Synthesis of Low Cost Inverter Using Harmonic Reduction through Pulse Pattern

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Abstract- This paper focuses on developing a low cost and a low harmonic traditional three level inverter (H-Bridge) using pulse pattern. Multilevel inverter as compared to traditional three level inverters have advantages like low harmonic contents and low electromagnetic interference (EMI) outputs and can operate on several voltage levels. The drawbacks includes: The requirement of isolated power supplies for each stage of the multi converter, cost feasibility and complexity of control system. So there is a need to design such three level inverter using harmonics cancellation which is easy to build, low cost and contain low Harmonics at high ac loads. This paper aims at how we synthesis low harmonic and low cost inverter using three level inverter. The proposed pulse pattern significantly reduces the number of dc voltage sources, switches, and power diodes. The performance of three level inverters with proposed waveform will be simulated in MATLAB.

Keywords-Multilevel Inverter (VSI), Cascade Inverter, Pulse Width Modulation (PWM), Total Harmonic Reduction (THD), Fundamental component

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I. INTRODUCTION

Power inverter circuit configuration has become famous research topics now a day due to the growth of Power Electronics and Semiconductor technology. So for every new day, new inverter circuits and their modulation techniques are developed by the researchers. The only purpose is to reduce more and more harmonics from the inverter as well as to reduce the cost of the inverter. All researches are working hard to make inverters output like ideal sine wave. The yield waveform of a perfect inverter ought to be sinusoidal. Ideal inverter can convert DC input signal into ideal sine wave. The DC input voltage of inverter maybe from the battery, PV cell, fuel cell or from DC generator. It depends on what type of supply available [i]. But practically inverters output is not a pure sinusoidal. It contains a lot of harmonics contents that make the inverters output non sinusoidal. With the passage of time digital technology is getting more and more advanced which leads to get close ideal results of inverter. In Early time we have used square wave inverter. The output of these inverters was like "Chopped AC" and it contains a lot of harmonics. So its applications were very limited. Then we shifted to quasi-square wave inverter. It was the advance type of square wave inverter which also contains a large amount of harmonics but less than square wave inverter. They are used in low and medium power applications. So they abundantly used in low power applications like home inverters. And the house-hold low power consuming electronics devices such as computers, cell phones, televisions, microwaves, etc. have been sourced by inverters. Due to high level of harmonic distortions and voltage nonlinearity can cause serious instability in house hold applications ultimately needing smoothed sinusoidal waveform [ii].

Today inverter is necessary for every industry. Industrial load are like induction motor, compressors, induction heating, blowers, pumps, and uninterruptible power supplies. For every power blackout, inverters are available to drive the maximum load of the industry. So for these high power applications harmonics should be very low so we moved to multilevel inverter. For this purpose, level of pulse for each positive and negative cycle must be increased to get closer to sinusoidal wave. These are so called multilevel inverters. Modern inverters use 6 levels or even 12 different levels of voltages for representing the sinusoidal waveform. The major advantage is a decrease in total harmonic distortion. There is also an advantage of using multi voltage level is that the load is less affected by harmonics, heating effect will be lower and an increased in load life because of low losses in power utilization [iii]. So multilevel inverters are known as a good alternative for high power and medium power applications. But Multilevel inverters have some drawbacks in which first is the need of isolated power supplies for each one of the stages of the multi converter, second is these are harder to build, third is they are more expensive, final and last is these are harder to control in software as well as in hardware. So there is a need to design such traditional three level inverter using harmonics cancellation which is easy to built, low cost and contain low harmonics at high ac loads.

II. TRADITIONAL TWO LEVEL INVERTER

The inverters which produce an output voltage or a current with level either +V or -V is known as two level inverters. This can be produced by Single H-Bridge Inverter.
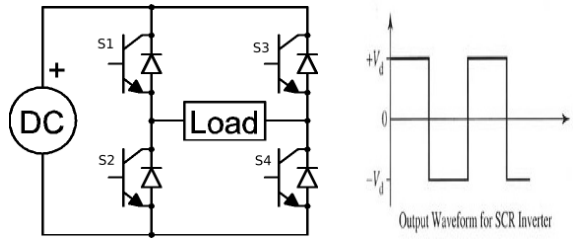
Fig.1. H-Bridge Inverter with output waveform

Fig.1 shows the circuit model of a single H-Bridge inverter configuration. An H-Bridge inverter is an electronic circuit in which four switches are arrangement in such a way that look like an alphabet H. The H-bridge is the most efficient one because there is no need to use the center tap transformers. The results become even better when four N-channel MOSFET are involved as a switch in H-bridge. Fig-3 is showing the arrangement of switches and load. The voltages across the load can be positive, negative or zero volts. These different types of voltages across the load can be achieved by switching these switches in different patterns. If we use motor as a load, then motor can rotate in clockwise, anti-clock wise direction or it will be off. It depends on different switching pattern. By using single H-Bridge we can get 2 voltage levels either +V or -V, Voltage step of each level is given by Vdc/2n, where n is number of H-bridges connected in cascaded. This inverter use high switching frequency with high voltage switches so switching loss becomes greater. To avoid switching loss there was a need to fabricate such type of switches which can handle high voltage and its gate drive voltage is low. Fortunately now-a-days such types of low cost switches are available which can operate at higher frequencies and they can bear high voltages. The output of this inverter is like square wave which is non-sinusoidal. So this output contains large number of harmonics and it has high value of THD. To remove these harmonics LC filter is required. High frequency harmonics can be removed easily because we require small LC filter but low frequency harmonics required high value of LC filter so a large space is required. So its cost and weight is also increased. At low and medium power applications this two level output is not dangerous even it contains a large number of harmonics contents but in high-power and high-voltage applications these two level inverters are not acceptable because the presence of large number of high frequency harmonics in the two level ac output could be dangerous for high power loads. [iv]. It is simpler than multilevel inverter and its control system is easily controlled by PWM.

III. HARMONICS

Undesirable currents or voltages in a signal are called Harmonics. They exist at some multiple of the fundamental frequency. If the signal's fundamental frequency is f then the frequency of second harmonic will be 2f and the frequency of third harmonic will 3f and so on. Even harmonics are the even number frequencies like 2f, 4f, 6f, etc. And odd harmonics are the odd number frequencies like 3f, 5f, 7f etc. Mathematical representation is

$$f_h = h \times f_0 \tag{1}$$

Where f_0 is known as fundamental component and h is an integer $(0 \rightarrow \infty)$

For example, given a 60Hz fundamental waveform, the 2nd, 3rd, 4th and 5th harmonic components will be at 120Hz, 180Hz, 240Hz and 300Hz respectively. For pure sine wave fundamental component contains all energy and for signal impure sine wave some energy is contained in the harmonics. The common examples of impure sine waves are Square wave and triangular wave.
Spectra (harmonics) characteristics of square wave:

1. Harmonic decreases with a factor of (1/n).
2. Even harmonics are absent
3. Nearest harmonics is the 3rd. If fundamental is 50Hz, then nearest harmonic is 150Hz.
4. Due to the small separation between the fundamental and harmonics, output low-pass filter design can be very difficult.
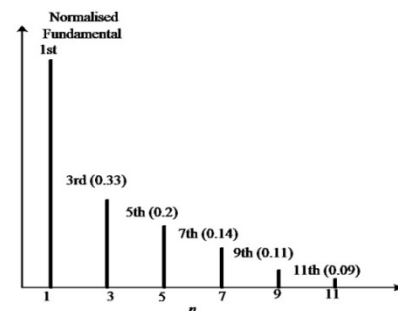
Spectrum of Square wave is given below

Fig.2. Spectrum of Square wave

Fig-2 indicates that the 3rd harmonics are 33% of fundamental component, 5th harmonics are 20% of fundamental component and 7th harmonics are 14% of fundamental component. The third, fifth, seventh and ninth harmonic are not easy to filter out. The reason is that the difference between fundamental component and harmonics is very small. Harmonic pollution in power converters creates a serious problem.

The harmonics can arise in three different ways [v]:

1) When non-sinusoidal voltage driving nonlinear load.
2) When sinusoidal voltage driving nonlinear load.
3) When non-sinusoidal voltage driving linear load.

The degree of the signal to diverse due to the addition of harmonics from its perfect sinusoidal values is called harmonic distortion. There is no diversion in the perfect sine wave so the value of harmonic components in it is zero. The standard measure for contortion is Total Harmonic Distortion (THD). Computation of all harmonic components (voltage/Current) correlated against the fundamental component (Voltage/Current) is called Total harmonic distortion (THD).

$$THD = \frac{\sqrt{\sum_{n=2}^{N} Vn^2}}{V1} * 100 \qquad (2)$$

Equation (2) shows that how to calculation THD of voltage signal. The net yield from this equation will compare the harmonic components and fundamental component of a signal in percentage form. If the value is higher than there will be more distortion on the mains signal. THD can be decreased by varying output waveform pattern. Most common example is that when output waveform of inverter is square wave then it has high THD and in contrary to that when there is a modification in the waveform then its THD decreases. In order to observe this change, one needs to decrease THD by modifying output waveform of inverter.

IV. MATHEMATICAL MODELING OF PROPOSED WAVEFORM

Proposed Three-Pulse train reveals one complete cycle of the wavform having voltage levels +Vdc and –Vdc. The pulse width and the delays are also mentioned.
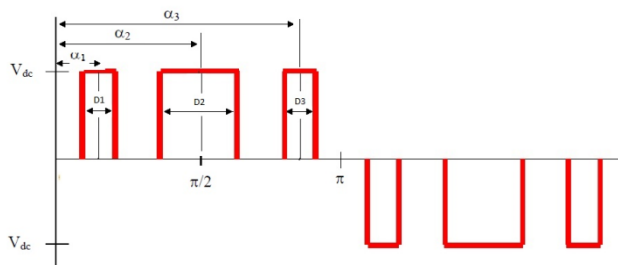

Fig.3. Proposed waveform for inverter

Generalized equations based on Fourier Transforms are

$$f(x) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos \frac{n\pi x}{L} + b_n \sin \frac{n\pi x}{L} \right) \qquad (3)$$

a_0 is a dc component which can be calculated as

$$a_0 = \frac{1}{2\pi} \int_0^{2\pi} V(t) dwt \qquad (4)$$

And a_n and b_n can be calculated from Fourier series as

$$a_n = \frac{2V(t)}{n\pi} [\sin n (a1 + \frac{d1}{2}) - \sin n (a1 - \frac{d1}{2}) + \sin n (a2 + \frac{d2}{2}) - \sin n (a2 - \frac{d2}{2}) + \sin n (a3 + \frac{d3}{2}) - \sin n (a3 - \frac{d3}{2})]$$
(5)

For n=1, 3, 5 …i.e., Odd
And
$$b_n = \frac{2V(t)}{n\pi} [\cos n (a1 + \frac{d1}{2}) - \cos n (a1 - \frac{d1}{2}) + \cos n (a2 + \frac{d2}{2}) - \cos n (a2 - \frac{d2}{2}) + \cos n (a3 + \frac{d3}{2}) - \cos n (a3 - \frac{d3}{2})]$$

(6)

For n=1, 3, 5 …i.e., Odd

V. MATLAB BASED SIMULATION

In this paper MATLAB and NI MULTISIM are used. NI MULTISIM is a real time software tool which is implemented before performing hardware. In MATLAB the upper given waveform is simulated with different pulse angles and pulse width. Results of output voltage and THD's are shown below.

Angle a 1 (θ)	Angle a 2 (θ)	Angle a 3 (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
27	90	153	18	76	18

1. Parameters or 3rd Harmonics Reduction
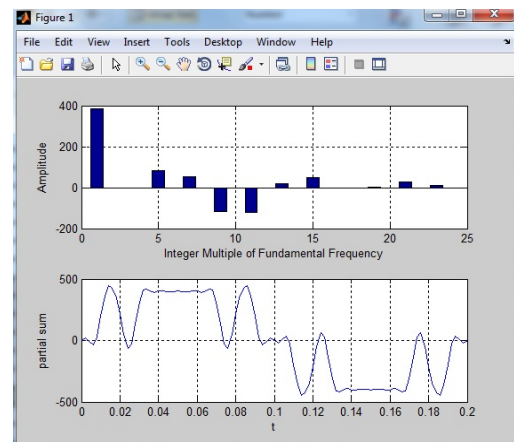
Fig.4. 3rd Harmonics Reduction

Angle a1 (θ)	Angle a2 (θ)	Angle a3 (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
27	90	153	18	106	18

2. Parameters or 5th Harmonics Reduction
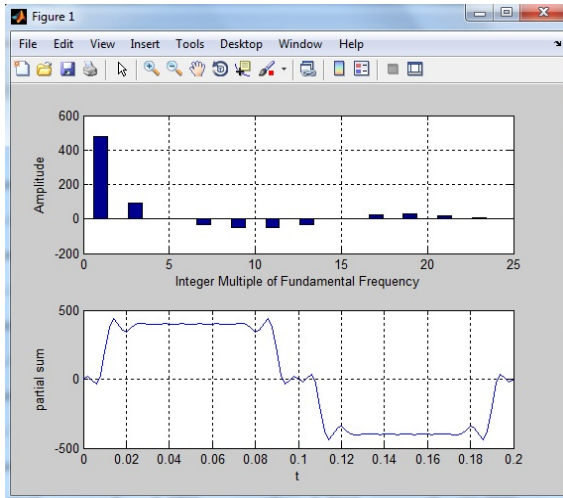
Angle a1 (θ)	Angle a2 (θ)	Angle a3 (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
22.5	90	157.5	11	102	11

4. Parameters for 3rd and 5th Harmonics Reduction

Fig.5. 5th Harmonics Reduction

Fig.7. 3rd and 5th Harmonics Reduction

Angle a1 (θ)	Angle a2 (θ)	Angle a3 (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
27	90	153	18	98	18

3. Parameters for 7th Harmonics Reduction

Angle a1 (θ)	Angle a2 (θ)	Angle a3 (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
22.5	90	157.5	11	114	11

5. Parameters for 5th and 7th Harmonics Reduction
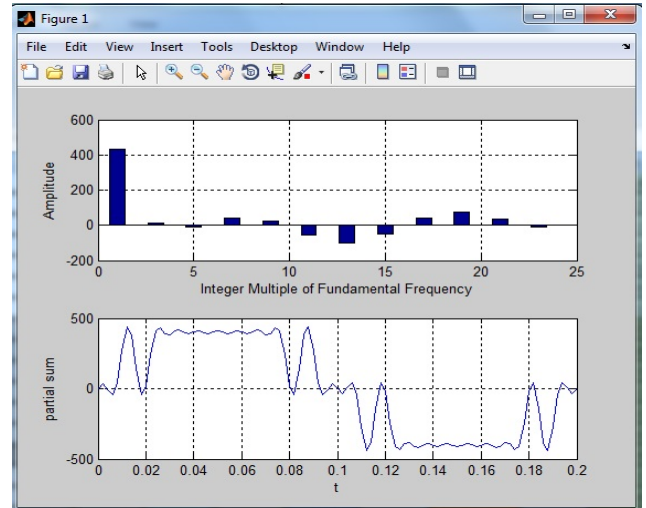

Fig.6. 7th Harmonics Reduction
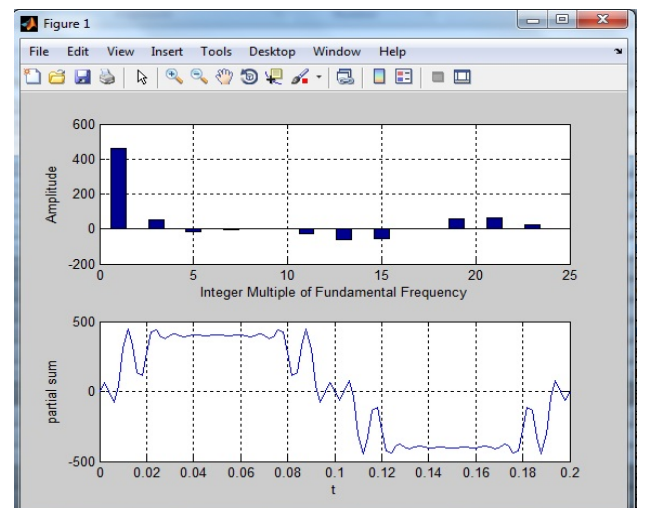
Fig.8. 5th and 7th Harmonics Reduction

Angle $a1$ (θ)	Angle $a2$ (θ)	Angle $a3$ (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)
22.5	90	157.5	9	104	9

6. Parameters for 3rd, 5th and 7th Harmonics Reduction

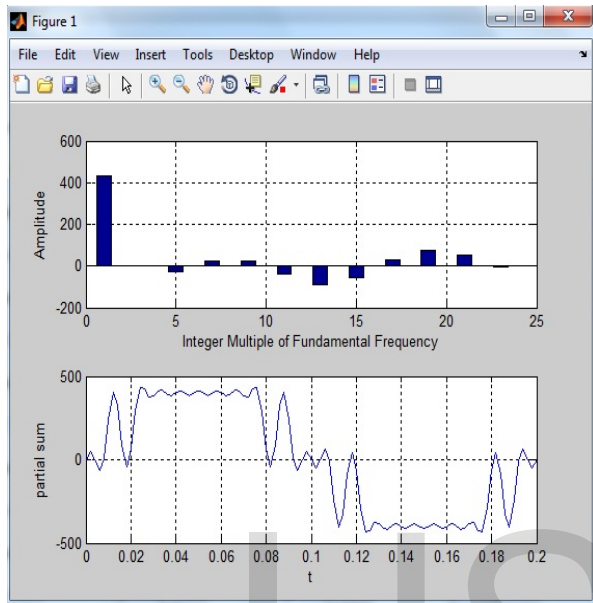Fig.9. Most optimized results

Table-1 is showing the Fundamental component, 3rd, 5th, 7th, and THD of the proposed signal with different values of angle and pulse width. Only 3rd harmonics reduced to zero when first combination is used. 5th harmonics are reduced to zero when second combination is used. 7th harmonics is used when third combination is used and so on...

7. Value's for the upper given Graphs

Sr. #	Angle $a1$ (θ)	Angle $a2$ (θ)	Angle $a3$ (θ)	Width D1 (θ)	Width D2 (θ)	Width D3 (θ)	Fund. Comp C1 (Voltage)	3rd Harm C3 (% of Fund.)	5th Harm C5 (% of Fund.)	7th Harm C7 (% of Fund.)
1	27	90	153	18	76	18	385.91	0.74	21.28	13.55
2	27	90	153	18	106	18	479.10	19.08	0.08	7.13
3	27	90	153	18	98	18	456.72	13.09	2.09	0.22
4	22.5	90	157.5	11	102	11	433.17	2.77	2.65	8.88
5	22.5	90	157.5	11	114	11	464.51	13.46	2.47	2.39
6	22.5	90	157.5	9	104	9	431.93	0.97	6.55	5.56

In "Fig.11" one can observe that the percentage of 3rd, 5th, and 7th order harmonics in graphical form we see at sixth combination most optimized results achieved using Matlab. 3rd order harmonics are completely removed. 5th and 7th order harmonics are in within 6% limit and THD is under 30%. And if we want to reduce THD to a low limit then

now we can use LC low pass filter whose cutoff frequency could be 300 Hz. LC filter with cut off frequency is given by.

$$fc = \frac{1}{2\pi\sqrt{LC}} \tag{7}$$

Where fc = Cutoff frequency
L = Inductor (Henry)
C = Capacitor (Farad)
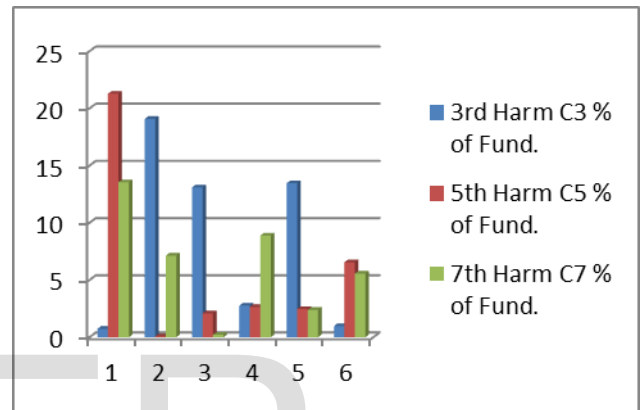Design values for low pass filter, cutoff frequency = 300 Hz, L = 0.5mH, C = 562 uF.

Fig.10. 3rd, 5th, 7th harmonics with respect to Table

VI. NI MULTISIM SIMULATIONS

The results have been calculated 3rd, 5th, 7th harmonics and THD for the different values of the pulse angles and pulse width using Matlab. One can also observe 3rd, 5th and 7th harmonics reduction from the figures and the table given above. And also from the given figures and table that the values in serial # 6 results optimized solution in term of 3rd, 5th, 7th harmonics and THD. So now there would a verification of these values by using NI Multisim software. In this software one ca make a circuit using Microcontroller and ideal comparator to make our proposed signal with parameters given in the table. Using NI Multisim Software output graphs of signal and power spectrum is given by:
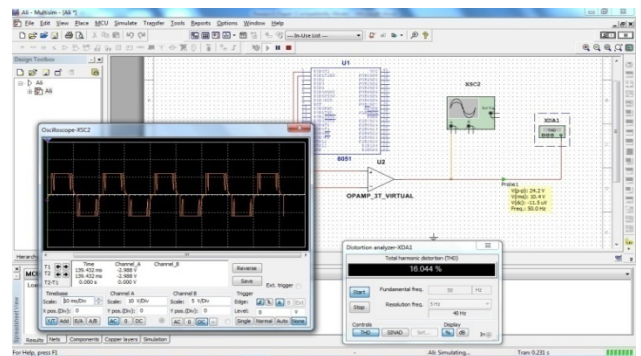

Fig.11. Signal and its power spectrum

Here one can observe that the THD of proposed signal is around 16% only. Previously, it was pointed out that the 3rd, 5th and 7th harmonics are negligible and upper order harmonics are available so one can filter these higher order harmonics using LC Low pas filter to decrease THD. After filtering these harmonics, output only contains fundamental components and negligible amount of harmonics.

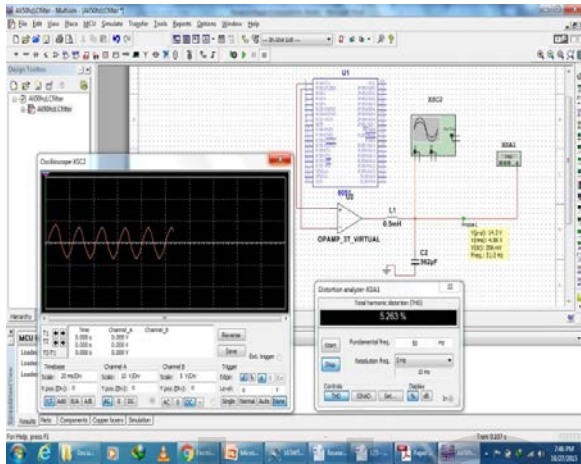NI Multisim filtered output and THD results are as follows:

Fig.12. Signal and its THD after LC filtering

Filtering THD of the signal reduced to 5% and one can observe that the signal is very close to the sinusoidal waveform.

VII. CONCLUSION

This research paper investigates and successfully implements optimal switching strategies for harmonic elimination in single phase voltage-source inverters. It is cleared from the results of this research work that proposed waveform when produced through H-Bridge inverter contain good fundamental component and negligible amount of odd harmonics. All results are tested and verified by other software's. So THD for this proposed waveform after filtering is only in the range of 5%. This value is very low when compared with Square wave and Modified sine wave. Square wave and Modified sine waves contain THD 45% and 24% respectively. So this type of waveform can accommodate both linear and non-linear loads and technically this control scheme is easier to design and then implemented on H-Bridge inverter. So one can effectively state that the proposed scheme of this research work is more efficient and economical.

ACKNOWLEDGMENT

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