications such as compressors, extruders, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, high-voltage direct-current transmission, hydro pumped storage, wind energy conversion and railway traction.

The Hybrid multilevel inverter requires a separate DC source for each H-bridge; thus, the high power and/or high voltage from the combination of the multiple modules would favour this topology in grid-connected applications. In grid-connected systems, the panels needed to reach the required power levels are usually arranged in multiple strings. Hence the proposed topology is designed for 81-level grid connected PV applications which is most widely used for reactive power compensation.

The harmonic distortions in the output voltage cause the unbalanced voltage problems and decrease the efficiency of multilevel inverters. Power electronic devices contribute with important part of harmonics in all kind of applications such as power rectifiers, converters and static VAR compensators. Multilevel inverters are promising that they have nearly sinusoidal output voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size and lower electromagnetic interface, all of which make them cheaper, lighter, and more compact. Normally, with voltage or current source inverters, as they generate discrete output waveforms, forcing the use of machines with special isolation and in some applications large inductances connected in series with the respective load are required. In other words, neither the voltage nor the current waveforms are as expected. Also, it is well known that distorted voltages and currents waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the load but also the associated controllers.

All these unwanted characteristics associated with PWM inverters can be overcome with multilevel inverters, with the addition that higher voltage levels can be achieved. With the use of amplitude modulation technique low frequency voltage harmonics are perfectly eliminated and generating an almost perfect sinusoidal waveforms, with a Total harmonic distortion lower than 5 %. Another important characteristic is that each converter operated at a low switching frequency, using Amplitude Modulation, reducing the semiconductor stresses and therefore reducing the switching losses. The main aim of this paper is to determine the simplest converter topology in terms of number of power semiconductors, for a given number of levels.

II. Proposed Topology

In this paper, the proposed topology overcomes the drawbacks of neutral point clamped and flying capacitor clamped, in which more number of clamping components such as capacitors and diodes are used, because of which the circuit becomes more complex.

In this topology, the control of the gates is very simple because only one power transistor is switched-on at a time. Then, there is a direct relation between the output voltage (Vout) and the transistor that has to be turn-on. However, despite the excellent characteristics of this topology, the number of transistors is still too large to allow the implementation of a practical converter with more than 50 levels. One solution to increase the number of steps could be the use of "H" converters, like the one shown in Fig.1, which consists of connecting two of the previously discussed topologies in series (two legs).

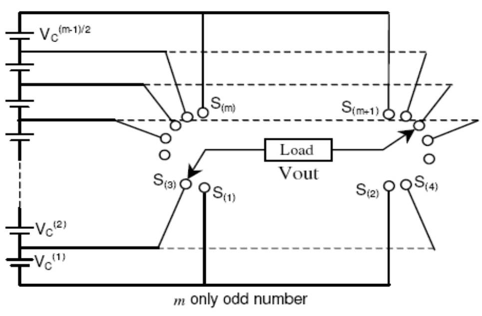


Figure.1 m-level inverter using an "H" bridge.

In the above Fig.1 Transistor-Clamped inverters are used to build like an "H" bridge converter, the number of transistors required for an m-level inverter is m+1, which means only one more power transistor than the required for a simple leg configuration. However, the number of dc sources is reduced in 50 %, which is the most important advantage of "H" bridge converters. Another characteristic is that the "H" topology has many redundant combination of switches position to produce the same voltage levels. As an example, the level "zero" can be generated when the switches of same leg are on, such as in position $S_{(1)}$ and $S_{(2)}$ or $S_{(3)}$ and $S_{(4)}$ or $S_{(5)}$ and $S_{(6)}$ and so on. Therefore, the problem related with increasing the number of levels and reducing the size and complexity has been partially solved, since power supplies have been reduced to 50 %.

III. Principle of Operation

The proposed topology circuit diagram having one main converter and three auxiliary converters shown in Fig. 2 (a) is fed with unequal dc voltage ratios between cells; some or even all voltage-level redundant switching states can be eliminated, maximizing the number of different voltage levels generated by the inverter.

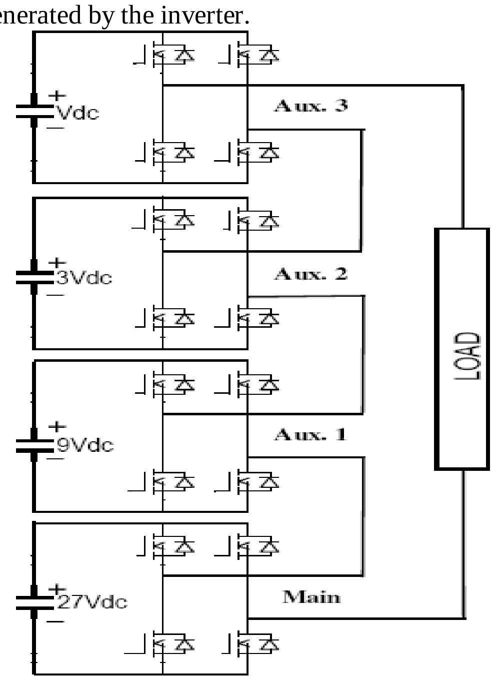


Figure.2 (a) proposed topology for 81-level inverter.

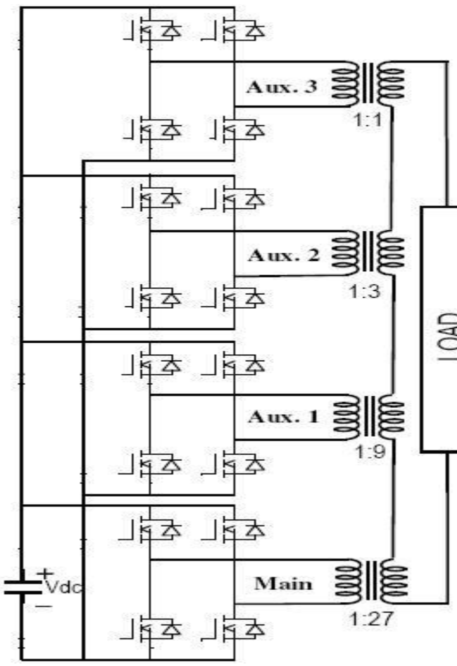


Figure.2 (b) 81-level inverter with single dc source.

The proposed topology circuit to get 81-levels of voltage has been built using 4-power supplies and 16-switching devices; enough to get almost perfect voltage waveforms for high power applications is shown in the Fig.2 (a) and (b), which has been built in two different topologies: Fig.2 (a) using four individual voltage sources for each module, and Fig.2 (b) using one single voltage source for all modules and voltage escalation through output transformers. The first topology is suitable for machine drives applications and the last configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters and reactive power compensation. In the last case, the power supply could also be a voltage regulated dc capacitor.

The principle of operation for the proposed 81-level inverter can be explained as when the total bridge is shorted then the output voltage is zero and it is indicated as “O”, according to the switching states negative output voltage by the bridge is indicated as “N” and positive output voltage is indicated as “P”. It is well explained with the following Table.1.

Table.1 Switching states of 81-level inverter.

V out	1Vdc	3Vdc	9Vdc	27Vdc
-40 Vdc	N	N	N	N
-39 Vdc	O	N	N	N
-38 Vdc	P	N	N	N
-37 Vdc	N	O	N	N
-36 Vdc	O	O	N	N
-35 Vdc	P	O	N	N
-34 Vdc	N	P	N	N
-33 Vdc	O	P	N	N
-32 Vdc	P	P	N	N
-31 Vdc	N	N	O	N
-30 Vdc	O	N	O	N
-29 Vdc	P	N	O	N
-28 Vdc	N	O	O	N
-27 Vdc	O	O	O	N
-26 Vdc	P	O	O	N
-25 Vdc	N	P	O	N
-24 Vdc	O	P	O	N
-23 Vdc	P	P	O	N
-22 Vdc	N	N	P	N
-21 Vdc	O	N	P	N
-20 Vdc	P	N	P	N
-19 Vdc	N	O	P	N
-18 Vdc	O	O	P	N
-17 Vdc	P	O	P	N
-16 Vdc	N	P	P	N
-15 Vdc	O	P	P	N
-14 Vdc	P	P	P	N
-13 Vdc	N	N	N	O
-12 Vdc	O	N	N	O
-11 Vdc	P	N	N	O
-10 Vdc	N	O	N	O
-9 Vdc	O	O	N	O
-8 Vdc	P	O	N	O
-7 Vdc	N	P	N	O
-6 Vdc	O	P	N	O
-5 Vdc	P	P	N	O
-4 Vdc	N	N	O	O
-3 Vdc	O	N	O	O
-2 Vdc	P	N	O	O
-1 Vdc	N	O	O	O
0 Vdc	O	O	O	O
+1 Vdc	P	O	O	O
+2 Vdc	N	P	O	O
+3 Vdc	O	P	O	O
+4 Vdc	P	P	O	O
+5 Vdc	N	N	P	O
+6 Vdc	O	N	P	O
+7 Vdc	P	N	P	O
+8 Vdc	N	O	P	O
+9 Vdc	O	O	P	O
+10Vdc	P	O	P	O
+11Vdc	N	P	P	O
+12Vdc	O	P	P	O
+13Vdc	P	P	P	O
+14Vdc	N	N	N	P
+15Vdc	O	N	N	P
+16Vdc	P	N	N	P
+17Vdc	N	O	N	P
+18Vdc	O	O	N	P
+19Vdc	P	O	N	P
+20Vdc	N	P	N	P
+21Vdc	O	P	N	P
+22Vdc	P	P	N	P
+23Vdc	N	N	O	P
+24Vdc	O	N	O	P
+25Vdc	P	N	O	P
+26Vdc	N	O	O	P
+27Vdc	O	O	O	P
+28Vdc	P	O	O	P
+29Vdc	N	P	O	P
+30Vdc	O	P	O	P
+31Vdc	P	P	O	P
+32Vdc	N	N	P	P
+33Vdc	O	N	P	P
+34Vdc	P	N	P	P
+35Vdc	N	O	P	P
+36Vdc	O	O	P	P
+37Vdc	P	O	P	P
+38Vdc	N	P	P	P
+39Vdc	O	P	P	P
+40Vdc	P	P	P	P

This configuration is good for variable frequency output such as machine drives of different kinds (three phase induction motors, synchronous and brushless dc motors). To avoid the three Main converters for three phases having to be isolated one from each other, the three windings of the machine have to be fed independently (no electrical connection between them). It is also possible to use independent output transformers with a common dc supply, as shown in Fig.2 (b).

One of the good advantages of the strategy described here for multilevel inverters is that most of the power delivered comes from the Main converter. More than 80% of the real power is delivered by the Main converter and only 20% by the auxiliary converters which show the power distribution of main and auxiliary converters shown in Fig.4 (b).

Even more, the second and third auxiliary converters only deliver 5% of the total power. That means the dc power sources needed by the auxiliary converters are small. This characteristic makes possible to feed the auxiliary converters with low power, isolated power sources, fed by a common power supply from the Main converter. These power sources need to be bidirectional, because the power factor of the load can produce negative active power in some of the auxiliary converters. The Fig.3 shows a bidirectional dc-dc power supply which can be used for this purpose.

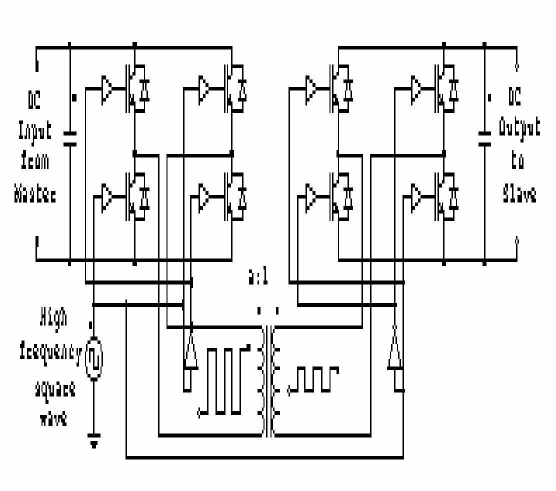
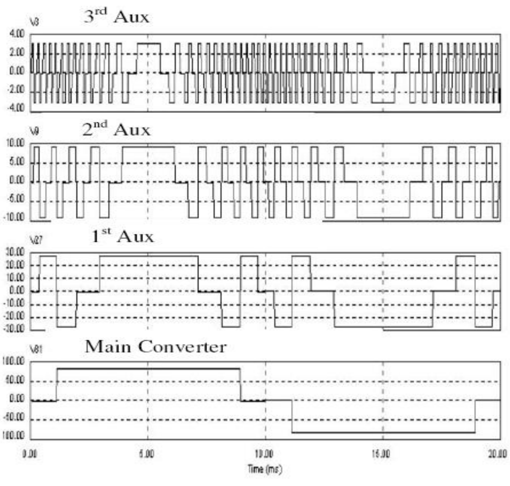


Figure.3 bidirectional DC-DC power supply

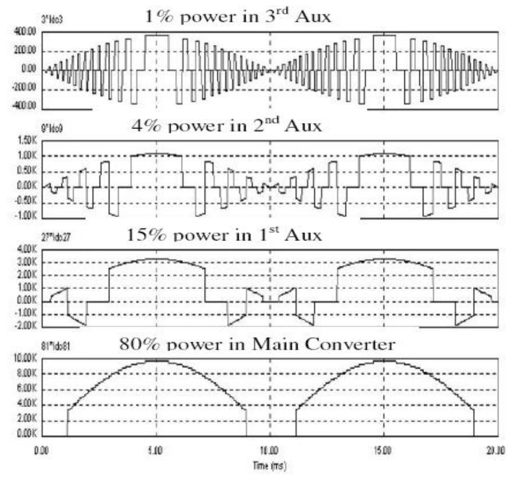
This Bidirectional DC-DC power supply will balance the input voltage to the auxiliary converters. Balancing the input voltage means boosting the output voltage. Another attribute of this configuration, which is possible to see in Fig.4 (a) and (b), is the very low switching frequency of each converter. But even better, the Main converter which carries most of the power operates at the lower switching frequency. Then the larger the power of the unit is the lower its switching frequency. In large power applications, the Main converter can be implemented with GTOs, and the auxiliary converters with IGBTs.



a)

Figure.4 (a) frequency of switching in each converter.

Fig.4 (a) and (b) shows the switching frequency and power distribution for each one of the four bridges (one main converter bridge and 3 auxiliary converter bridges) used for the implementation of the 81-level multilevel inverter respectively. The example of Fig.4 (b) shows the power distribution in one of the four-stage converter, feeding a pure resistive load with sinusoidal voltage. The Main Converter is switched at the fundamental frequency, minimizing switching losses and improving efficiency.



b)

Figure.4 (b) power distribution in each converter.

IV. Proposed Topology for practical approach

The 81-level hybrid multilevel inverter topology consists of four H-bridge converters connected in series is shown in Fig.5. Each DC link is fed by a short string of PV panels.

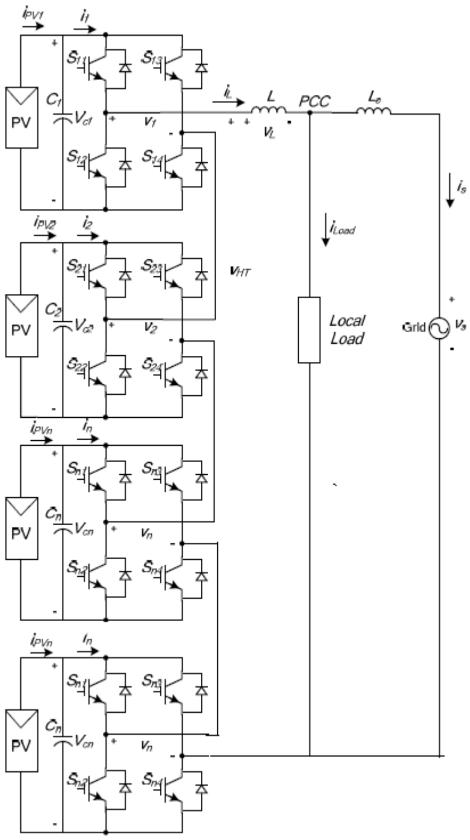
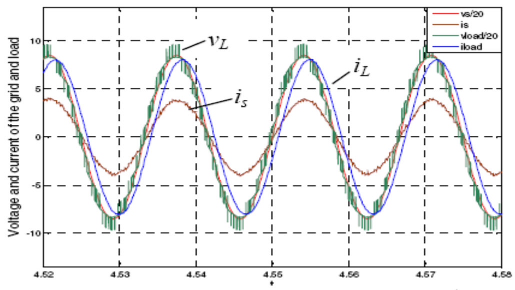


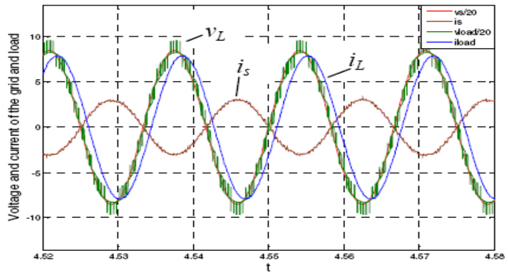
Figure.5 proposed topology for the grid-connected PV system.

By different combinations of the four switches in each H-bridge, three output voltage levels can be generated, –Vc, 0, or +Vc. A hybrid multilevel inverter with n-input sources will provide 2n+1 levels to synthesize the AC output waveform. This (2n+1) level voltage waveform enables the reduction of harmonics in the generated current, reducing the output filters.

As shown in Fig.5 the 81-level hybrid multilevel inverter is connected to the grid through an L filter, which is used to reduce the switching harmonics. There is also a local load connected in parallel. PV power is delivered to the load/grid according to the system operation conditions. The voltage and current waveforms of the grid and load are shown in Fig.6. It can be seen that the load voltage is tracking the grid voltage. The load current is lagging the voltage, however, even if the grid is sending power to the local load or receiving power from the PV system, the grid current has the same phase as the voltage, which means the grid has unity power factor. Sending or receiving power of the grid depends on the operation conditions of the PV panels. For example, when the PV panels are operated under irradiance S=1000 W/m2, temperature T=25 °C, the PV system can provide enough power to the local load and send the extra power to the grid.



(a) S=1000 W/m2, grid receives power from PV.



(b) S=400 W/m2, local load receives power from grid.

Figure.6 Voltage and current waveforms of grid and load (T=25 °C).

In the above Fig.6, when voltage and current are in same phase having unity power factor, then the grid receives the power from PV, and where as the voltage and current are out of phase then the local load receives the power from grid which shows the reactive power compensation. Due to the hybrid multilevel inverter, the THD is low even without any filter. The high order harmonics could be easily eliminated by adding a small filter, and the THD can be further reduced.

This proposed topology can also be used for the Electric vehicle drives for 3-phase application; in the design of EV drives, two auxiliary converters of the four converters can be fed with small DC-DC bi-directional power supplies.

V. Voltage Boosting

Voltage boosting can be explained with the following H-bridge converter shown in the Fig.7 shown below.

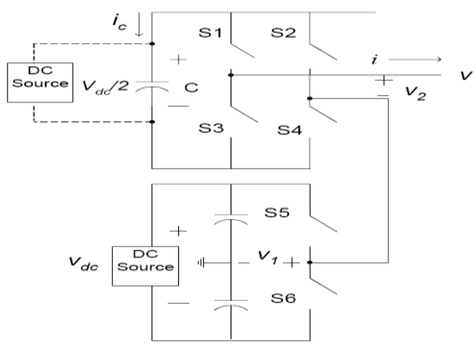


Figure.7 simplified single-phase topology of the hybrid multilevel inverter for voltage boost.

The bottom of the inverter is one leg of a standard 3-leg inverter with a dc power source. The top is an H-bridge in series with each standard inverter leg. The H-bridge can use a separate dc power source or a capacitor as the dc power source.

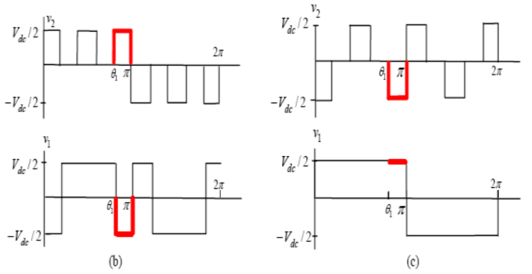


Figure.8 capacitor voltage regulation process.

The above Fig.8 shows the voltage boosting with maintaining the equal charge and discharge cycles. This method of regulating the capacitor voltage depends on the voltage and current not being in phase. That means one needs positive (or negative) current when the voltage is passing through zero in order to charge or discharge the capacitor. Consequently, the amount of capacitor voltage the scheme can regulate depends on the phase angle difference of output voltage and current. It is noted that the above capacitor voltage regulation method is described using a fundamental amplitude modulation. The realization of capacitor voltage regulation and inverter boost function depends on the phase angle difference of output voltage and current. Actually, that means they are related to the amount of reactive power required by the load.

VI. Comparison with Other Topologies

Multilevel inverters can operate not only with PWM techniques but also with amplitude modulation (AM), improving significantly the quality of the output voltage waveform. Different levels of proposed multilevel inverter are controlled with amplitude modulation which is obtained through the control of the gates of the switches used in each one of the four converters. With the use of amplitude modulation, low frequency voltage harmonics are perfectly eliminated. And compared to other topologies this proposed topology is used for grid connection applications, EV and HEV drives and possess the voltage balancing & boosting topologies.

In the Fig.9 (a) and (b) shows the comparison between the PWM method and amplitude modulation (AM). Fig.9 (b) with amplitude modulation showing the smooth waveform without distortions.

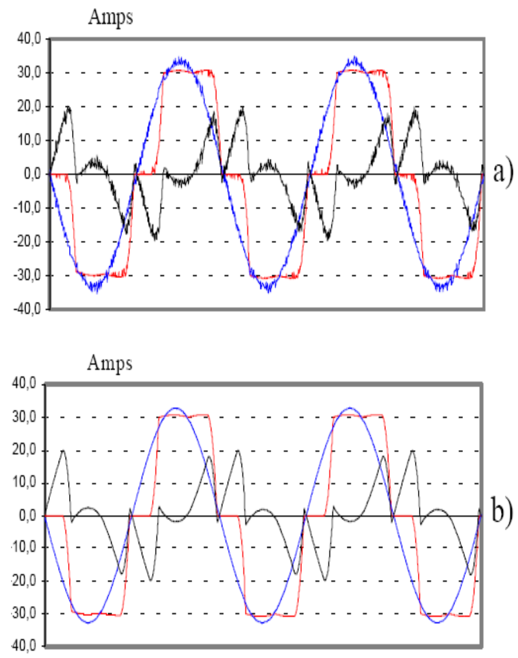


Figure.9(a) PWM modulation (b) Amplitude modulation.

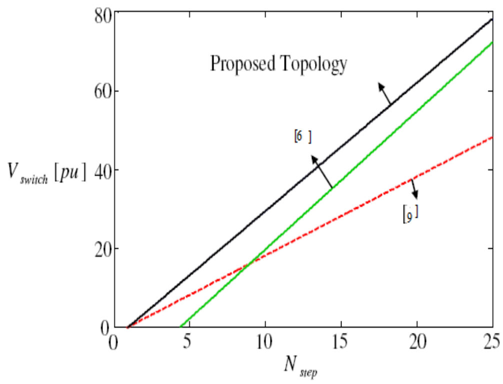


Figure.10 comparison of standing voltages on switches in the proposed topology and presented topologies in [6] and [9].

From the above Fig.10 it is shown that less number of switches are required and better standing voltage on switches in the proposed topology. Hence complexity is reduced for high number of levels.

VII. Simulation Results

The Matlab/Simulink model of the proposed inverter for 81-level output is shown in Fig.11 The Amplitude Modulation of the proposed converter is obtained through the control of gates of the switches used in each one of the four converters internally.

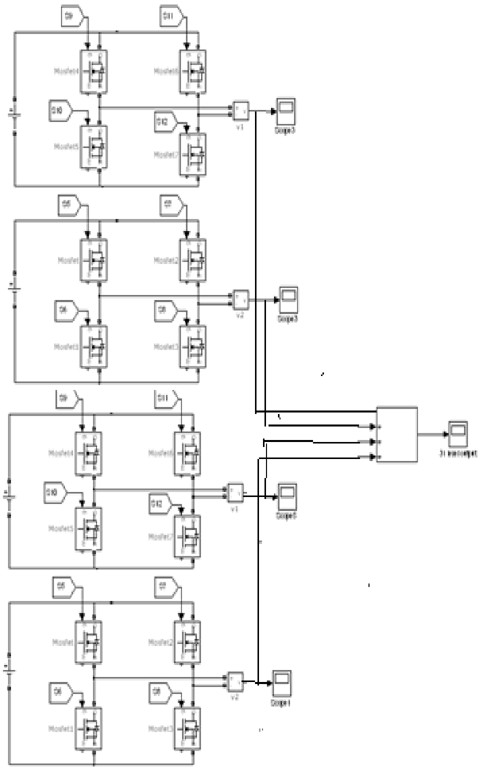


Figure.11 Matlab/Simulink model for 81-level inverter.

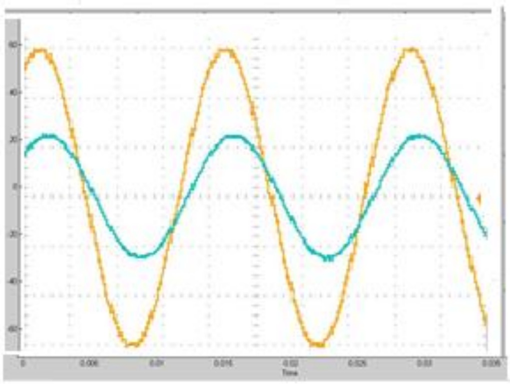


Figure.12 simulation results of 81-level inverter output voltage and current.

Fig.12 shows 81-level output Voltage and current waveforms. Simulation is performed for the proposed circuit with Matlab/Simulink. It is clear that as the number of level increases, distortion in output waveforms reduces and reduces the switches required in the proposed topology compared to other topologies.

VIII. Conclusion

Multilevel inverters with 81-levels have been analyzed. The main contribution has been focused in minimizing the number of power transistors for a given number of levels. The suggested topology needs less number of switching devices with minimum standing voltage. THD is also reduced without using PWM techniques. The Hybrid multilevel inverter requires a separate DC source for each H-bridge; thus, the high power and/or high voltage from the combination of the multiple modules would favour this topology in grid-connected PV applications. And the proposed topology shows how to operate the hybrid multilevel inverter without any voltage unbalance problems. The simulation results are shown which are accorded with the theoretical results. And the voltage boosting topology is shown. The proposed inverter is used in high power applications like grid-connected PV systems, EV and HEV drives.

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