Comparative Analysis of Standard Cascaded H-Bridge and Improved Switched Capacitor Multilevel Inverter

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ABSTRACT

The demand for higher power quality in industrial applications led to the replacement of two stage inverters with multilevel inverters, which may provide multiple steps of ac output voltage with lower harmonic content. They can thus be utilized in high-voltage and high-power applications. Cascaded H bridge inverters are one of the most used multilevel inverter techniques. Yet as the number of output levels rises, H-bridge inverters use more voltage sources and switching devices, which is one of their main drawbacks. As a result, switching stress and losses rise. In this paper, a modified structure of a switched capacitor multilevel inverter (SCMLI) supplied from a single DC source and requiring fewer switching devices is compared to a conventional cascaded H-bridge inverter. This paper also presents the total harmonic distortion (THD) comparison of 9 levels, 17 levels, and 33 levels of switched capacitor and conventional cascaded H-bridge multilevel inverters. The THD of 9 levels, 17 levels, and 33-level conventional cascaded H-bridge inverters is 14.2, 13.2, and 7.5 respectively. By introducing the modified topology of a switched capacitor multilevel inverter the THD is reduced to 12.57, 9.59, and 4.4 respectively. From the comparison study, the modified SCMLI configuration is considered the most efficient topology with self-balanced voltage capability, a lesser number of switches, and reduced harmonics.

Keywords: Multilevel Inverter, SC-MLI, THD

1 Introduction

Nowadays the demand of power increased in the industrial and commercial applications. Therefore the development of renewable energy resources becomes essential to meet the raising demand of power. Solar energy, wind, ocean, biomass and geothermal are some sources of renewable energy. Among these energy sources, solar radiation is the most significant source of renewable energy. It generates direct current which is then converted into AC power to be adaptable to modern electronics. However, certain industrial equipment only needs a little amount of electricity to function. Industrial load may be damaged by high power sources, even if some motors that require high power might benefit from them. And medium voltage motor drives are required for utility applications and certain medium voltage motor drives. And also the need of acquiring an essentially sine wave for the output voltage is becoming most important due to the raising need for supply with high power quality in industrial applications. An inverter with pulse width modulation (PWM) and a high cut filter can theoretically deliver this ideal output voltage waveform. However, the increased dv/dt strain of the inverting bridges and the higher operating frequency of the 2-level inverter would result in higher switching loss (EMI). In terms of evaluation, the multilevel inverter (MLI) method has long attracted a lot of attention due to its many appealing benefits, such as lower switching frequencies, nearly sinusoidal waveforms of output voltage, and reduced dv/dt stresses, among other things. Due to its capacity to produce reduced harmonic content while reaching higher voltage, multi-level inverters have a variety of uses in the power sector. In cases requiring medium voltage and higher power, the Multilevel Inverter, which functions similarly to an inverter, is employed in industrial applications.

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The multilevel inverter with cascaded H bridges (CHBMLI) in [1] converts DC input into AC, providing low THD. There are mainly 3 varieties of MLIs: Neutral point clamped (NPC), Cascaded H-Bridge inverters (CHBMLI), and flying capacitor (FC) multilevel inverters are three different types of voltage source inverters. Because they offer larger power levels, higher output voltages, and more dependability, cascaded H bridge multilevel inverters are well-liked. Such an inverter's switch control is likewise easy and quick to construct [2]. CHB inverters use fewer switching components and are flexible in design, making them easier to manufacture. Applications requiring high voltage and power are also carried out by these converters. There are also photovoltaic power conversion applications, reactive power reduction applications, magnetic resonance imaging, synchronous static compensators, active filters and an uninterruptable power supply.

There is also symmetrical and unsymmetrical multilevel inverter. Multiple voltage sources with the same value are utilized in symmetric MLIs, whereas voltage sources with different value are used in unsymmetrical MLIs. Hence the switching devices and the sources used in the circuit can be minimized by using unsymmetrical configuration of the inverter. The suggested inverter in [2] may offer a greater number of output voltage steps than standard cascaded MLIs while consuming less power from electronic components like power diodes, driver circuits, dc voltage supplies and power switches. This design has advantages over conventional design and its variants are thus commonly used. In [3], the basic configuration of CHBMLI has been modified to yield 5-step single phase output with fewer switches than the standard version's eight switches. Ie, the well-known CHB multilevel inverter design is used for the review. Because it requires fewer components than other MLI configurations. An updated pulse width modulation (PWM) is employed to provide switching pulses so as to further reduce output total harmonic distortion (THD). This method was chosen after its performance was compared to that of other comparable methods. To further reduce THD, an output filter can be utilized at the inverter.

In contrast to flying capacitor (FLC) and neutral point clamped (NPC), which both have unequal capacitor voltages and complicated level shifting circuits for raising output levels, there is another version of MLI based on switched capacitor (SC) methodology that has a straight forward design and capacitor voltages are self-balancing [4]. Additionally, it is distinct from H-Bridge MLIs, which needs several number of DC sources. Because an SC-MLI has the ability to boost itself, a single reduced voltage supply is commonly used. After that, Hinago and Koizumi [5] develop a straightforward series/parallel SC-MLI structure. This setup generates 2n+3 output voltage steps, each of which is same as the DC source voltage, using n SC units and an inverter H-bridge. In the SC unit, all elements are rated for input voltage, and the construction is adaptive. But several capacitors, and isolated gate controllers are needed to activate these power switches. The series as well as parallel SC-MLIs must trigger several switches to give the greatest output voltage, which results in a significant voltage drop on the conducting state of the switches and a rise in conduction losses. Sadhu and Roy created a novel SC-MLI configuration to address this issue that takes use of several switches with various voltage ratings. However, these switches must be able to block bipolar voltage H-bridge [6] offers an improve SC-MLI with a lot of switching devices to do away with the need for inverters. The capacitor voltage and total output levels obtained grow along with the total SC units used. These SC-MLIs use fewer parts while producing higher output levels, however when low-voltage capacitors are used to charge high-voltage capacitors, a serious issue known as capacitor voltage ripple accumulation (CVRA) is observed.

According to the literature review indicated above, almost all SC-MLIs benefit from self-boosting capabilities and self-balanced capacitor voltages. Furthermore, the CVRA issue is typically accompanied with larger voltage gains and more output levels when employing the equal number of SC units. As a result, it is uncommon to adjust the BF (Boosting Factor), the total components included in the circuit, the CVRA, and the output levels obtained all at once. In this study, a modified architecture of SC-MLI with a single

DC supply is compared to the typical cascaded H-Bridge inverter. It has reduced harmonics and uses fewer number of switching devices.

2 Conventional Cascaded H-Bridge Inverter

The CHBMLI employs a huge number of switching components, and each H-bridge is driven by different input DC voltage sources. Three separate voltages-zero, negative DC, and positive DC can be developed by each H-Bridge cell. By cascading two or even more H-Bridge cells, the numbers of levels of output voltage may be increased. The advantage of this type of multilayer inverter over diode clamped as well as flying capacitor inverters is that it requires fewer components. This inverter is lighter and less priced compared to the other inverters as well. This paper introduces conventional H-bridge inverter which produces 9-levels, 17-levels and 33-levels of AC output voltage.

2.1 9 Level Cascaded H-Bridge inverter

By combining two or even more H-bridge converters to produce multilevel output, a standard cascaded H-Bridge inverter setup may be created. In general, a cascaded multilevel inverter generates (2n+1) levels of output ac voltage with 'n' DC source with same voltage. The total voltage levels produced increases when an imbalanced DC supply is used.

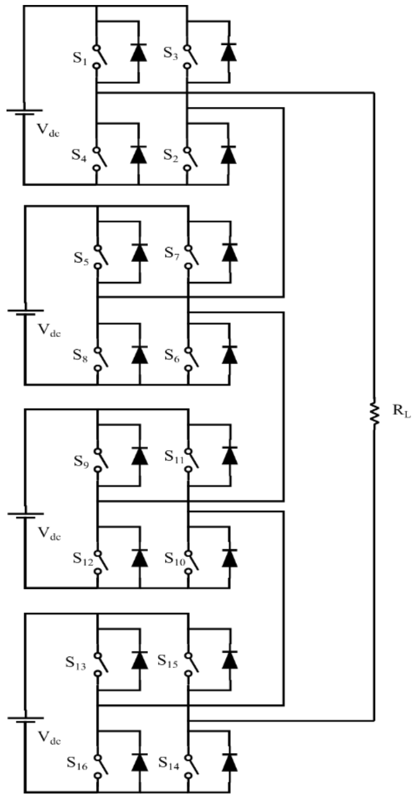

Figure 1: *9 Level H-Bridge Multilevel Inverter*

Figure 1 depicts the fundamental arrangement of the 9 level CHB inverter. 16 transistor switches, 4 voltage sources, and R load make up this architecture. Nine output voltage levels are produced by this configuration.

Harmonic analysis may be used to evaluate the multilevel inverter's accuracy. Approximately 14.18% THD is present in standard cascaded multilevel inverters [7].

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2.2 17 Level Cascaded H-Bridge Multilevel Inverter

By the use of additional H-bridge units in the system, inverters may be capable of providing an output AC voltage with more stages. This standard architecture employs eight H-bridge cells for generating 17 levels of output voltage, indicating the need for several DC sources and power supplies. i.e., it has 8 equal DC voltage sources and 32 switching devices. Figure 2 depicts the traditional architecture of a standard H-Bridge inverter with 17 levels.

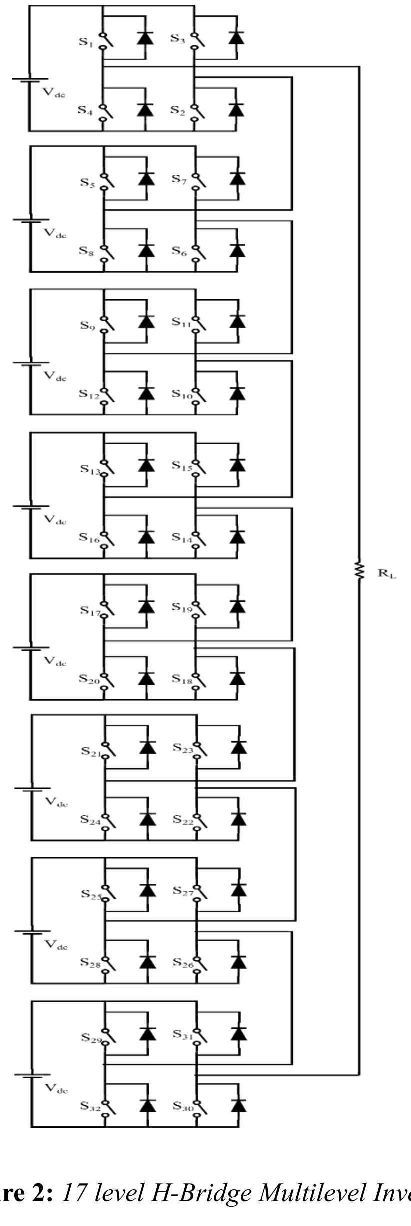

Figure 2: *17 level H-Bridge Multilevel Inverter*

This 17-level symmetrical multilevel inverter generates an output voltage. And this inverter's THD is around 13.18% [8].

2.3 33 Level Cascaded H-Bridge Multilevel Inverter

By raising total steps of the AC voltage output, an MLI's THD and output profile quality may be improved. This may be accomplished by utilizing more H-Bridge cells than usual. 64 switching units and 16 DC voltage sources make up the 16 H-Bridge cells that constitute a standard 35 level cascaded H-Bridge MLI [9]. This 33 level MLI's THD is around 7.5%.

3 Modified Switched Capacitor Multilevel Inverter

This paper introduces an innovative SC-MLI architecture. It is made by fusing a neutral-point-piloted (NPP) network with SC units. Each SC units are known as double mode SC. It utilizes a single DC supply and fewer switching components than traditional multilevel inverters. Other benefits of this suggested design include lower THD and self-balanced voltage capabilities [10]. The two switches in the switched capacitor units operate in complementary manner and one switch in the NPP unit is bidirectional. Unlike other switches, which only use one device, this bidirectional switch is accomplished by using two transistors.

3.1 9 Level Switched Capacitor Multilevel Inverter

Four H-Bridge cells, 16 switching elements, and four dc voltage sources make up a conventional nine-level CHB multilevel inverter. The new arrangement, which may be supplied by one DC source, can reduce the number of switches. There are 8 switches, 4 capacitors, and 2 diodes in this 9 level SC-MLI. The switching capacitor unit produces the various output voltage levels in steps. Figure 3 depicts the suggested 9 level SC-circuit MLI's design.

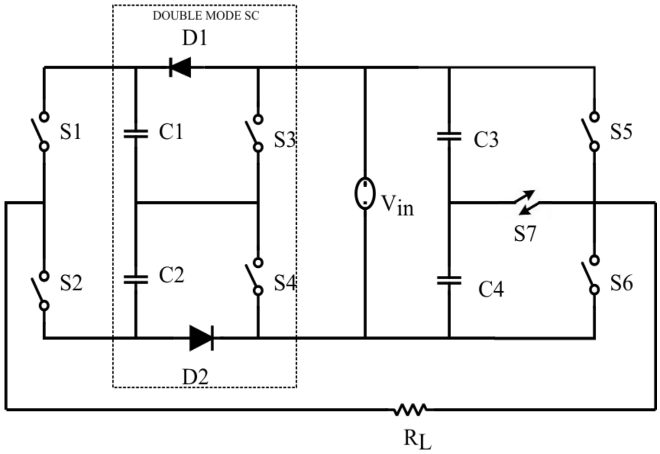

Figure 3: *Circuit diagram of modified 9 Level Switched capacitor multilevel inverter*

By the use of Fast Fourier Transform (FFT) analysis, the THD of the inverter may be evaluated. This multilevel inverter has a THD of 12.57 %.

3.2 17 level Switched Capacitor Multilevel Inverter

The basic arrangement can have extra switching capacitor units added to it, which will raise the output voltage levels obtained. For the reason, the CVRA's impact might be nullified. The proposed topology of 17 Level SC-MLI generates 17 levels of output voltage (-8Vdc to +8Vdc) supplied from a single DC source. It consists of 10 switching devices, 6 capacitors and 4 diodes. In other words, a 9-level inverter is converted into a 17-level SC-MLI by adding a switched capacitor unit to the circuit. Each voltage level in the AC output voltage is controlled by the charging and discharging states of the switched capacitor units. Any of the 3 switches (S4–S6) in the NPP unit is ever switched on at any given moment. Additionally, each combination of switches (S1&S2, S3&S4, and S5&S6) maintains the complimentary roles of its two transistors. The inverter can generate 17 various steps of AC output voltage using the nine switches. In comparison to the traditional multilevel inverter, the THD is also lower. Figure 4 depicts the circuit schematic for the suggested 17 level SC multilevel inverter. Additionally, the inverter has a THD of 9.59%, which is lesser than compared to other topologies.

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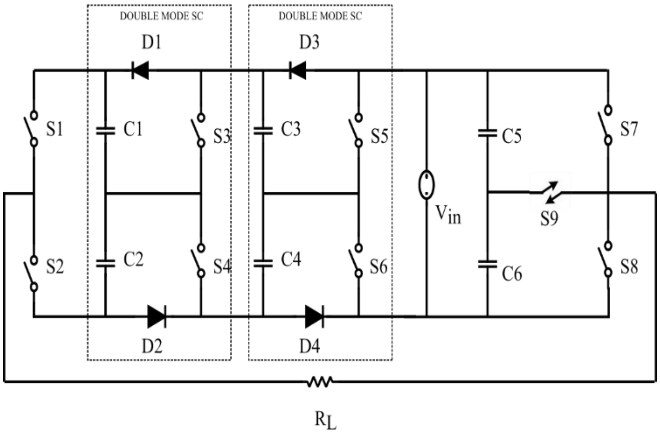

Figure 4: *Circuit Diagram of proposed 17 level Switched capacitor multilevel inverter*

3.3 33 Level Switched Capacitor Multilevel Inverter

It is possible to create the 33-level SC-MLI by rearranging the switching states of the switches and adding one more switched capacitor section to the 17-level MLI. It consists of 12 switching devices, 8 capacitors and 6 diodes. This suggested inverter produces 33 output voltage levels, from -16Vdc to +16Vdc. The circuit diagram is shown in Figure 5. And the THD is about 4.4%.

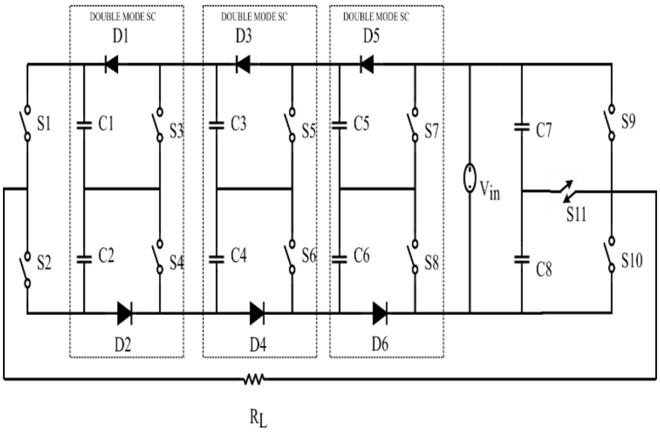

Figure 5: *Circuit diagram of modified 33-level Switched capacitor multilevel inverter*

4 Simulation Results and Discussions

Simulations have been conducted using MATLAB simulink for the standard 9-level inverter, as well as modified inverters with 9-levels, 17 levels and 33-levels. And THD analysis is also being carried out using the FFT Simulink spectrum. All inverters are designed for an R-load of 100Ω. The modified topologies are more convenient than other conventional topologies and they will minimize the DC sources and the switches used in the circuit. The suggested inverter methodology utilizes only one DC source.

4.1 9-level Cascaded H-Bridge inverter

The CHB inverter circuit is simulated with Matlab simulink model. This configuration utilizes 4 DC sources. The waveform of the AC voltage output and load current of the inverter is shown in Figure 6. And the harmonic spectrum of the suggested inverter is represented in Figure 7.

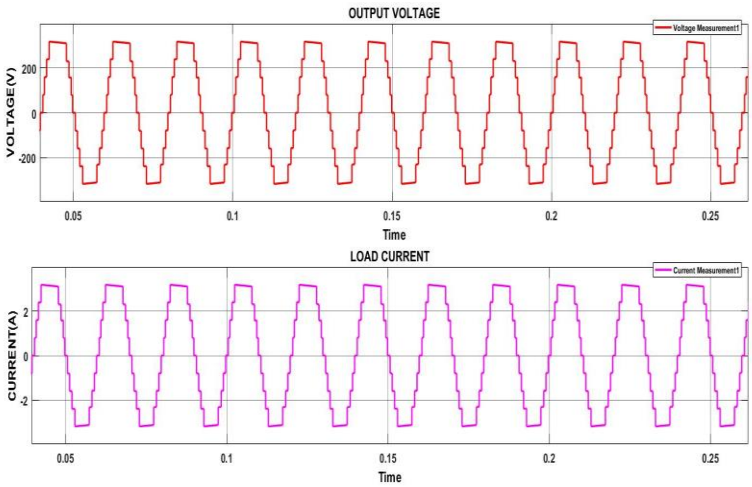

Figure 6: *Output voltage and load current waveform of 9-level Cascaded H-Bridge inverter.*

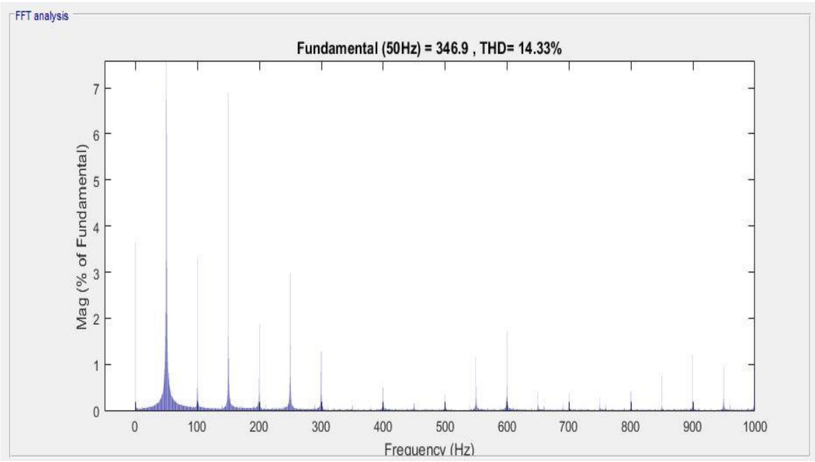

Figure 7: *FFT analysis of 9-level Cascaded H-Bridge inverter*

4.2 Proposed 9-level switched capacitor Multilevel inverter

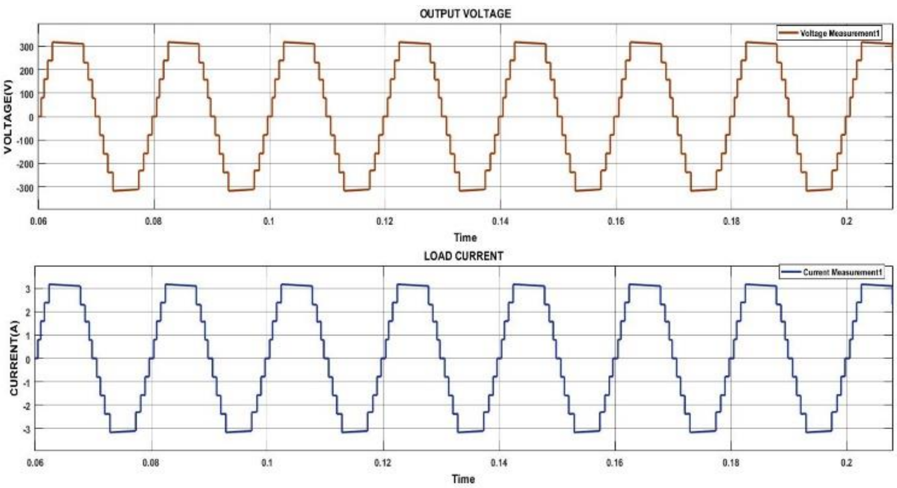

Figure 8: *Output voltage and load current waveform of suggested 9-level inverter*

This inverter generates a nine-level voltage waveform with 320 V as its maximum value. The model was simulated with 160V DC input voltage. Figure 8 depicts the voltage output and also the load current characteristics of the inverter. And the THD analysis of the inverter taken for 50 cycles is given in the Figure 9.

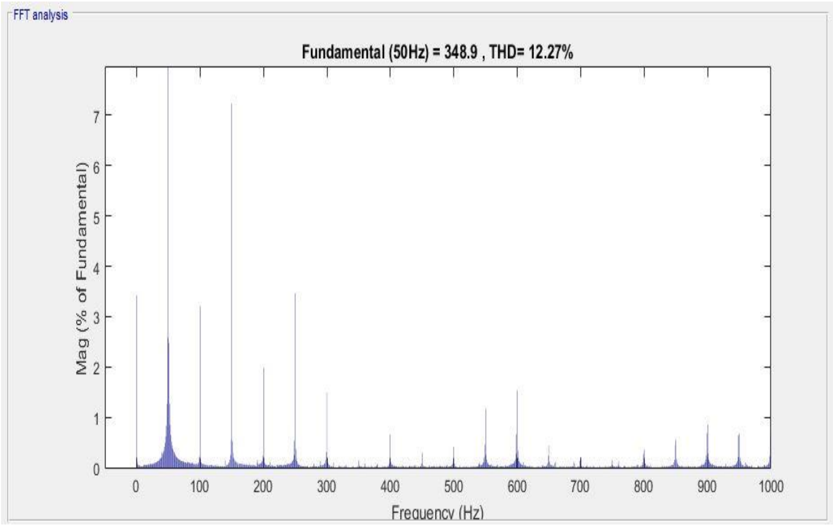

Figure 9: *FFT analysis of suggested 9-level inverter*

4.3 Proposed 17-level switched capacitor multilevel inverter

The circuit configuration for proposed 17-level SCMLI is simulated for a load of 100 Ω resistance with input voltage of 160V. Figure 10 and Figure 11 respectively depicts the waveform of output voltage, load current and the harmonic analysis spectrum of the suggested 17-level switched capacitor methodology.

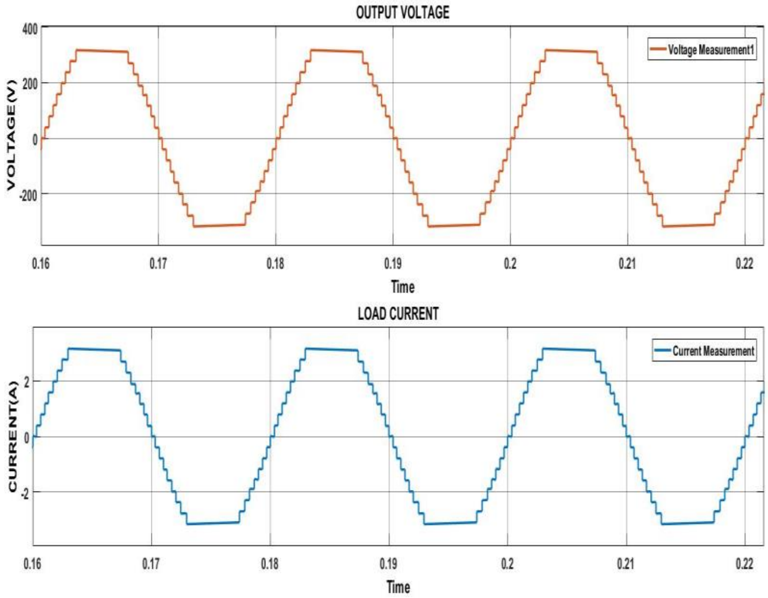

Figure 10: *Output voltage and load current waveform for suggested 17-level inverter*

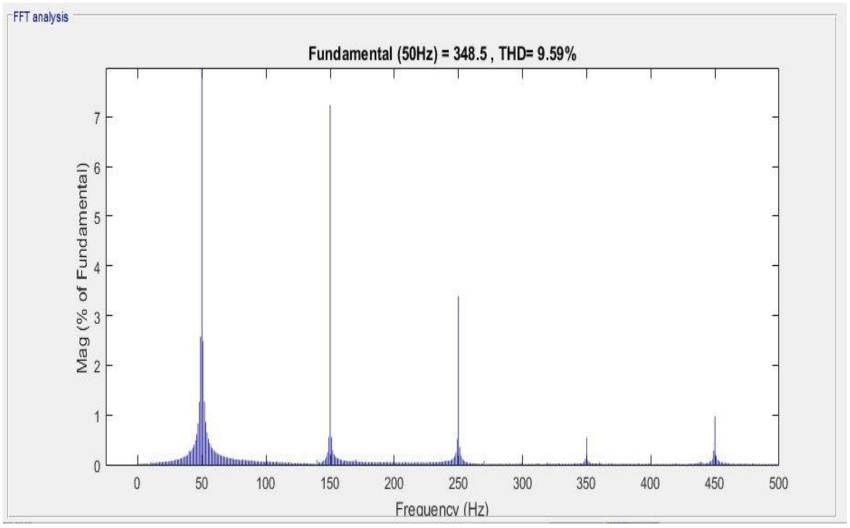

Figure 11: *FFT analysis spectrum of proposed 17-level SCMLI*

4.4 Proposed 33-level switched capacitor Multilevel inverter

With the use of 12 switches, a 33-level voltage can be produced at the load side by this inverter configuration. The input to the system is 48V. The simulation is done using Matlab simulink model with the load of 100Ω. Figure 12 and figure 13 respectively depicts the waveform of stepped AC voltage output, load current and the FFT analysis of the suggested 33-level inverter.

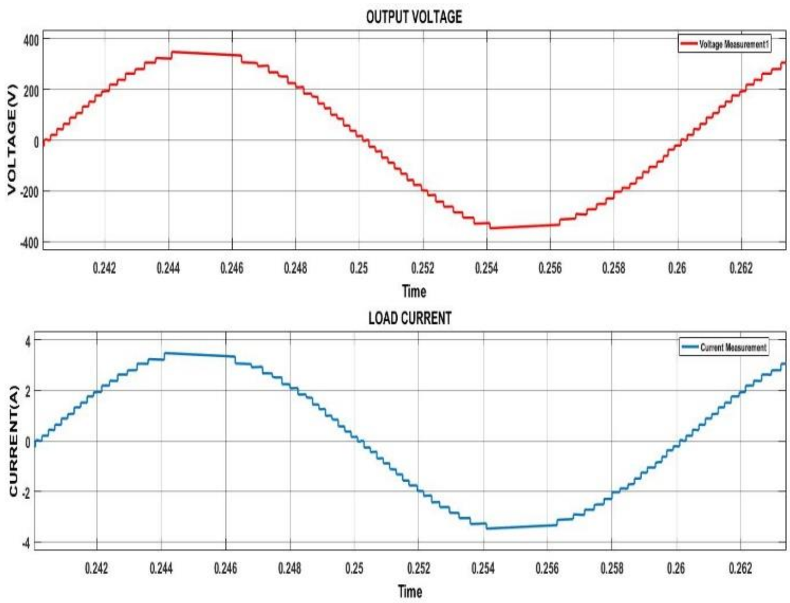

Figure 12: *Output voltage and load current waveform of proposed 33-level SCMLI*

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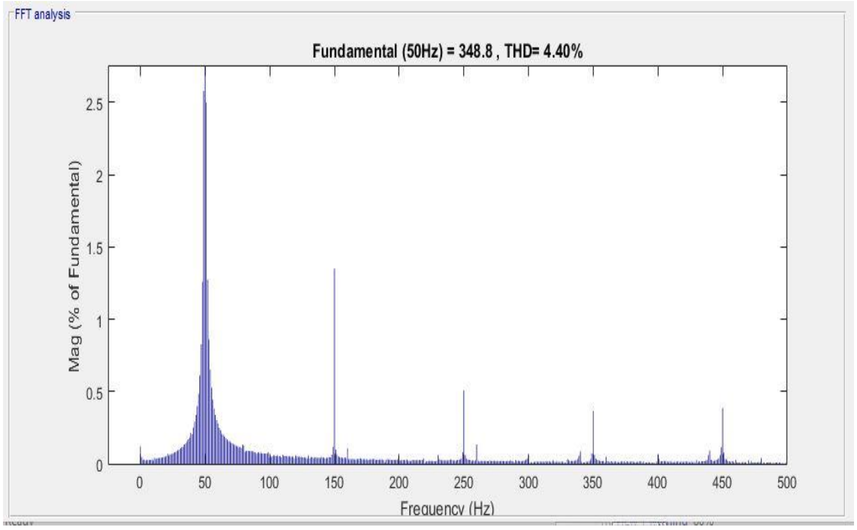

Figure 13: *FFT analysis spectrum of proposed 33-level inverter*

5 Comparison Study

The comparative analysis of conventional CHB multilevel Inverter and the modified topology of SC-MLI are described in this paper. The THD, the switching components used and the DC voltage supplies are compared. Table 1 presents the comparison table.

This comparison table indicates that the modified switched capacitor multilevel inverter topology is more efficient than the conventional topologies. The modified configuration uses only one dc supply, whereas the traditional configuration uses 4,8 and 16 dc sources to supply the 9-level, 17-level, and 33-level multilevel inverter. Additionally, the new arrangement benefits from a lower THD and lesser switching components.

Table 1: *Comparison Study of CHBMLI And Modified SC-MLI*

	CHBMLI			Modified SC-MLI		
	Number of Switches	DC sources	THD (%)	No. of Switches	DC sources	THD (%)
9 Level	16	4	14.2	8	1	12.57
17 Level	32	8	13.2	10	1	9.59
33 Level	64	16	7.5	12	1	4.4

According to the comparative research, a general equation for the total output levels generated, the total active switches and the DC sources needed for the conventional CHBMLI and the modified inverter may be calculated, as seen in table 2.

Table 2: *General Equations for Standard CHBMLI And Modified SC-MLI*

	Standard CHBMLI	Modified SC-MLI
No. of levels	2N+1	2^M+1
No. of switches	4N	2M+2
No.of DC sources	N	1

It shows the general equations for CHB and modified SCMLI in terms of N and M respectively. As an example for 9 level CHB, N is equal to 4 and for 9 level SCMLI, M will be 3.

6 Conclusion

Higher quality and a pure sinusoidal output are necessary for many industrial applications. It is produced by a 2-level inverter, although it has drawbacks such as large switching losses and dv/dt stress. As a result, A multilevel inverter produces a sinusoidal waveform that is stepwise or staircase-like and of very high quality. When the level number increases, which reduces the harmonics, the output voltage waveform resembles a sinusoidal waveform more and more. Cascaded H-bridges are the most frequently used multilevel inverter technique out of all the others. But it uses more voltage sources and switching devices. As a result, both the overall system cost and switching stress increases. The improved self-balancing switched capacitor multilevel inverter is powered by a single DC source. It has fewer components and a reduced THD when compared to a standard CHB multilevel inverter. This topology can be used for applications requiring motor drive and power quality.

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