



# A Comparative Analysis of Different Multilevel Inverters

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**ABSTRACT:** In recent days, power demand is continuously increasing. Therefore, the use of nonconventional energy sources is rapidly increasing. Among the various non-conventional sources solar energy is more promising one. The Solar energy is converted into electricity using Photovoltaic modules whose output is DC in nature. This DC is required to convert into Ac using multilevel inverters. In multilevel inverters as the number of levels in the output voltage increases, the accuracy of the system increases and the output voltage approaches nearer to the sinusoidal. As the levels in multilevel inverter increases, the complexity of the system increases due to their control strategy requirement. So at every stage user has to make a trade off with the quality of the output and complexity of the circuit. This paper deals with the 5, 7, 9, 11 levels of H bridge cascaded inverters and the simulation studies using MATLAB/Simulink software, with equal angle switching and equal area switching methods for different levels of inverters. A comparative study between different parameters of the multilevel inverters is performed for the selection of required multilevel inverter. The results obtained are also presented.

**KEYWORDS:** Multilevel inverter, MATLAB/Simulink, equal angle method, equal area method, THD.

## I. INTRODUCTION

As the cost of fossil fuels continue to rise, other sources of energies are becoming important. Renewable energy sources (solar, wind, fuel cell etc) are considered as alternative energy sources to conventional fossil fuel energy sources due to environmental pollution and global warming problems. Solar energy is one of the most promising renewable sources that can be used to produce electric energy through photovoltaic (PV) process. A significant advantage of PV system is the use of abundant and free energy from the sun. However, these systems still face major obstacles that limit their widespread use due to their high cost and low efficiency when compared with other renewable technologies. Moreover, the intermittent nature of the output power of PV systems reduces their reliability in providing continuous power to customers. In addition, the fluctuations in the output power due to variations in irradiance and presence of harmonics might lead to undesirable performance of the electric network. Grid-connected PV-Systems consist of three main blocks: DC bus (PV panels), power converter and electrical network. The power converter acts as an interface between the DC voltage, and AC grid, injecting power into electrical network. The DC/AC conversion is performed in this power converter introduces harmonics, some power losses such as switching losses, conduction losses and losses in reactive elements. An optimal design is needed to reduce these losses so that a reliable quality output and higher efficiency is obtained.

In comparison with the hard switched two level inverter, multilevel inverter can operate at high voltage with lower  $dv/dt$  [7]. There are three basic MLI topologies: neutral-point-clamped, flying-capacitor MLIs, requiring only one dc source, and cascaded H-bridge MLI (CHB-MLI), [2] requiring separate dc sources. The latter characteristic, which is a drawback when a single dc source is available, becomes a very attractive feature in the case of PV systems, because solar cells can be assembled in a number of separate generators. Since their output voltage is a modulated staircase, they outperform two-level PWM inverters in terms of total harmonic distortion (THD), without the use of bulky expensive and dissipative passive filters. Therefore, recently, they have been proposed in the field of renewable energies [6].

## II.CASCADE H-BRIDGE MULTILEVEL INVERTER

The basic topology of H-bridge multilevel inverter with symmetrical switches is shown in figure 2.1 (a)(b). This type of topology consists of several H-bridges connected in cascade, with every unit having its own dc source. With different combination of sources corresponding to the switching pattern, different levels of output voltage can be obtained. The required number of levels in the output is given by the equation[3],  $M = 2S + 1$  Where  $M$  = Number of levels,  $S$  = Number of H-bridges, The output of the multilevel inverter should be quarter symmetric to generate a sine wave. Due to quarter wave symmetry even harmonics are absent in the output of the multilevel inverter. There are various switching scheme available to generate the output voltage waveform, in which fundamental switching scheme is the simplest one.

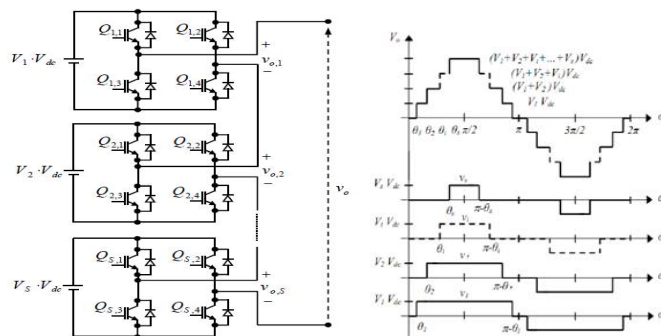


Fig 2.1. (a)Single phase H-bridge multilevel inverter circuit diagram and (b)output waveform

Generated output voltage waveform by fundamental switching scheme is shown in fig 1(b). The Fourier series expansion of the output voltage waveform can be given as follows [3]

$$V_0(wt) = \sum_{n=1,3,\dots}^{\infty} \frac{4V_{dc}}{n\pi} [V_1 \cdot \cos(n\theta_1) + V_2 \cdot \cos(n\theta_2) + V_3 \cdot \cos(n\theta_3) + \dots + V_s \cos(n\theta_s)] \sin(nwt) \dots (1)$$

Where  $V_s$  and  $\theta_s$  are the voltage value and switching angle for the  $S^{\text{th}}$  voltage source.

For any waveform which not sinusoidal in nature, then its Fourier expansion contains components respective to the multiple of fundamental frequency. From equation (1), we can observe that the obtained output waveform is not a sinusoidal and it contains harmonics which reduce output quality. Different topologies and control strategies have been proposed for different levels of output to improve the performance of multilevel inverters for practical application.[5][6] There are various algorithms and switching schemes available to remove most severe harmonics [2]. In this paper we are depicting the parameters of different level inverters. The results of this paper can be used for further analysis.

## III.ANALYSIS OF DIFFERENT LEVEL INVERTERS

### 3.1- Five Levels H-BridgeMultilevel Inverter

A 5-level cascaded multilevel inverter with two DC sources and the corresponding phase voltage waveform is shown in Figures 3(a)an3(b) respectively. The number of output voltage levels are  $2n+1$ , where  $n$  is the number of cells or separate DC source. 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 types. DC sources can be equal or unequal so we have two configurations, symmetric and asymmetric cascade H-bridge multilevel inverter. The output waveforms of multilevel inverters are in a stepped waveform therefore they have reduced harmonics compared to a square wave inverter. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge inverter. Each inverter level can generate three different voltage outputs  $+V_{dc}$ ,  $0$ ,  $-V_{dc}$ , by connecting the dc source to the ac output by different combinations of the four switches,  $S_1$ ,  $S_2$ ,  $S_3$ , and  $S_4$ . The ac outputs of each of the different full-bridge inverter levels are connected in cascade such that the synthesized voltage waveform is the sum of the inverter outputs. In this analysis to get 315 volts peak at the load we have used 2 H- Bridges of symmetrical DC input voltages of 156 volts.

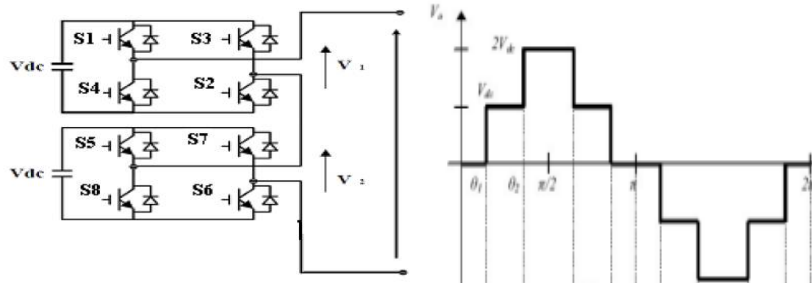
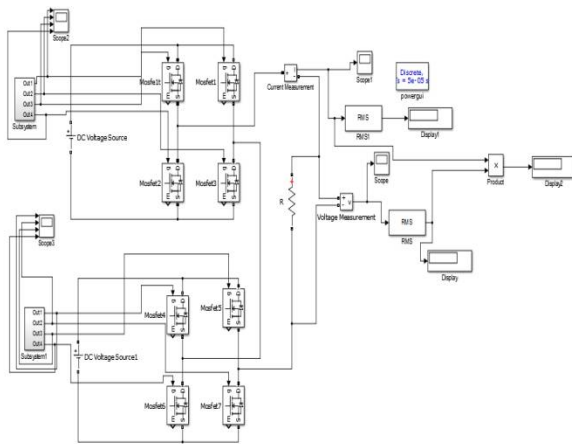


Fig.3.1(a) Five Level Circuit Diagram and (b) Waveform



	S1	S2	S3	S4	S5	S6	S7	S8
2v	1	1	0	0	1	1	0	0
V	1	1	0	0	0	1	0	0
0	0	0	0	1	0	0	0	1
-v	0	0	1	1	0	1	0	0
-2v	0	0	1	1	0	0	1	1

Fig 3.1(c).MATLAB/Simulink model of 5 level MLI and Table 3.1 Switching Table for 5 Level Inverter

### 3.2 Seven Level H-Bridge Multilevel Inverter

The concept of this inverter is based on connecting 3 H-bridge inverters with separate DC sources in cascade to get a sinusoidal voltage output. The output voltage is the sum of the voltage that is generated by each cell. Figure 3.2(a) shows a seven level cascaded H-bridge multilevel inverter. The converter consists of three series connected H-bridge cells which are fed by independent symmetrical voltage sources of 104volts. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs. The output voltage is given by  $V=V_1 +V_2 +V_3$  Where the output voltage of the first cell is labelled V1 and the output voltage of the second cell is denoted by V2 and the output voltage of the Third cell is denoted by V3. There are seven level of output voltage i.e. 3V, 2V, V, 0, -V, -2V,-3V. In this analysis to get 315 volts peak at the load we have used 3 H- Bridges of symmetrical DC input voltages of 104 volts.

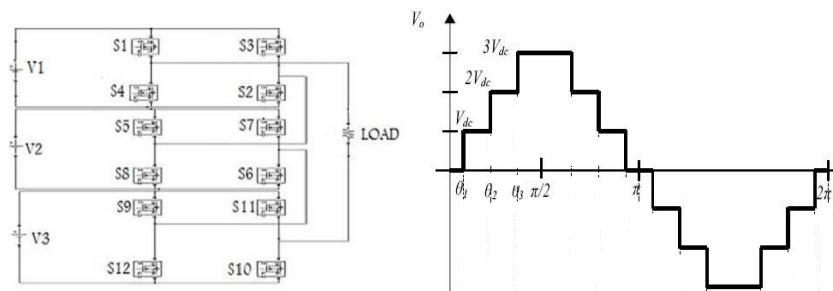
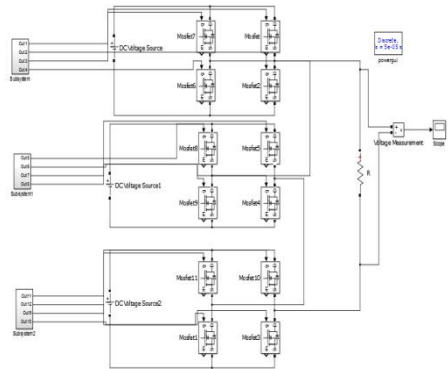


Fig 3.2 Seven-level H-bridge multilevel inverter (a) circuit diagram and (b) waveform



	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
3v	1	1	0	0	1	1	0	0	1	1	0	0
2V	1	1	0	0	1	1	0	0	0	1	0	0
V	1	1	0	0	0	1	0	0	0	1	0	0
0	0	0	0	1	0	0	0	1	0	0	0	1
-v	0	0	1	1	0	0	0	1	0	0	0	1
-2v	0	0	1	1	0	0	1	1	0	0	0	1
-3v	0	0	1	1	0	0	1	1	0	0	1	1

Fig 3.2(c).MATLAB/Simulink model of 7level MLI

Table 3.2 Switching Table for 7 Level Inverter

### 3.3 Nine Level H-Bridge Multilevel Inverter

The concept of this inverter is based on connecting four H-bridge inverters with separate DC sources in cascade to get a sinusoidal voltage output. The general function of this multilevel inverter is to synthesis a desired voltage from several Separate DC Sources (SDCSs), which may be obtained from photovoltaic cells. The output voltage is the sum of voltage that is generated by each cell. Figure 3.3 shows a nine level cascaded H-bridge multilevel inverter. The converter consists of four series connected H-bridge cells which are fed by independent voltage sources of 78 volts. The output of the H-bridge cells is connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs. The output voltage is given by  $V=V1 +V2 +V3+V4$  Where the output voltage of the first cell is labelled V1 and the output voltage of the second cell is denoted by V2 , the output voltage of the Third cell is denoted by V3 and the output voltage of the fourth cell is denoted by V4. There are nine level of output voltage i.e. 4V, 3V, 2V, V, 0, -V, -2V,-3V,-4V. In this analysis to get 315 volts peak at the load we have used four H-bridges of symmetrical DC input voltages of 78 volts.

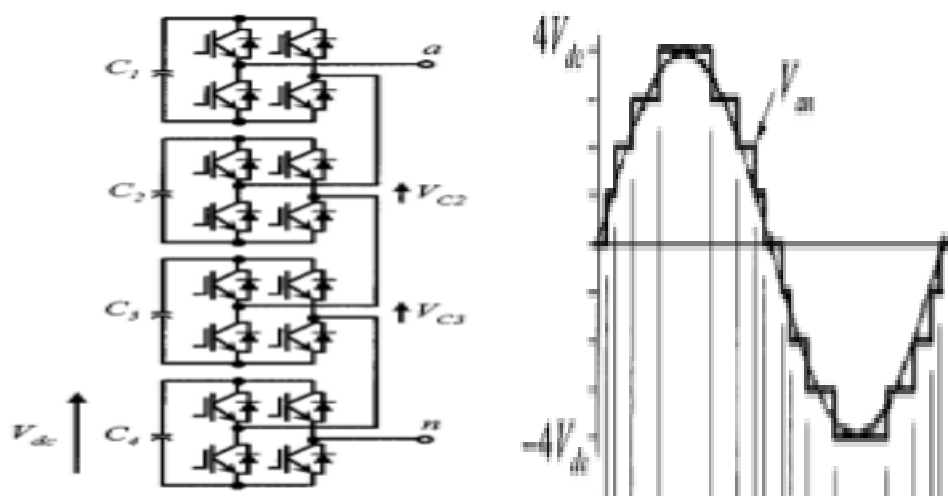


Fig 3.3.Nine level H-bridge multilevel inverter (a) circuit diagram and (b) waveform

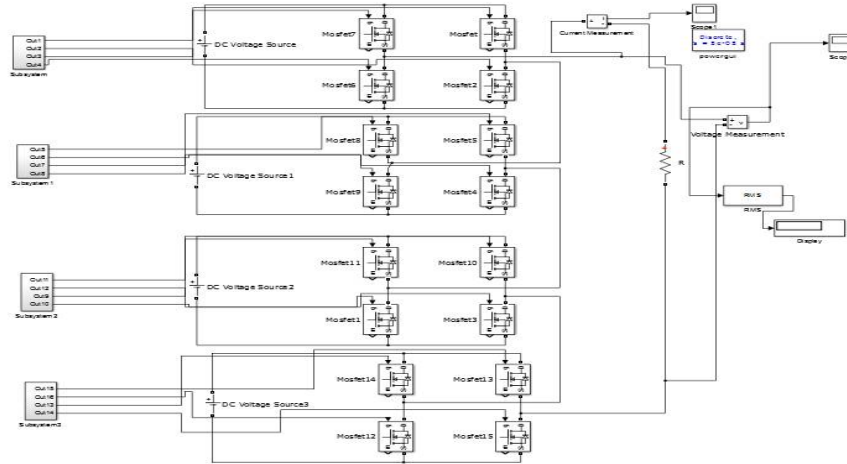


Fig 3.3 (c). Simulink model for nine level h-bridge inverter

Table 3.3: Switching Table for 9 Level Multilevel Inverter

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
4v	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
3V	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0
2V	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0
V	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
-v	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1
-2v	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0	1
-3v	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1
-4v	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1

### 3.4 Eleven Level H-Bridge Multilevel Inverter

The concept of this inverter is based on connecting five H-bridge inverters with separate DC sources in cascade to get more close to sinusoidal voltage output. The general function of this multilevel inverter is to synthesis a desired voltage from several Separate DC Sources (SDCSs), which may be obtained from batteries, fuel cells, or ultra-capacitors. The output voltage is the sum of the voltage that is generated by each cell. Figure shows a nine level cascaded H-bridge multilevel inverter. The converter consists of five series connected H-bridge cells which are fed by independent voltage sources of 63 volts. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs. The output voltage is given by  $V = +V_1 + V_2 + V_3 + V_4$  Where the output voltage of the first cell is labelled  $V_1$  and the output voltage of the second cell is denoted by  $V_2$ , the output voltage of the Third cell is denoted by  $V_2$ , the output voltage of the fourth cell is denoted by  $V_4$  and the output voltage of the fifth cell is denoted by  $+V_5$ . There are seven level of output voltage ie 5V,4V,3V, 2V, V, 0, -V, -2V,-3V,-4V,-5V. In this analysis to get 315 volts peak at the load we have used 5 H- bridges of symmetrical DC input voltages of 63 volts.

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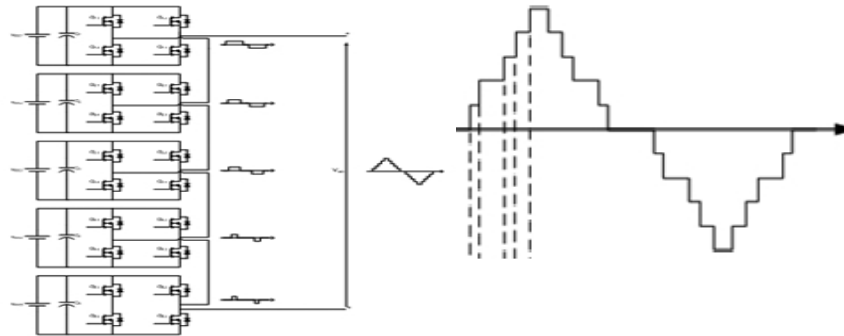


Fig 3.4. Eleven level H-bridge multilevel inverter (a) circuit diagram and (b) waveform

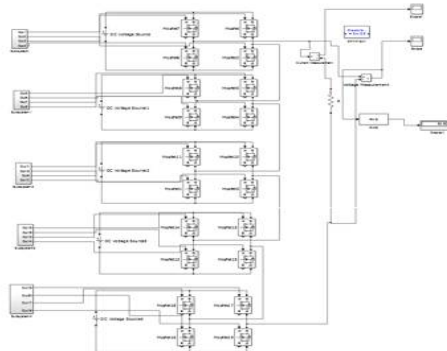


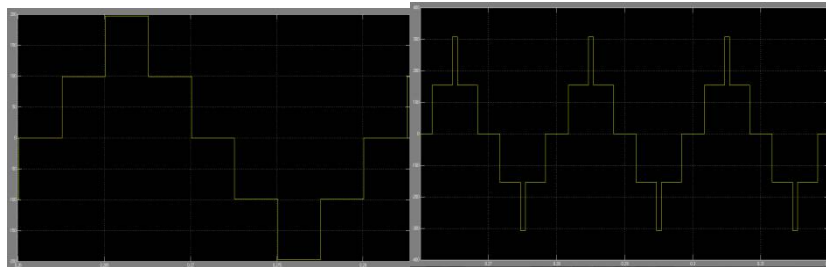
Fig 3.4 (c). Simulink model for eleven level h-bridge inverter

Table 3.4. Switching Table for Eleven Level Inverter

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
5V	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	1
4V	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0
3V	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0
2V	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
V	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
-V	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
-2V	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1
-3V	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	0	0	0	0	1
-4V	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1
-5V	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1

**IV.SIMULATION RESULTS USING MATLAB/SIMULINK**

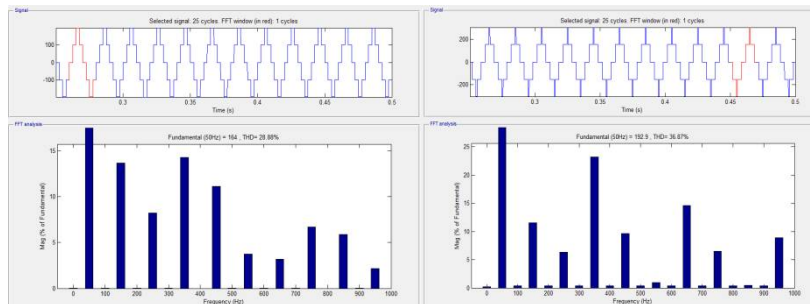
**4.1 Five Level multilevel inverter**



(a)Equal angle method (b) Equal area method

Fig 4.1 Output voltage waveform for Five level MLI

The 5 level inverter has been simulated using MATLAB/Simulink by considering a resistive load of 25 ohms. It makes use of two separate DC sources of equal magnitude for the two H-bridges of the inverter circuit. The magnitude of the DC sources considered for analysis are  $V_{dc1}=V_{dc2}=156V$  each to get an AC output of 220V RMS. The simulation results obtained are tabulated in table 4.5.

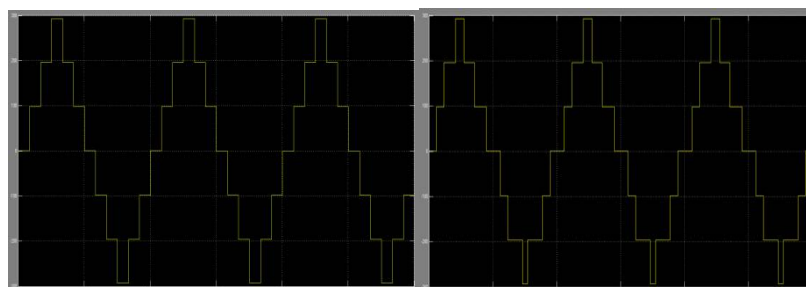


(c) Equal angle method (d) Equal area method

Fig4.1 FFT analysis of Five level MLI output

Figure 4.1 shows the simulated output voltage waveforms and FFT analysis chart for the five level inverter considered. The graph also shows the percentage of different harmonics present in the output signal. The FFT graph shows that 7<sup>th</sup> harmonic is dominant compared to 3<sup>rd</sup> and 5<sup>th</sup> harmonics.

**4.2 Seven Level Multilevel Inverter**



(a) Equal angle criteria (b) Equal area criteria

Fig 4.2 Output voltage waveform for Seven level MLI

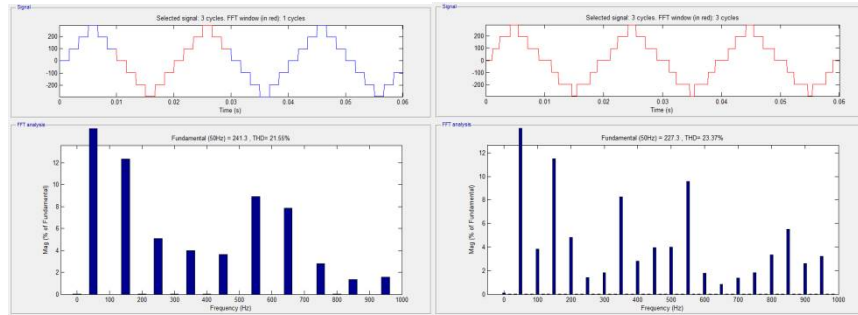
The 7 level inverter has been simulated using MATLAB/Simulink by considering a resistive load of 25 ohms. It makes use of three separate DC sources of equal magnitude for the three H-bridges of the inverter circuit. The magnitude of the DC

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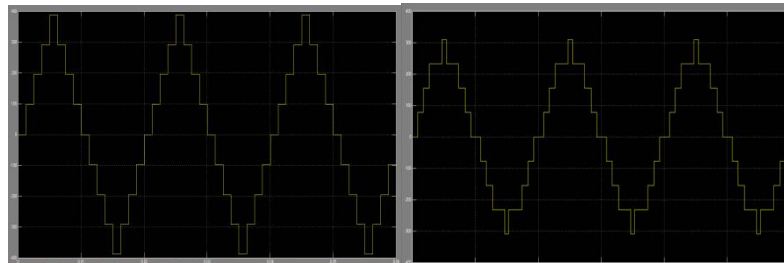
sources considered for analysis are  $V_{dc1}=V_{dc2}=V_{dc3}=104V$  each to get an AC output of 220V RMS. The simulation results obtained are tabulated in table 4.5.



(c) Equal angle method (d) Equal area method  
Fig 4.2 FFT analysis of Seven level MLI output

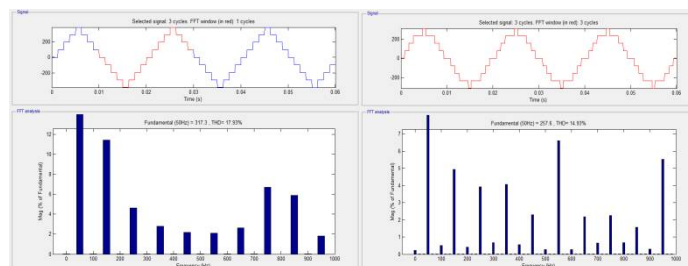
Figure 4.2 shows the simulated output voltage waveforms and FFT analysis chart for the seven level inverter considered. The graph also shows the percentage of different harmonics present in the output signal. The FFT graph shows that 3<sup>rd</sup> harmonic is dominant compared to other harmonics.

### 4.3- Nine Level Multilevel Inverter



(a) Equal angle method (b) Equal area method  
Fig 4.3 Output voltage waveform for Nine level MLI

The 9 level inverter has been simulated using MATLAB/Simulink by considering a resistive load of 25 ohms. It makes use of four separate DC sources of equal magnitude for the four H-bridges of the inverter circuit. The magnitude of the DC sources considered for analysis are  $V_{dc1}=V_{dc2}=V_{dc3}=V_{dc4}=78V$  each to get an AC output of 220V RMS. The simulation results obtained are tabulated in table 4.5.

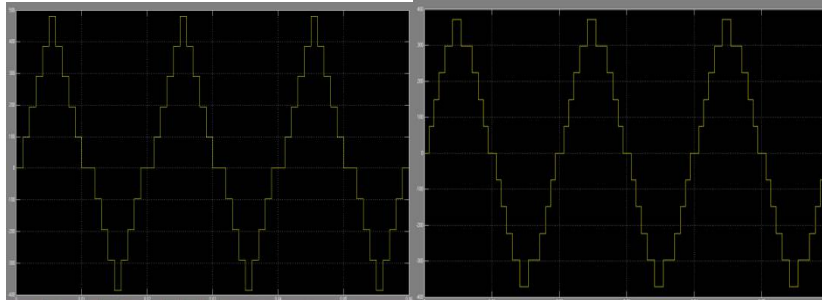


(c) Equal angle method (d) Equal area method  
Fig 4.3 FFT analysis of Nine level MLI output



Figure 4.3 shows the simulated output voltage waveforms and FFT analysis chart for the nine level inverter considered. The graph also shows the percentage of different harmonics present in the output signal. The FFT graph shows that 3<sup>rd</sup> harmonic is dominant in case of equal angle method and 11<sup>th</sup> harmonic is dominant in case of equal area method.

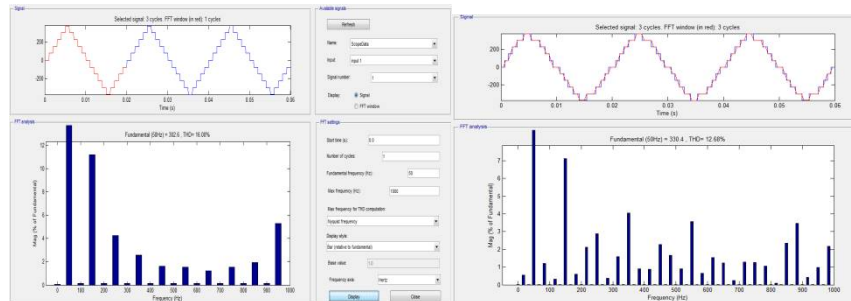
### 4.4 Eleven Level Multilevel Inverter



(a) Equal angle method (b) Equal area method

Fig 4.4 Output voltage waveform for Eleven level MLI

The 11 level inverter has been simulated using MATLAB/Simulink by considering a resistive load of 25 ohms. It makes use of five separate DC sources of equal magnitude for the five H-bridges of the inverter circuit. The magnitude of the DC sources considered for analysis are  $V_{dc1}=V_{dc2}=V_{dc3}=V_{dc4}=V_{dc5}=63V$  each to get an AC output of 220V RMS. The simulation results obtained are tabulated in table 4.5.



(c) Equal angle method (d) Equal area method

Fig 4.4 FFT analysis of 11 level MLI output

Figure 4.4 shows the simulated output voltage waveforms and FFT analysis chart for the eleven level inverter considered. The graph also shows the percentage of different harmonics present in the output signal. The FFT graph shows that 3<sup>rd</sup> harmonic is dominant in both the methods as compared to other harmonics.

Table 4.1 Comparative Analysis Of Results Of Inverters

Levels	Input voltage (each dc source)	Equal Angle method			Equal Area method		
		THD	fundamental (50 hz)	Output Voltage(rms)	THD	fundamental (50 hz)	Output Voltage(rms)
5 Level	156×2	29	255	182v	36.87	192.9v	145.4v
7 Level	104×3	21.71	254	184.6v	23.37	236.4v	171.61v
9 Level	78×4	17.97	247.5	177.7v	14.83	251.9	180v
11 Level	63×5	16.1	243	172.6v	12.39	269.9	192v



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## V. CONCLUSION

In multilevel inverter applications the quality of output voltage is the main constraint. Since the output of multilevel inverter is not perfect AC in nature, one has to take care about the percentage THD at the output. From the simulation studies the percentage THD with both the methods Equal Angle method and Equal Area method is shown. From the table 4.5, it is concluded that the output derived approaching more sinusoidal as the levels in the output voltage is increased. However, the Output voltage and output power remains almost constant even the levels are changed. There are various aspects involved that has to be taken care while selecting or analysing any kind of multilevel inverter, one of which is the quality of sine wave the multilevel inverter is providing at the output. In this paper different multilevel inverters are simulated using MATLAB/Simulink software successfully and the obtained results with waveforms are tabulated in a comparative manner for a resistive load of  $25\Omega$  to validate the implementation.

## REFERENCES

1. J-S. Lai and F.Z. Peng, "Multilevel converters – a new breed of power converters," *IEEE Trans. Ind. Appl.*, vol. 32, no. 3, pp. 509-517, May/June 1996.
2. Jih-Sheng Lai and Fang ZhengPeng and José Rodríguez "Multilevel Inverters: A Survey of Topologies, Controls, and Applications" *IEEE Trans. On industrial electronics*. VOL. 49, NO. 4, pp. 724-738 AUGUST 2002.
3. Zahra Bayat and EbrahimBabaei" Low Order Harmonics Elimination in Multilevel Inverters Using Fuzzy Logic Controller Considering the Variations of DC Voltage Sources"IEEE Conference on Electrical Machines and Systems (ICEMS), pp, 1-6 20-23 Aug. 2011
4. G. Carrara, S. Gardella, M. Marchesoni, R. Salutari, and G. Sciotto, "A new multilevel PWM method a theoretical analysis," *IEEE Trans. Power Electron.*, vol. 7, no. 4, pp. 497-505, Nov./Dec. 1989.
5. H.S. Patel and R.G. Hof, "Generalized techniques of harmonic elimination and voltage control in thyristor inverters: part I– Harmonic elimination," *IEEE Trans. Ind. Appl.*, vol. 3, no. 3, May/June 1973.
6. P.N. Enjeti, P.D. Ziogas, and J.S. Lindsay, "Programmed PWM techniques to eliminate harmonics a critical evaluation," *IEEE Trans. Ind. Appl.*, vol. 26; no. 2; pp. 302-16, 1990.
7. J.S. Chassan, L.M. Tolbert, K.J. Mckenze, and Z. Du, "Control of a multilevel converter using resultant theory," *IEEE Trans. Control Syst. Theory*, vol. 11, pp. 345-54, 2003.
8. F.-S. Shyu and Y.-S. Lai, "Virtual stage pulse-width modulation technique for multilevel inverter/converter," *IEEE Trans. Power Electron.*, vol. 17, pp. 332–341, May 2002.
9. Sinha and T. A. Lipo, "A four level rectifier-inverter system for drive applications," in Proc. Conf. Rec. 1996 IEEE IAS Annu. Meet., Oct. 1996, pp. 980–987.
10. J. K. Steinke, "Control strategy for a three phase AC traction drive with three level GTO PWM inverter," in IEEE Power Electronic Specialists Conf., 1988, pp. 431–438.
11. M. H. Ohsato, G. Kimura, and M. Shioya, "Five-stepped PWM inverter used in photo-voltaic systems," *IEEE Transactions on Industrial Electronics*, Vol. 38, October, 1991, pp. 393-397.
12. J. Rodriguez, J.-S. Lai, and F. Z. Peng, "Multi-level inverter: a survey of topologies, controls, and applications,"*IEEE Trans.Ind.Electron* , vol. 49, no. 4, pp. 724–738, Aug. 2002
13. Gerardo Ceglia, Víctor Guzmán, Member ,IEEE, Carlos Sánchez, Fernando Ibáñez, Julio Walter, and María I. Giménez, Member ,IEEE , "A New Simplified Multilevel Inverter Topology for DC–AC Conversion,"*IEEE Transactions on Power Electronics*, vol. 21, no. 5, Sep.2006.