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A Series Connected Multilevel Inverter with Reduced Number of Switches

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***Abstract* - The main aim behind using the multilevel inverters is to reduce the voltage stress on the inverter switches. At the same time the voltage quality is also very important. The power level of the inverter is also vital depending on the applications that it is used for. Voltage quality improves with the number of levels in the inverter. But, to increase the power levels, it is necessary to increase the voltage capacity of the inverter. This paper proposes a new cascaded multilevel converter. In a cascaded multilevel converter, the thesis recommends using fewer H-bridges to create more voltage levels. The converter employs fewer H-bridges, and the suggested switching technique results in a staircase waveform with more voltage levels and equal steps. The angles are selected for the total removal of additional undesirable harmonics since the resultant voltage levels are equal. MATLAB/SIMULINK was used to simulate the switching scheme in single configurations, and the frequency spectrum of the resulting waveform as well as its total harmonic distortion was shown to verify the results. The converter's number of switches is reduced considerably.**

***Index Terms* - Voltage quality, H-bridges, harmonics, frequency spectrum**

I INTRODUCTION

An inverter is a power electrical device that converts direct current (DC) into alternating current (AC). In a GE study titled "The Inverter," David Chandler Prince coined the word "inverter." The word inverter, according to Prince, refers to any fixed or spinning equipment that converts alternating electricity to direct current. Mechanically rectified DC was the term for early AC to DC converters that used an AC motor to drive a DC generator for rectification. The same motor-generator combination was made to work backwards, resulting in AC from DC. Inverted converter was the name given to this combination.

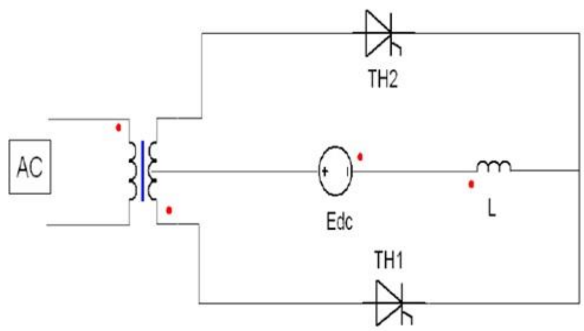

FIGURE 1 Prince's inverter

These Solid-state converters, which used vacuum tubes or gas-filled tubes, eventually supplanted mechanical power converters. Vacuum tubes and gas-filled tubes were utilised as switches in AC-DC and DC-AC converters from the late nineteenth century to the middle of the twentieth century. As a converter switch, the thyratron was the most extensively used device. Thyristors were first introduced in 1957. The invention of thyristors marked a watershed moment in solid-state switching technology.

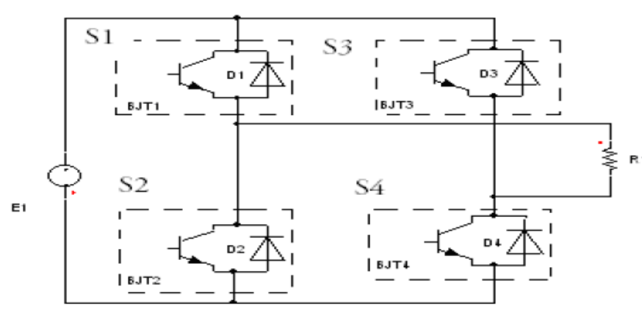

FIGURE 2 Full Bridge Inverter.

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For single and three phase inverters, a variety of topologies were developed. Figure 1 depicts one of the first inverter topologies proposed by Prince. Two solid-state switches and a center-tapped transformer were used to create the inverter. The input side of the transformer is the center-tapped side. One of the DC source's terminals is linked to the transformer's center-tapped terminal. The solid-state switches are linked to the transformer's other two terminals. The AC voltage appears across the inverter's output terminals. When switch TH1 is switched on and switch TH2 is left off, the positive half of the AC voltage is received. When switch TH2 is switched on and switch TH1 is turned off, the other half of the AC voltage is produced. A half-bridge inverter is another name for this inverter scheme. The full-bridge inverter is the other fundamental inverter architecture, and it is the basic building component of a cascaded multilevel converter (MLC).

TABLE 1 Switching table for H-Bridge Inverter

Switch				Voltage
S1	S2	S3	S4	
1	0	1	0	0
1	0	0	1	+V
0	1	1	0	-V
0	1	0	1	0

Four transistors and four diodes make form a single-phase full-bridge inverter. Other solid-state switches, including as thyristors, MOSFETs, GTOs, and IGBTs, may be used to replace the transistor. Solid-state switches are unidirectional switches, meaning they only conduct one way. To create a bidirectional switch, a diode is linked anti-parallel to each transistor. The fullbridge inverter is also known as an H-bridge inverter because of the circuit's resemblance to the letter 'H.'

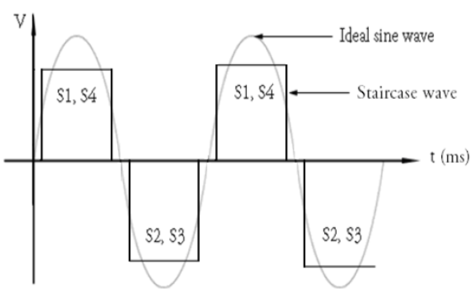


FIGURE 3 Staircase waveform produced by MLI.

A. Harmonics

Harmonics in a system are unwanted oscillations that occur at integer multiples of the fundamental frequency. In an AC system, the voltage and current waveforms should be sinusoidal with constant amplitude, constant frequency, and single frequency. The fundamental's waveform is distorted by the harmonics.

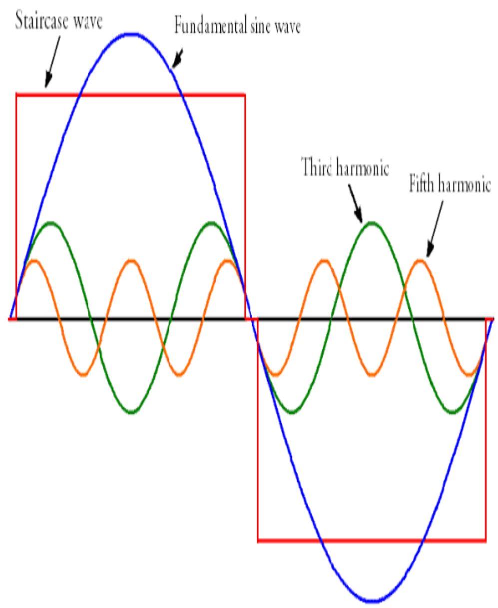


FIGURE 4 Harmonics in square wave.

With the use of the Fourier series, a staircase wave may be dissected into its fundamental and harmonic components, as shown in Figure.1.4 For clarity, only the fundamental, third, and fifth harmonics are depicted in Figure 1.4 The waveform is a mathematical summation of an endless succession of harmonics. The magnitude of the harmonics decreases as the harmonic number increases. Harmonics must always be kept below conventional threshold values, both in terms of THD and individual magnitudes [5].

To measure the quality of the output quantities, the factor called total harmonic distortion (THD) is used. Using this, the purity of voltage and current wave form also can be judged. Following expression is used to measure the quality of the output voltage of a wave form.

$$THD = \frac{|I_{dist}|}{|I_1|} \times 100$$

$$= \sqrt{\left(\frac{|I|}{|I_1|}\right)^2 - 1} \times 100$$

The variable can be voltage also in above equation. The other factor is the distortion factor, the expression is given by

$$pf = \frac{|P|}{|S|} = \frac{|V_S||I_{S,1}|\cos\ \phi_1}{|V_S||I_S|}$$

$$pf = \frac{|I_{S,1}|}{|I_S|}\cos\ \phi_1$$

$$dpf = \cos\ \phi_1$$

$$pf = \frac{1}{\sqrt{1+THD^2}}.dpf$$

Harmonic voltages and currents flow through the periphery of the conductor and reduce the crosssectional area of the conductor because they are high frequency components of the fundamental. The conductor's equivalent resistance rises as a result of this. Overheating occurs in the wiring of motors, transformers, and other electrical devices as a result of this. It leads to the premature breakdown of insulating materials and a reduction in the electrical machine's lifetime. As a result, harmonics reduce the system's reliability and efficiency. A thorough analysis of the harmonics present in the system is required to reduce or eliminate harmonics from the system. The Fourier series is a powerful tool for analysing periodic functions.

B. Periodic function

A function which repeats over a certain time interval is called a periodic function. The time interval for which it repeats is called period of that waveform. Generally the output of the inverter is a periodic waveform, if it is operated at fundamental frequency. The function can be either an odd or an even function. Below are the properties of the functions.

$$f(t) = f(-t)$$

$$f(t) = -f(t)$$

$$f(t) = f_{even}(t) + f_{odd}(t)$$

$$f(t) = -f\left(t + \frac{T}{2}\right)$$

Quarter-wave symmetry describes a periodic function that is both half-wave symmetric and even or odd.

The periodic function f (t) displays hidden symmetry when it is moved in time by a constant. Using Fourier analysis, a periodic wave from the inverter may be divided into a sequence of basic and harmonic terms.

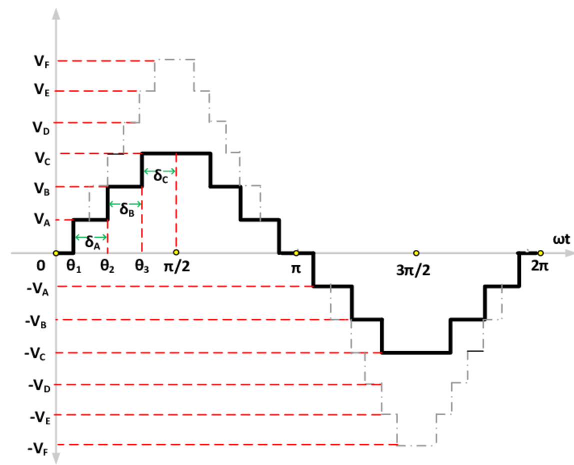


FIGURE 5 Output wave form for THD calculation.

II MULTILEVEL INVERTERS

Multilevel inverters are the best circuits to get the closer waveform to the sinusoidal. It allows adding any number of levels in output staircase waveform. Following are the important advantages of the multilevel inverters.

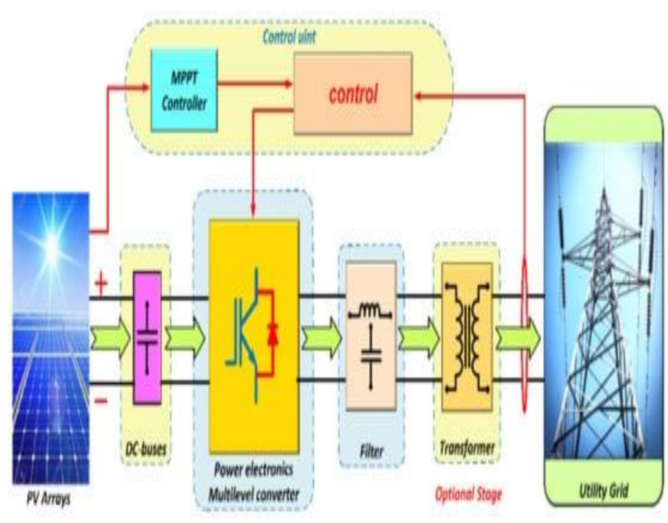


FIGURE 6 An application of MLI.

- Operated at fundamental frequency
- More suitable for high power applications
- Reduced voltage stress

- Low dv/dt stress.

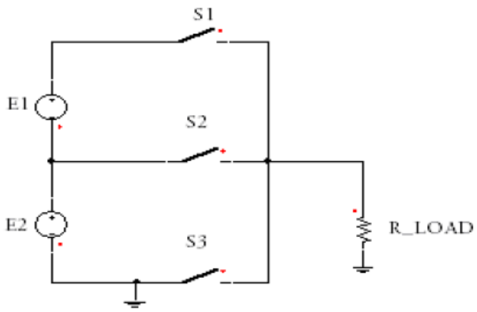


FIGURE 7 Concept of multilevel inverter.

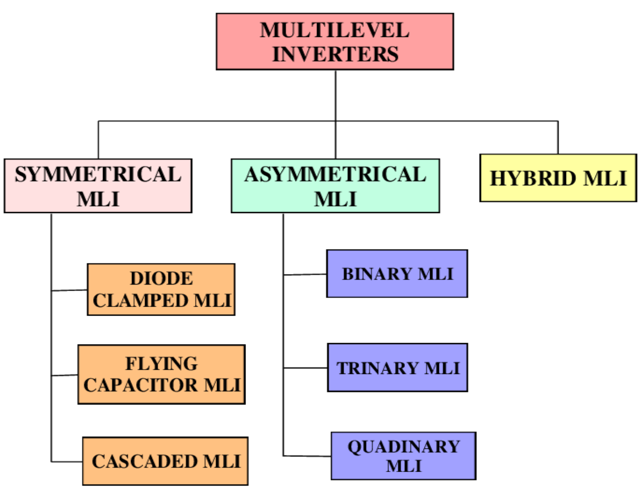
TABLE 2 Switching table of MLI.

Switch			Voltage across the load
S1	S2	S3	Volts
0	0	1	0
0	1	0	E1
1	0	0	E1+E2

A.Types in multilevel inverter

Following are the types in conventional multilevel inverters.

- Diode clamped multilevel inverts
- Flying capacitor multilevel inverters
- Cascaded H Bridge Inverters.



B.Modulation methods

Modulation method is nothing but the way of generating the gating pulses for a multilevel inverter. There are many types in modulation methods of a MLI. Following are the types in multilevel inverter modulation methods.

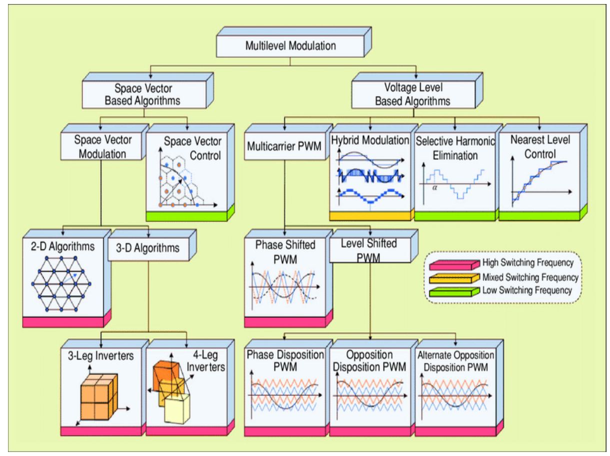


FIGURE 8 Classification of MLI modulation methods.

Few modulation methods are:

- Sinusoidal pulse width modulation
- Stair case modulation
- Selective harmonic elimination
- Space vector modulation
- Nearest level modulation
- Delta sigma modulation

IV MULTILEVEL INVERTER WITH LESS NUMBER OF SWITCHES

The total loss in a multilevel inverter depends on the total switching performed during the operation of the inverter. If the numbers of switches are high, then it leads to a lesser power conversion efficiency. To overcome this, the researchers proposed various advanced multilevel inverters, which are called reduced count multilevel inverter. Following are the various reduced count multilevel inverters.

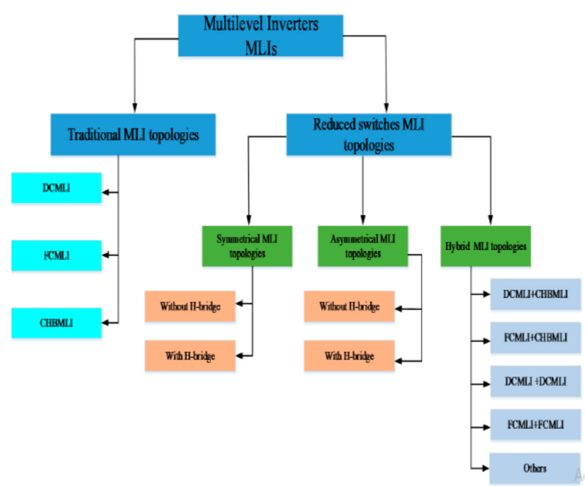


FIGURE 9 Various reduced count MLIs.

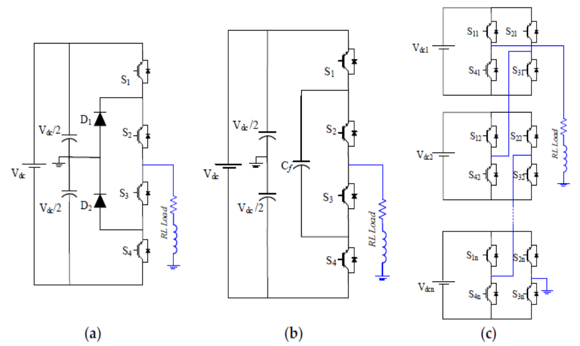


FIGURE 10 Conventional MLIs.

Reduced count MLIs:
Following are the various types in reduced component count multilevel inverters.

A. Symmetrical MLIs without H bridge:

Inverters with a low number of different levels will be utilised with these types of inverters. The design is symmetrical, however there are no modules in it. The configurations for symmetrical MLIs without H Bridge are listed below.

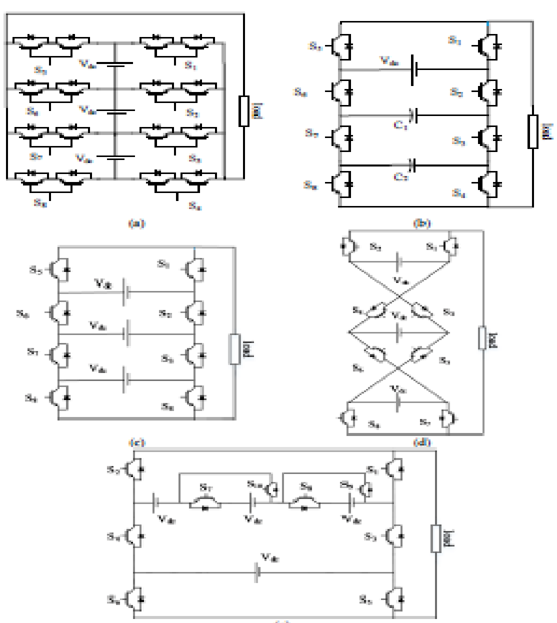


FIGURE 11 Without H bridge topology.

B. Symmetrical with H Bridge

This inverters are based on the H bridge structure. By making some minimum changes in H bridge, this topologies can be derived.

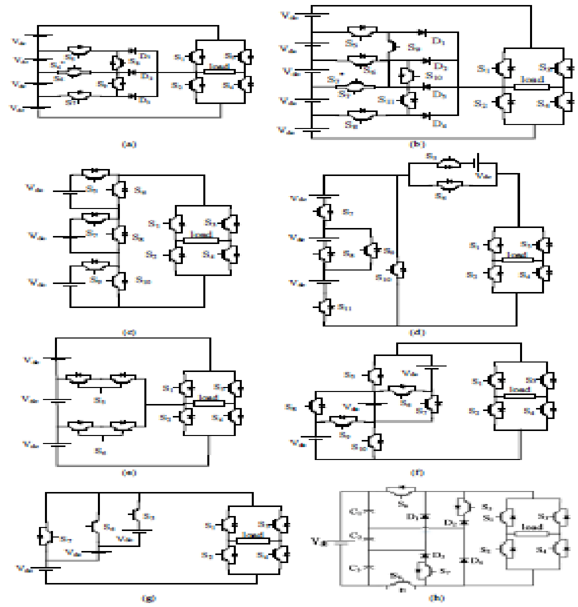


FIGURE 12 Topology of MLI with H bridge.

C. Asymmetric MLIs

If the magnitudes of all the voltage sources are not equal then it is called an asymmetrical multilevel inverter.These configurations provide lot of redundant states. Due to this using less number of switches, it is possible to generate more voltage levels. Following are the few configurations of asymmetric MLIs.

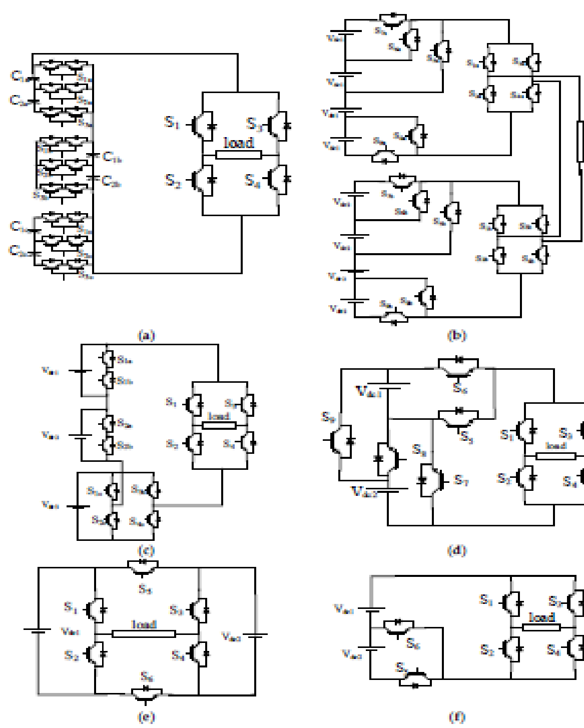


FIGURE 13 Asymmetric MLIs configuration.

D. Proposed Multilevel Inverter

In this work, a seven level series connected H bridge based multilevel inverter is proposed, modelled and simulated. The circuit topology of the same is shown below.

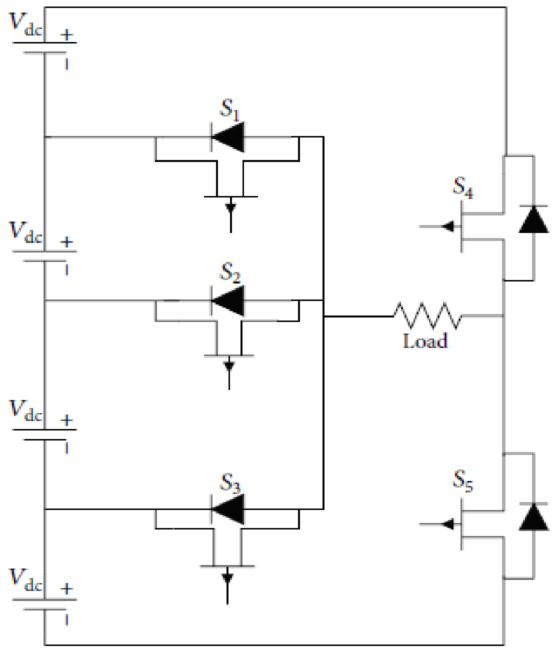


FIGURE 14 Proposed seven level MLI with less number of switches.

The proposed MLI can generate seven levels in output wave forms using only five switches. Whereas the conventional MLI requires 12 main switches. This reduces switching loss associated with the power conversion process. Following is the switching table of the proposed multilevel inverter.

V SIMULATION RESULTS

Following are the specifications of the proposed 7 level five switch multilevel inverter circuit.

- Number of levels = 7
- Number of switches = 5
- Configuration = Cascaded H Bridge.
- Modulation Method used = Fundamental frequency
- Load value = Resistive, 10 OHM.
- Source voltage = 10 V.
- Number of voltage sources = 4
- Switch used = MOSFET.

The simulation of the proposed inverter with five switches is shown in the figure below.

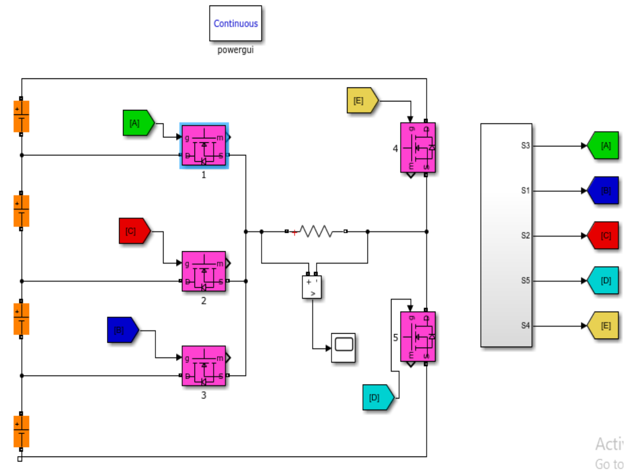


FIGURE 15 Proposed MLI.

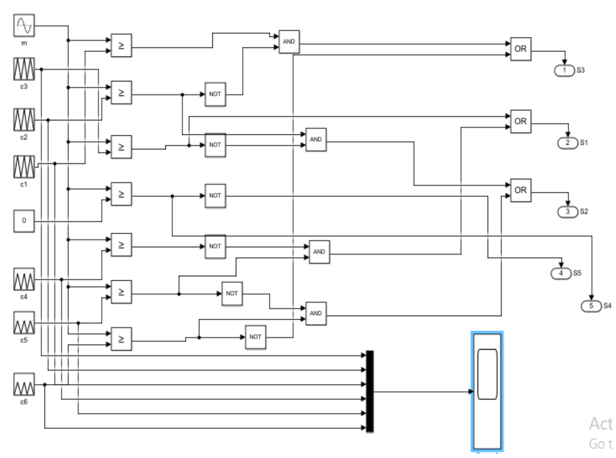


FIGURE 16 Switching circuit.

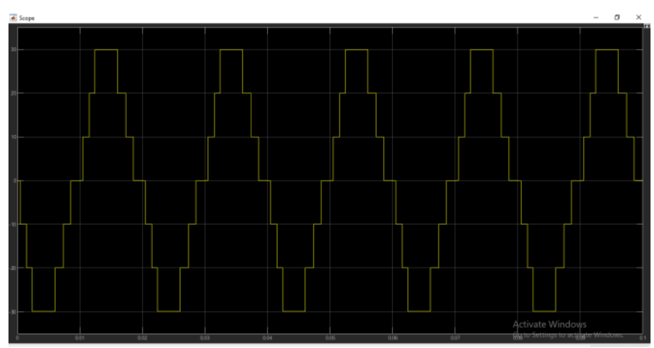
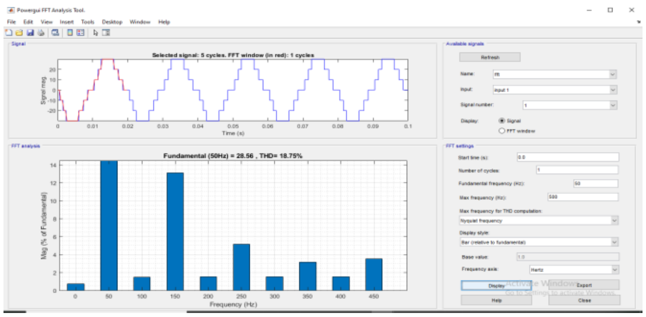


FIGURE 17 Output voltage waveform of the proposed MLI.

The output voltage waveform derived from modelling of the designed 7 level five switch multilevel power converter is shown above. There are three positive levels, three negative levels, and a zero level in this system. The maximum voltage is 30 volts, with a peak to peak voltage of 60 volts.

The FFT analysis is used to check the terminal voltage effectiveness of the suggested MLI, wherein the THD is calculated. The FFT analysis of the output voltage waveform generated by the proposed MLI is shown in the figures below.



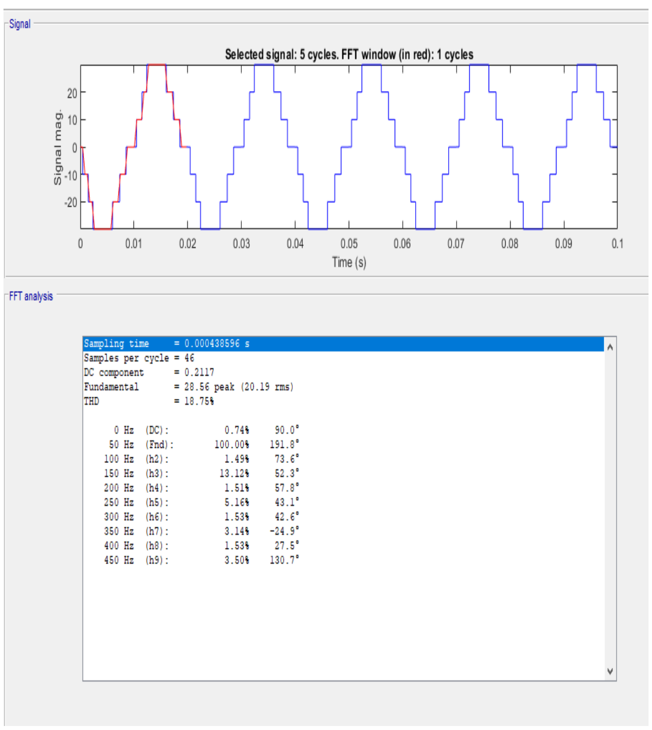


FIGURE 18 FFT analysis of the output voltage waveform.

The above figure shows the FFT analysis of the output voltage waveforms obtained by the proposed reduced switch multilevel inverter. Following are the various parameters obtained from the FFT analysis.

- The output voltage RMS = 20.19
- The output voltage peak = 30 V
- THD in percentage = 18.75 %
- Fundamental Component = 28.56 V
- Percentage of fundamental component = 100%
- Fundamental frequency = 50 HZ
- The maximum frequency considered = 500 HZ

TABLE 3 Comparison of the proposed topology with other topologies.

Inbuilt structure	Flying capacitor	Diode clamped	Cascaded 7-level	7-level, 9 switches	7-level, 7 switches	7-level, 6 switches	Proposed 7-level, 5 switches
No. of capacitors	14	6	-	-	-	-	-
No. of diodes	-	≥8	-	-	-	-	-
No. of switches	10	10	12	9	7	6	5*
No. of dc sources	-	-	3	3	3	4	4*

From the comparison table, it is clear that the the proposed inverter produces less THD in output compared with the many existing topologies. It also reduces the switching loss.

CONCLUSION

The 7 levelreduced switch count multi level inverter topology is proposed in this work.The same inverter is studies and designed. Following points are the major conclusions

- A seven level MLI with only five switches is designed.
- Comparison is made with other topologies.
- The output voltage quality is improved.
- The working component in the voltage is high with proposed inverter..

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FUTURE WORK

Following factors of the woks are left as a future scope of this project.

- Full load operation of the proposed inverters
- Design for high power application.

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