



Analysis and Simulation of Eleven Inverter Topology

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Abstract-Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. This paper presents modeling and simulation of a single phase simplified eleven-level inverter (SELI). Multilevel inverter offers high power capability. Its performance is highly superior to that of conventional two-level inverter due to reduced harmonic distortion, lower electromagnetic interference and higher dc link voltage. Recent advances in technology have realized the cascaded inverters with separate DC sources to have a considerable reduction in switching losses and the ability to control the harmonic content. The elementary concept of a multilevel converter to achieve higher power to use a series of power semiconductor switches with several lower voltage dc source to perform the power conversion by synthesizing a staircase voltage waveform. Simulations of eleven level of the proposed inverter topology along with MATALAB simulation results are presented.

Keywords-Simplified Eleven-level Inverter (SELI), Flying Capacitor, Active neutral point clamped.

I.INTRODUCTION

The earliest concept of multilevel topology consisted of a series connection of multiple DC sources with switches connected to different level of the voltage source and a simple 3-level realization is showed in Fig.1 (a) . An improvement that can equalize the stress on the switches resulted in the structure shown in Fig.1 (b) which is called stacked commutation cell or 3-pole cell. This topology uses series connection of switches which show more complexity of the commutation and control for higher level converters. At the same time, neutral-point-clamped (NPC) structure was developed. A 3-level NPC topology shown in Fig.1 (c) can be considered as the particular way of implementing 3-pole cell topology: two inner switches and two clamping diodes are used to play the role of middle level track. This structure can be easily extended to higher level called diode clamped multilevel converter known as the most popular multilevel topology. Nevertheless, some drawbacks exist for this topology, such as rapidly increasing number of clamping diodes for higher level, neutral point voltage balancing problem, indirect clamping of the inner devices, unequal distribution of losses in semiconductor devices, etc. To overcome these disadvantages, flying capacitors

were introduced as the clamping devices then hybrid converter clamped with diode and capacitor was presented, shown in Fig.1 (d).

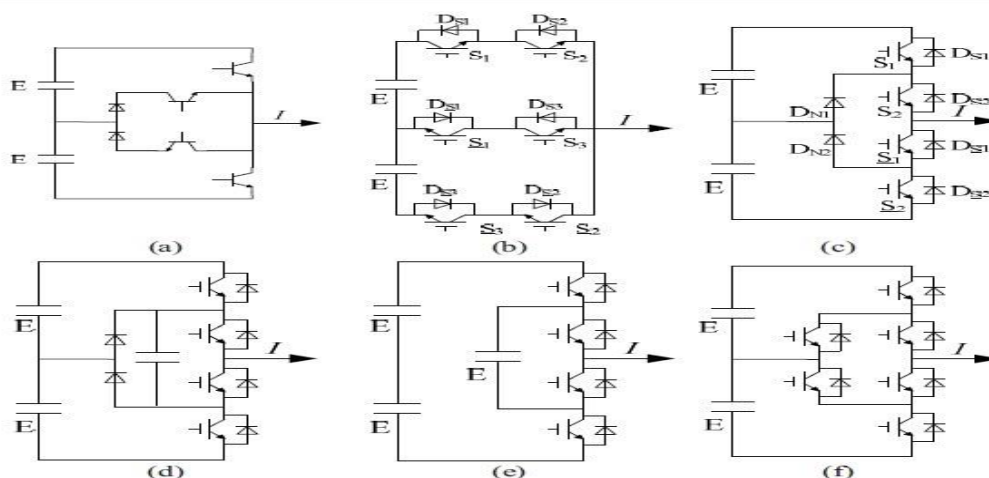


Fig. 1. Basic topologies.

Then flying-capacitor converter (also called multi cell) which uses only the flying capacitors as clamping devices was presented in and discussed comprehensively by Meynard shown in Fig.1 (e). As the capacitors can provide extra capability during power output, the voltage synthesis in a flying-capacitor converter presents more flexibility than a diode-clamped converter. Furthermore, the more redundancy of switch combination is beneficial for balancing voltages of the flying capacitors. Nevertheless, its control is more complicated, and an excessive number of storage capacitors are required for higher level. Considering that the size of flying capacitor is inversely proportional to the switching frequency, the NPC structure is more advantageous than flying-capacitor structure in the field of low and moderate frequencies. Another topology called active neutral-point clamped (ANPC) was also proposed to avoid the problems of indirect clamping and unequal loss distribution of power devices in NPC converters. As is shown in Fig.1 (f), additional active switches anti parallel to the NPC diodes are used to ensure the equal voltage sharing of the series-connected NPC diodes. With appropriate control, losses distribution can be more balanced, that can give substantial increase of the output power or switching frequency.

II. MULTILEVEL INVERTER TOPOLOGIES

The term 'Multilevel' has been coined to emphasize the ability to increase the instantaneous voltage levels in steps, accomplished by addition of components in series. Multilevel inverter is based on the fact that sine wave can be approximated to a stepped waveform synthesized output waveform has more steps, producing a very fine stair case wave and approaching very closely to the desired sine wave. It can be easily understood that as motor steps are included in the waveform the harmonic distortion of the output wave decrease, approaching zero as the number of levels approaches infinity. Hence Multi-level inverters offer a better choice at the high power end because the high volt- ampere ratings are possible with these inverters without the problems of high dv/dt and the other associated ones.

Generally, the output waveform of the multilevel inverter is generated from different voltage sources obtained from the capacitor voltage sources. In the past two decades, several multilevel voltage source converters have been introduced. In that some of the topologies are popular and some are not popular.

The basic three types of multilevel topologies used are

- (A) Cascaded inverter with separate DC sources.
- (B) Flying capacitors multilevel inverter or capacitor clamped multilevel inverter.
- (C) Diode clamped multilevel inverters.

A. Cascaded Inverters with Separate DC Source

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. One of the advantages of this type of multilevel inverter is that it needs less number of components comparative to the Diode clamped or the flying capacitor, so the price and the weight of the inverter is less than that of the two former types Fig.2 shows cascaded H-bridge multilevel inverter. The switching angles calculation method that is used in this inverter is the same as for the previous multilevel inverters. An n level cascaded H-bridge multilevel inverter needs $2(n-1)$ switching devices where n is the number of the output voltage level.

i) Advantages of cascaded multi-level inverter

1. Require the least number of components among all multi-level converter to achieve the same number voltage levels.
2. Modulized circuit layout and packaging it possible because each level has the structure, and there are no extra clamping diodes or voltage balancing capacitors.
3. Soft switching can be used in this structure to avoid bulky and lossy resistor, capacitor, diode, snubbers.

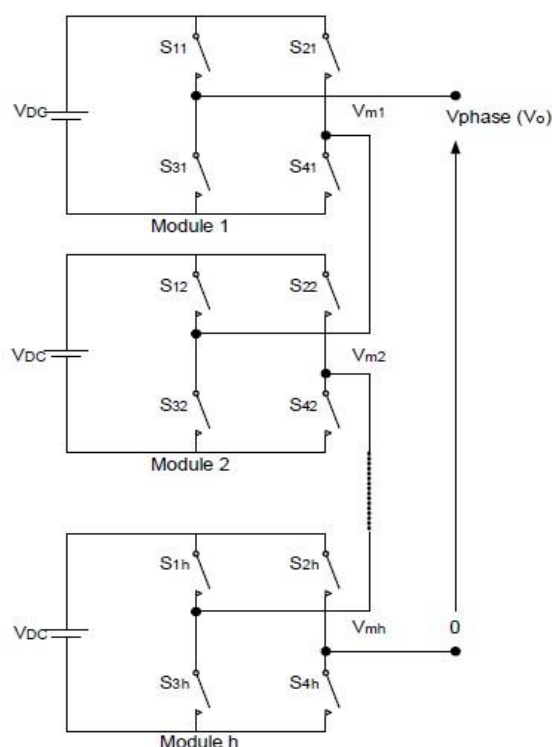


Fig. 2 One phase of a cascaded H-bridge multilevel inverter

ii) Disadvantages of cascaded multi-level inverter

1. Limited to certain applications where separate DC sources are available.

B. Flying Capacitor Multilevel Inverter

This inverter uses capacitors to limit the voltage of the power devices. The configuration of the flying capacitor multilevel inverter is like a diode clamped multilevel inverter except that capacitors are used to divide the input DC voltage. The voltage over each capacitor and each switch is V_{dc} . Fig.3 shows the flying capacitor three level inverter.

C. Diode Clamped Multilevel Inverters

The main concept of this inverter is to use diodes to limit the power devices voltage stress. The voltage over each capacitor and each switch is V_{dc} . An n level inverter needs $(n-1)$ voltage sources, $2(n-1)$ switching devices and $(n-1)(n-2)$ diodes. The maximum output voltage in the output is half of the DC source. It is a drawback of the diode clamped multilevel inverter. This problem can be solved by using a two times voltage source or cascading two diode clamped multilevel inverters. Fig. 4 show the diode clamped three level inverter. The comparison of each topology is show in the Table I.

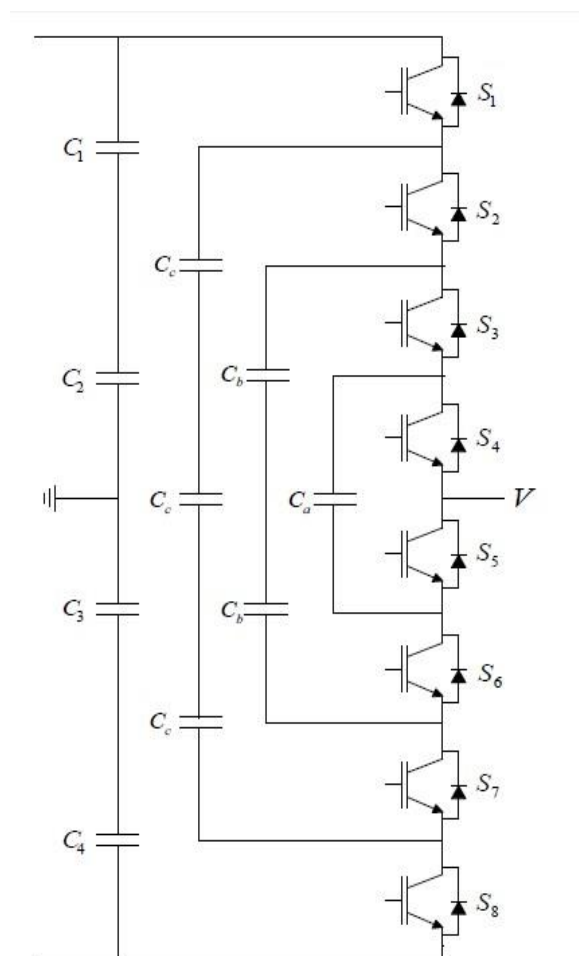


Fig. 3 One phase of a 5-level Flying capacitor multilevel inverter

Table I Devices Required In Different Topologies

Topologies (5-level)	Switches (main and clamping)	Diodes(anti parallel and clamping)	Clamping capacitors
Generalized	20	20	6
Diode-Clamped	8	20	0
Flying Capacitor	8	8	6
Capacitor-Clamped	8	20	6
Novel Topology (Used in Current Paper)	4	8	2

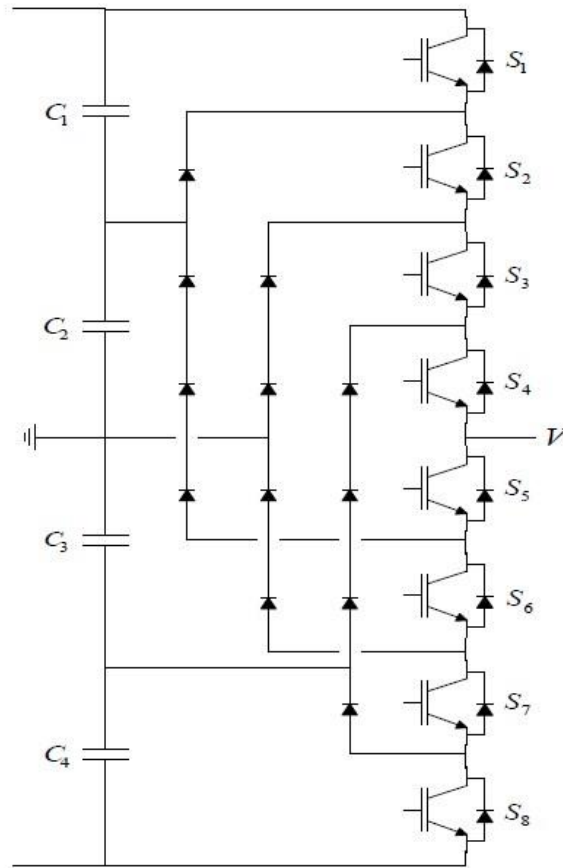


Fig. 4 One phase of a diode clamped inverter

III. SIMULATION RESULTS.

In order to reduce the overall number of switching devices in conventional multilevel inverter topologies, a new topology has been proposed. The novel topology uses less number of switches, keeping efficiency high and THD close to 15%.

A. POWER CIRCUIT

A single phase simplified multilevel inverter has the following merits over other existing multilevel inverter topologies.

1. Improved output waveforms.
2. Reduced number of switches employed.
3. Less complexity of the circuit as the levels increase.
4. Smaller filter size.
5. Lower electromagnetic interference and total harmonic distortion.

In addition to this, the capacitors are connected in parallel with the main DC power supply, no significant capacitor voltage swing is produced during normal operation, avoiding a problem that can limit operating range in some other multilevel configurations.

B. Power Circuit Description

The proposed single phase simplified eleven-level inverter was developed from the five-level inverter. It consists of a single phase conventional H-bridge inverter, four bidirectional switches and a capacitor voltage divider formed by C1, C2, C3, C4, C5. The auxiliary switches formed by the controlled switch S5, S6, S7, S8 and with sixteen diodes D1 to D16.

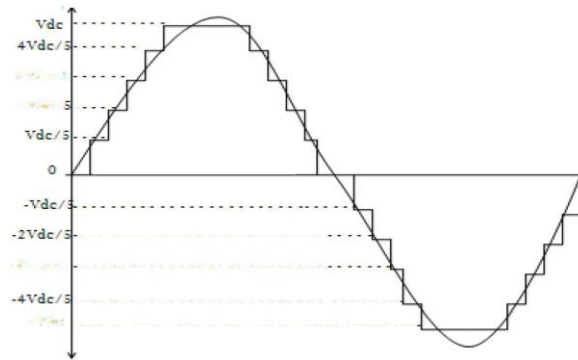


Fig.5 Eleven-level inverter output wave form.

The inverter is capable of producing eleven levels of output voltages (V_{dc} , $4V_{dc}/5$, $3V_{dc}/5$, $2V_{dc}/5$, $V_{dc}/5$, 0 , $-V_{dc}/5$, $-2V_{dc}/5$, $-3V_{dc}/5$, $-4V_{dc}/5$, $-V_{dc}$) from the DC supply voltage V_{dc} shown in Fig.5.

There are eleven modes of operation in which two switches conduct for every modes of operation, while other switches remains in OFF position. The different voltage levels of the inverter can be synthesized from the following modes of operation and can be understood using Table. II. There are eleven modes of operation in which two switches conduct for every modes of operation, while other switches remains in OFF position. The MATLAB/Simulink model of Eleven level Inverter is shown in the Fig. 6. The different voltage levels of the inverter can be synthesized from the following modes of operation and can be understood using Table. II.

1. Mode I Operation:

During mode I operation switches S1 and S4 are turned ON providing an output voltage level of V_{dc} volts.

2. Mode II Operation:

During mode II operation switches S4 and S5 are turned ON providing an output voltage level of $4V_{dc}/5$ volts.

3 Mode III Operation:

During mode III operation switches S4 and S6 are turned ON providing an output voltage level of $3V_{dc}/5$ volts.

4. Mode IV Operation:

During mode IV operation switches S4 and S7 are turned ON providing an output voltage level of $2V_{dc}/5$ volts.

5. Mode V Operation:

During mode V operation switches S4 and S8 are turned ON providing an output voltage level of $V_{dc}/5$ volts.

6. Mode VI Operation:

This mode of operation has two possible switching combinations. Either switches S3 and S4 are ON or S1 and S2 are ON providing an output voltage level of 0 volts.

7. Mode VII Operation:

During mode VII operation switches S2 and S5 are turned ON providing an output voltage level of $-V_{dc}/5$ volts.

8. Mode VIII Operation:

During mode VIII operation switches S2 and S6 are turned ON providing an output voltage level of $-2V_{dc}/5$ volts.

9. Mode IX Operation:

During mode IX operation switches S2 and S7 are turned ON providing an output voltage level of $-3V_{dc}/5$ volts.

10. Mode X Operation:

During mode X operation switches S2 and S8 are turned ON providing an output voltage level of $-4V_{dc}/5$ volts.

11. Mode XI operation:

During mode XI operation switches S2 and S3 are turned ON providing an output voltage level of $-V_{dc}$ volts.

TABLE II
 Switching Combinations Required To Generate
 The Eleven-Level Output Voltage

V_o	S1	S2	S3	S4	S5	S6	S7	S8
Vdc	1	0	0	1	0	0	0	0
4Vdc/5	0	0	0	1	1	0	0	0
3Vdc/5	0	0	0	1	0	1	0	0
2Vdc/5	0	0	0	1	0	0	1	0
Vdc/5	0	0	0	1	0	0	0	1
0	1	1	0	0	0	0	0	0
0*	0	0	1	1	0	0	0	0
-Vdc/5	0	1	0	0	1	0	0	0
-2Vdc/5	0	1	0	0	0	1	0	0
-3Vdc/5	0	1	0	0	0	0	1	0
-4Vdc/5	0	1	0	0	0	0	0	1
-Vdc	0	1	1	0	0	0	0	0

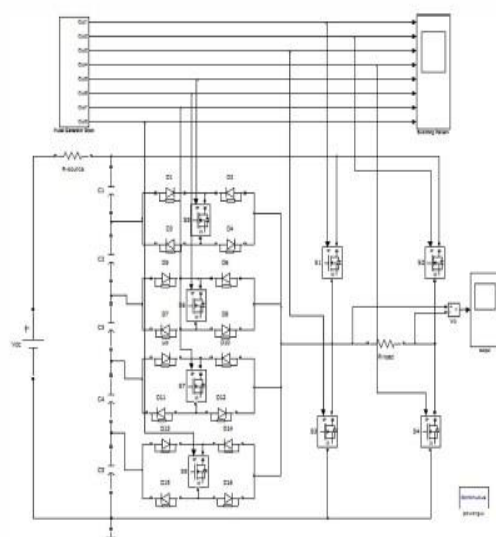


Fig.6 Schematic of Eleven Level Inverter

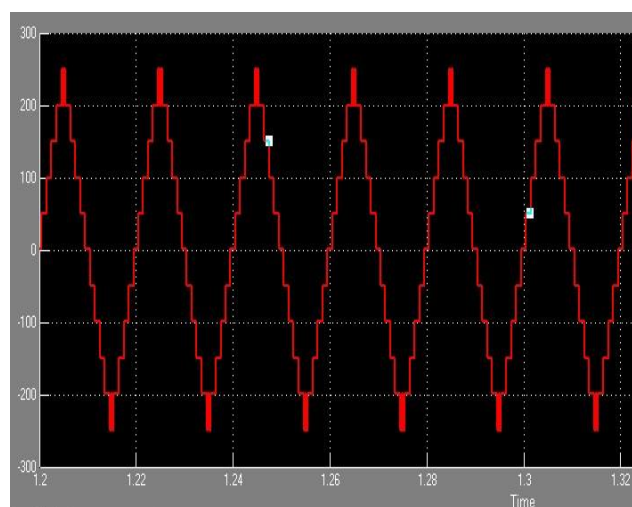


Fig.7 Output of Eleven level inverter (Voltage)

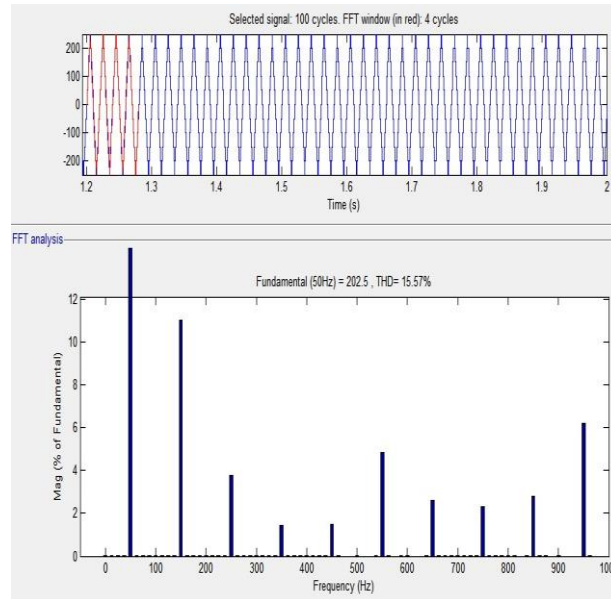


Fig.8FFT analysis

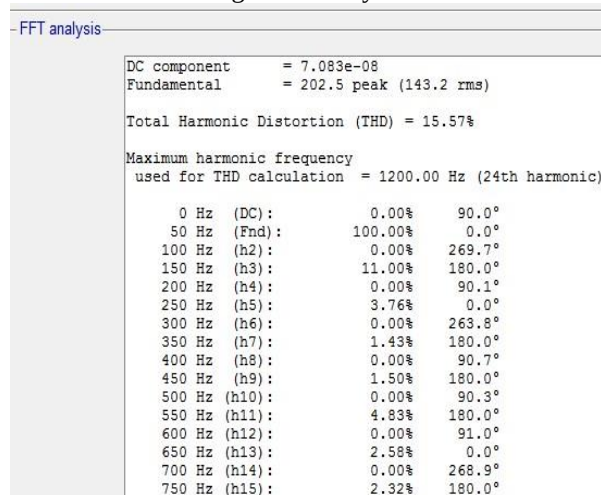


Fig.9 FFT analysis with DC component

V.CONCLUSION

A new family of multilevel inverters has been presented and built in MATLAB-Simulink. Multilevel inverters offer improved output waveforms and lower THD. The output waveform shown in the Fig. 7 is close to sine wave. The novel topology uses less number of switches keeping switching losses minimum. The Total Harmonic Distortion (THD) of the eleven- level inverter is observed that 15.57% and fundamental voltage is 202.5V(50Hz)that has been illustrated in Fig.8.and Fig. 9 with efficiency of 81% .The DC component in the novel topology is low which is illustrated in Fig. 9. The 7th harmonic component which is problematic for Induction motor is low. By using selective harmonic elimination methods the third harmonic component can be eliminated easily to reduce the THD% close to acceptable value of less than 5%. The inverter model developed was shown to provide accurate results and provided valuable insight into eleven-level inverter performances. which has superior salient features over conventional topologies in terms of the power switches count and isolated dc supplies, control requirements, cost, and reliability. It is shown that this topology can be a good candidate for converters used in power applications such as renewable systems, FACTS, UPS, etc. Using the novel topology higher level inverters like 17 level can be designed easily to reduce the THD% further. The main advantages of multilevel inverters are the series connection allows higher voltage without increasing voltage stress on switches, Higher voltage capability, Higher power quality, Lower switching losses and its achieved lower harmonic distortion due to more levels the output waveform.

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