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The Latest Development in Modelling and Control of Multilevel Inverters -A Review

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ABSTRACT*:* In today's era, the number of PV installations has made an exponential growth mainly due to the governments and utility companies who are in the favour of the green energy. One of the most important types of PV installation is the grid connected multilevel inverter configurations. This paper presents the latest development of modelling and control of multilevel inverters. Different multilevel inverters have been discussed with their experimental models. In order to eliminate the selective harmonics from the output waveform of the inverters, an approach is made towards minimization of the same.These structures are based on a multilevel inverter, switching angles at fundamental frequency are obtained by solving the selective harmonic elimination equations in such a way that the fundamental voltage is obtained as desired and certain lower order harmonics are eliminated, in this paper it is done by using software. The technique used to eliminate harmonics and to obtain approximate pure sinusoidal output waveform is Pulse Width Modulation technique. The models discussed in this paper have been simulated on Matlab/Simulink software and the respective THD has been determined by FFT analysis of the output waveform by the software. The computational results are shown graphically for better understanding and to prove the effectiveness of the method.

KEYWORDS: MATLAB/SIMULINK, Total Harmonic Distortion(THD), Multilevel Inverters, PWM.

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I.INTRODUCTION

Various industrial applications have begun to require higher power apparatus in recent years. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power inverter structure has been introduced as an alternative in high power and medium voltage applications. A multilevel inverter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel inverter system for a high power application [1-3]. The concept of multilevel inverters has been introduced since 1975 [4]. The term multilevel began with the three-level converter [5]. Subsequently, several multilevel inverter topologies have been developed [6-13]. However, the elementary concept of a multilevel inverter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. A multilevel inverter has several advantages over a conventional two-level converter that uses high switching frequency pulse width modulation (PWM).

It should be noted that lower switching frequency usually means lower switching loss and higher efficiency. But, multilevel inverters do have some disadvantages. One particular disadvantage is the greater number of power semiconductor switches needed. Although lower voltage rated switches can be utilized in a multilevel converter, each switch requires a related gate drive circuit. This may cause the overall system to be more expensive and complex. Many multilevel converter topologies have been proposed during the last two decades. Contemporary research has involved novel inverter topologies with unique modulation schemes. Particular concentration is addressed in modern and more practical industrial applications of multilevel converters. A procedure for calculating the parameters including design are described.

The proposed multilevel inverter includes an array of power semiconducting devices and dc voltage sources; it generates the output voltage with stepped waveforms. Compared to conventional multilevel inverters, proposed

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multilevel inverter is used to synthesize the output voltage and current with reduced harmonic distortion and lower electromagnetic interference (EMI). By increasing number of levels in the output of multilevel inverter, the output voltage will have more number of steps in generating a staircase waveform, which results in reduced harmonic distortion. However, the generation of large number of levels in the output will increase the number of devices and that will be controlled or compensated by the proposed multilevel inverter topology. That means the complexity of the equipment is minimized.

II.PROPOSED MULTILEVEL INVERTERS

The multilevel inverters can be divided into two groups from the view point of the dc voltage sources amplitudes: the symmetric and the asymmetric topologies. In the symmetric topology, the values of all of the dc voltage sources are equal. This characteristic gives the topology with good modularity. However, the number of the switching devices will be increased by increasing the number of output voltage level. In order to increase the number of output voltage level, the values of the dc voltage sources are selected to be different, these topologies are called asymmetric.

Multilevel Inverter Types	15 Level	17 Level	27 Level	31 Level

A. Fifteen Level Inverter

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. When the number of levels increases, the total harmonic distortion decreases significantly. This proposed method produce the pulses using Matlab/Simulink based embedded controller for fifteen level asymmetrical cascaded multilevel inverter. Each H-bridge inverter can produce fifteen different voltages, the output levels are 7Vdc, 6Vdc, 5Vdc, 4Vdc, 3Vdc, 2Vdc, Vdc, 0, -Vdc, -2Vdc, -3Vdc, -4Vdc, -5Vdc, -6Vdc, -7Vdc.

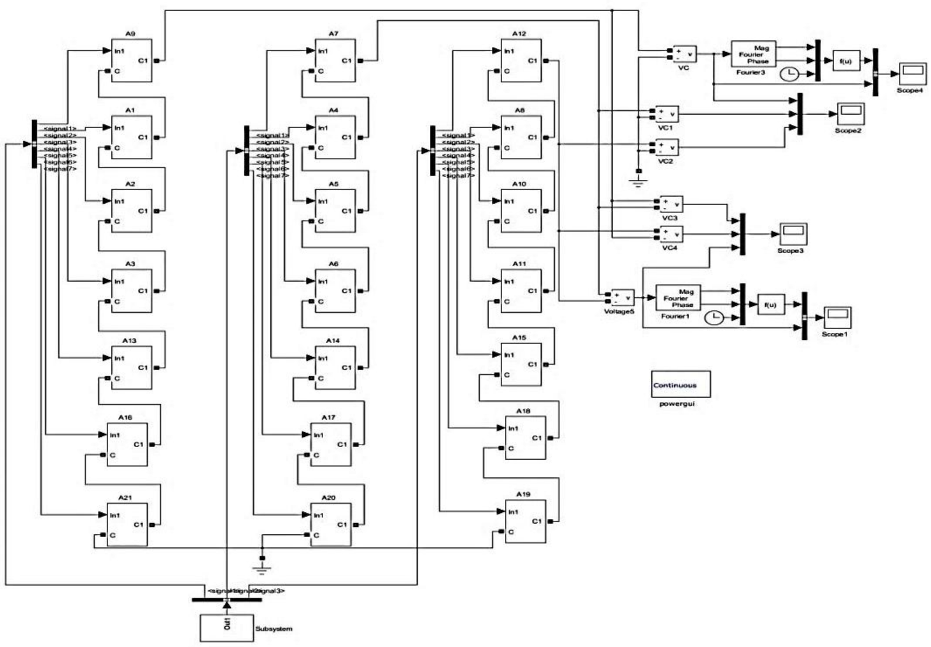

Figure 1. Simulation Diagram of 15-Level Inverter

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. Soft-switching techniques can be used to reduce switching losses and device stresses.

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The total harmonic distortion (THD), which is a measure of closeness in shape between a waveform and its fundamental component.When the voltage levels of the topologies are increases, the harmonic content of the output voltage waveform decreases significantly. The switching loss of the proposed system was low compared with the minimum levels of cascaded multilevel inverter by using this embedded controller. The Total Harmonic Distortion (THD) was reduced so that the performance of the proposed system also increased.

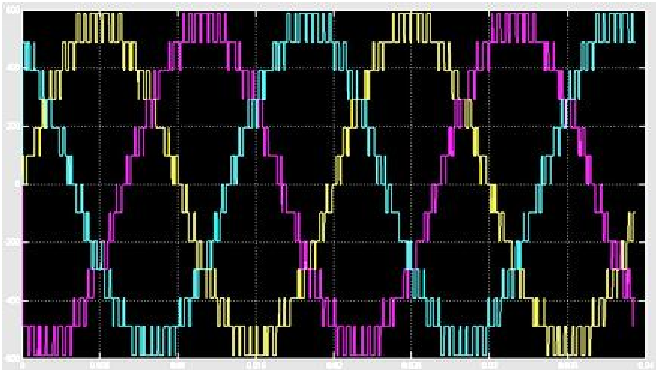

Figure 2(a). Output Waveform of 15-Level Inverter

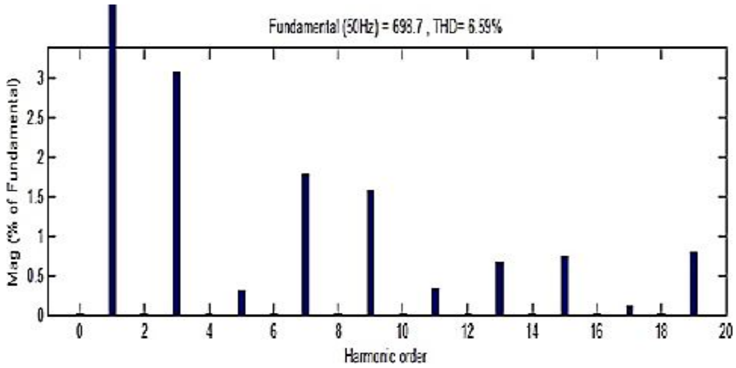

Figure 2(b). THD in 15-Level Inverter

B. Seventeen Level Inverter

The main advantages of the seventeen level inverter are: (a) Improve the output voltage quality, (b) Reduced number of switching devices, cost & complexity, (c) Improves the power factor, (d) Small on-state voltage drop and conduction losses, (d) Reduction of dv/dt stresses on the load; Using optimized harmonic stepped waveform technique. The output waveform of Three Phase Single switch cascaded multilevel inverter circuit was simulated using MATLAB. The total harmonic content present in the output current of proposed circuit after applying OHSW is 7.16% in MATLAB.

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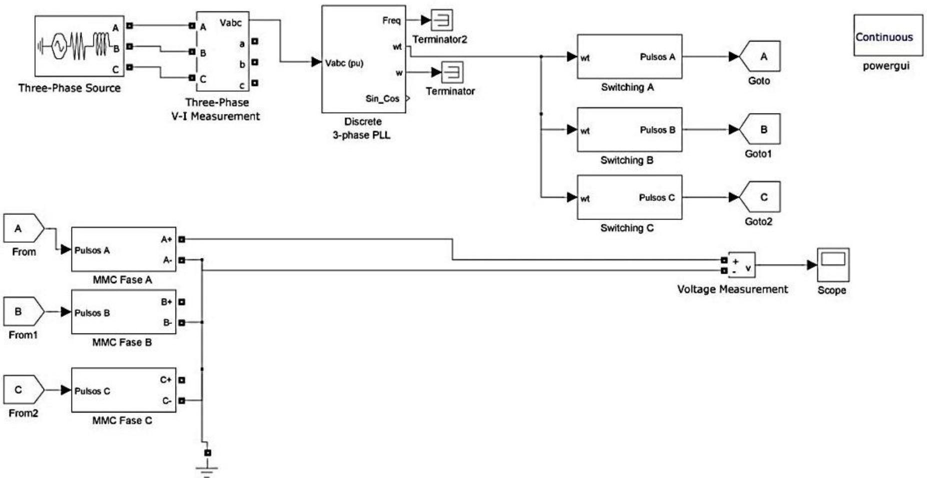

Figure 3. Seventeen Level Inverter Simulink Model

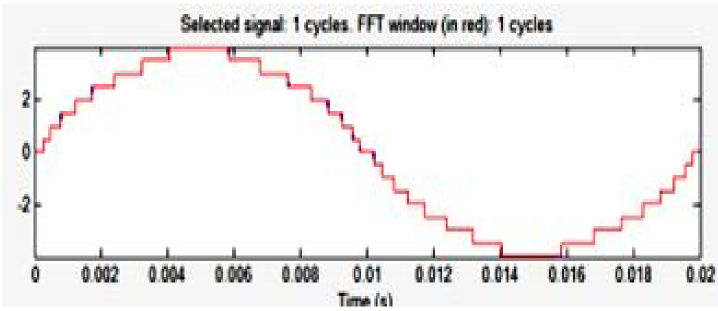

Figure 4(a). Output Waveform of 17-Level Inverter

In the FFT analysis, one cycle of output stepped waveform of 17-level inverter is shown in figure 4(a). on the basis of this waveform the total harmonic distortion in 17-level inverter is calculated by FFT analysis and the calculated THD with its plot has been shown in figure 4(b) below.

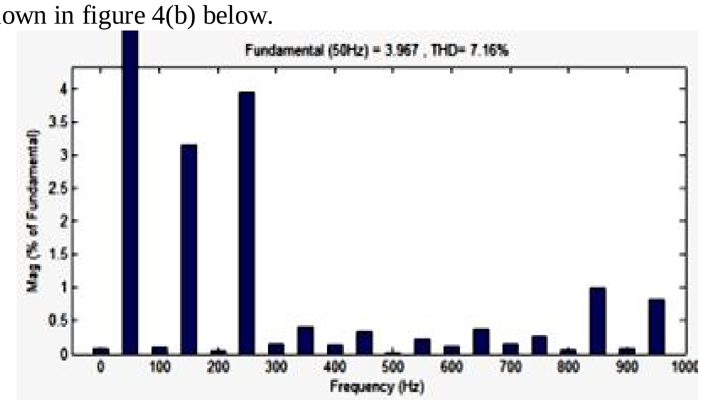

Figure 4(b). Total Harmonic Distortion of 17-Level Inverter

C. Twenty Seven Level Inverter

It gives three phase output voltage of 27Levels. Usually multilevel inverter needs more number of DC source. But here the single DC source is used with multi winding transformer. The level shift multicarrier PWM allows obtaining the desired number of voltage and frequency. The model can be used for the applications like drives, inverter etc.,

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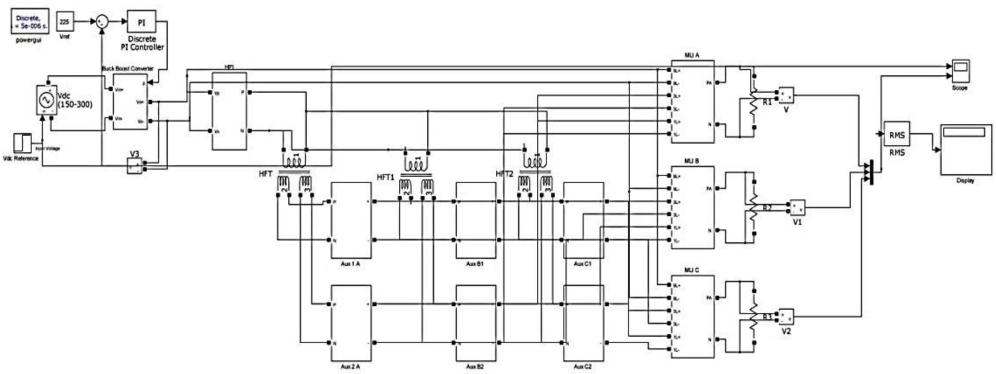

Figure 5. Three Phase 27 Level Inverter Simulink Model

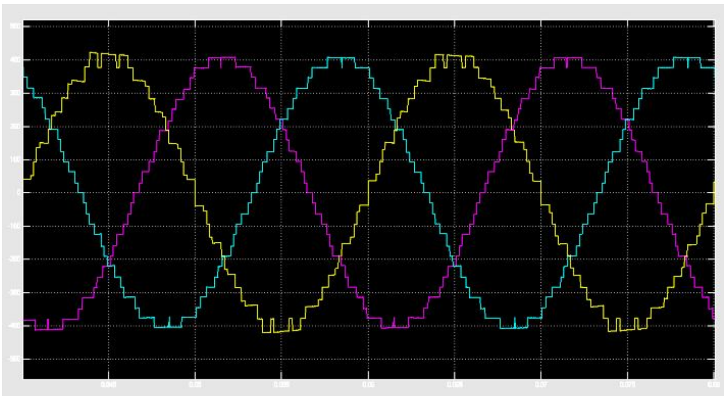

Figure 6(a). Output Waveform of Three Phase 27 Level Inverter

In the FFT analysis, one cycle of output stepped waveform of 27-level inverter is shown in figure 6(a). on the basis of this waveform the total harmonic distortion in 27-level inverter is calculated by FFT analysis and the calculated THD with its plot has been shown in figure 6(b) below.

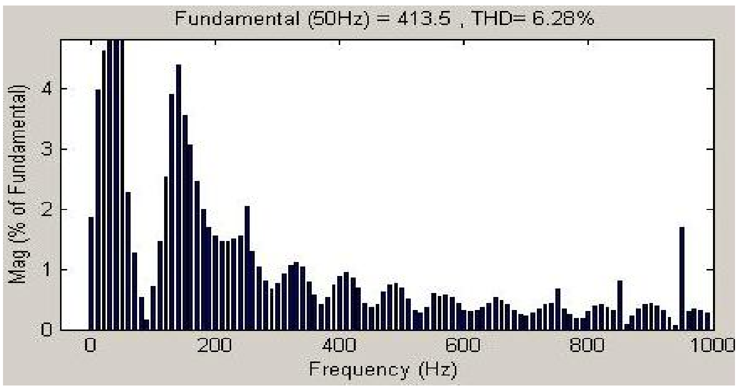

Figure 6(b). Total Harmonic Distortion in Three Phase 27 Level Inverter

An improved new hybrid 27 level multilevel inverter structure is proposed. Basic new hybrid inverter scheme is to get the better sinusoidal output compared with low level inverters. The asymmetrical multilevel inverter is used to obtain a high resolution. By this method decrease the input voltage and get better efficiency in a 27-level multi-level inverter structure. The asymmetrical hybrid technique is used to improve the level of inverter and extends the design flexibility and reduces the harmonics.

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D. Thirty One Level Inverter

Four half H bridges are used with four (binary logic) distributed DC sources (1:2:4:8). Level shift sinusoidal modulation scheme used to obtain the desired level and output voltage. The model can be used for the applications like drives, inverter etc. Cascaded multilevel inverter with asymmetrical configuration, since it uses several levels of dc voltage sources, which would be available from batteries, ultra-capacitors, or fuel cells. Because of these several levels of dc sources may cause voltage unbalances which leads to the increase of harmonics and total harmonic distortion.

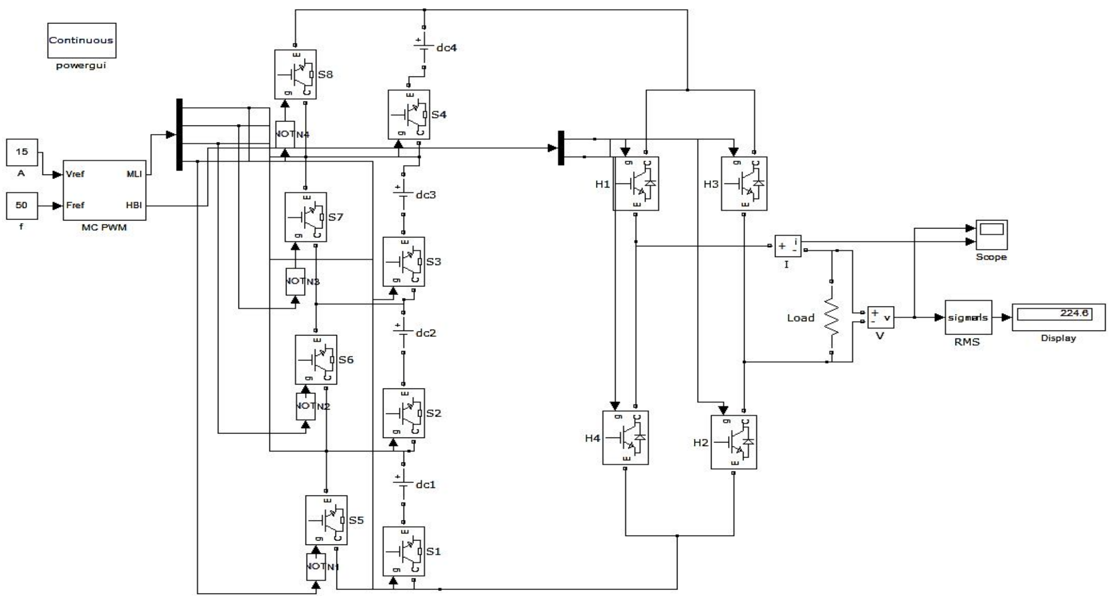

Figure 7. 31-Level Inverter Simulink Model

The Matlab/Simulink model of the proposed inverter for 31-level output is shown in Figure 7. The output waveform and the total harmonic distortion is presented in the figure below. The total harmonic distortion in 31-level inverter is calculated to be 3.88% where fundamental frequency was 317.4 at 50hz supply.

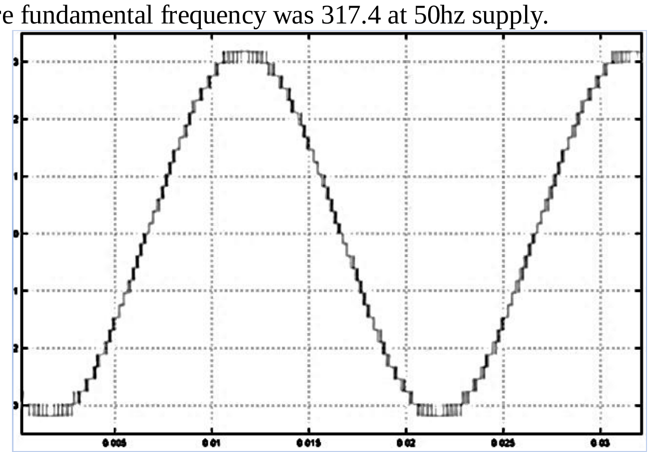

Figure 8(a). Magnified Output Waveform of 31-Level Inverter

In the FFT analysis, one cycle of output stepped waveform of 31-level inverter is shown in figure 8(a). on the basis of this waveform the total harmonic distortion in 31-level inverter is calculated by FFT analysis and the calculated THD with its plot has been shown in figure 8(b) .

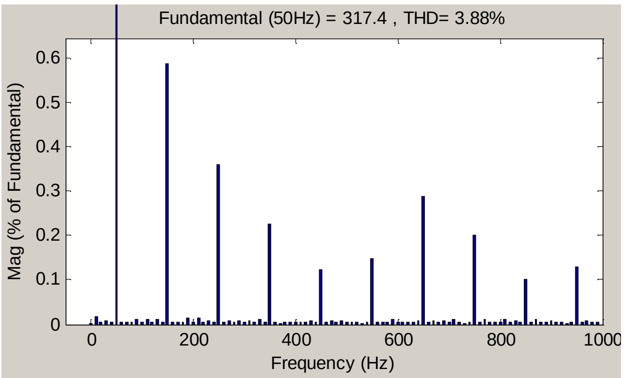

Figure 8(b). THD in 31-Level Inverter

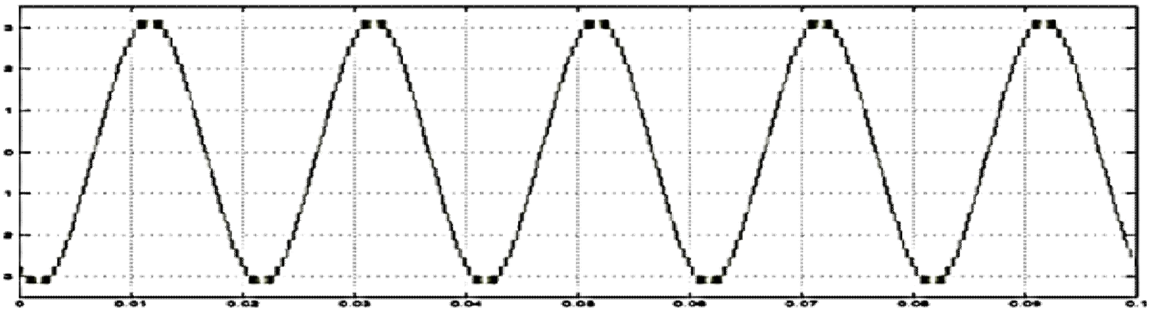

Figure 9. Output Waveform-Large View of 31-Level Inverter

III. RESULTS AND DISCUSSION

The main attention behind the objective of proposed project fifteen, seventeen, twenty seven and thirty one level inverter topologies is to achieve the high power quality, low total harmonic distortion and better power factor. The harmonic content can be measured in terms of total harmonic distortion by using FFT analysis harmonic spectrum. The proposed multilevel inverters have been validated using MATLAB/SIMULINK software and the comparison of results on basis of analysis has been tabulated below.

Table of comparison

No. of Levels	Fundamental Frequency	Total Harmonic Distortion
15	698.7	6.59%
17	3.967	7.16%
27	413.5	6.28%
31	317.4	3.88%

The attractive features of a multilevel inverter can be briefly summarized as follows.

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(a) **Staircase waveform quality**: Multilevel inverters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses; therefore electromagnetic compatibility (EMC) problems can be reduced.

(b)**Common-mode (CM) voltage**: Multilevel inverters produce smaller CM voltage; therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced. Furthermore, CM voltage can be eliminated by using advanced modulation strategies such as that proposed in [14].

(c)**Input current**: Multilevel inverters can draw input current with low distortion.

(d)**Switching frequency**: Multilevel converters can operate at both fundamental switching frequency and high switching frequency PWM

IV. CONCLUSION

Multilevel cascaded H-bridge inverters of fifteen, seventeen, twenty seven and thirty one levels have been simulated using Matlab/simulink. The THD calculation is done by the FFT analysis of output waveform of each inverter and it was found that, as the levels in the inverters are increased the THD is decreased. The symmetrical Cascaded H-bridge multilevel inverter consists of the number of switches increases for increase the number of levels. And also control circuit, complexity, maintenance increases.. The THD decreases to increase the number of levels, some lower or higher harmonic contents remain dominant in eachlevel. These will be more dangerous induction drives. Hence the future work may be focus on implementing closed loop control with suitable harmonic elimination technique to achieve better performance of the converter. The fuel cell and photo voltaic cells are used for multilevel inverter input voltage of dc sources. The future scope is to determine the pwm techniques of asymmetrical multilevel inverters then to reduce the harmonic content in the output voltage of the asymmetrical multilevel inverters.

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