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Hybrid Multilevel Inverter

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Abstract

Multilevel inverters arepopular for its high performance. Their performance is highly better than normal inverters due to reduced total harmonic distortion, less magnetic interference. Multilevel inverter is a source of high power, often used in industrial applications. Instead of using one converter to convert an AC current into DC current, a multilevel inverter uses a series of semiconductor power converters thus generating higher voltage. The Hybrid multilevel inverter topology is introduced with a reduced number of switches to improve the multilevel performance. The project proposes a hybrid CHB multilevel inverter. It uses a simple cascaded H-bridge structure and was developed. This topology consists of a full-bridge with four bidirectional switch. The new topology used will offer lower component count and reduced layout complexity. The operation and performance of the Hybrid Multilevel Inverter using the proposed Multicarrier PWM with Selective Harmonic Elimination technique is validated through Simulation using MATLAB software and experimentation using microcontroller.

Keywords: Cascaded H-bridge(CHB) multilevel inverter, Pulse Width Modulation (PWM) technique.

Introduction

In general this DC to AC converter is classified into two types namely VSI and CSI. The traditional DC to AC converters has the two level output voltage, which requires the filter circuit. The multilevel inverter produces n-number of output voltage levels from the given input DC supply. Multilevel inverter produces the near sinusoidal waveform from the DC input supply. So the filter requirement can be reduced by using this multilevel inverter [1]. The concept of multilevel inverter came in 1975. For medium and high voltage equipment over 1KV, a multilevel inverter is applied. The three-level inverter is the multilevel inverter with the smallest number of levels.

They are a source of high power often used in new areas of medium-and high-voltage applications. The multilevel inverter is classified into three types. First the cascaded multilevel inverter was proposed then diode-clamped multilevel inverter wasproposed and then capacitor clamped was introduced.The capacitor clamped multilevel inverter [2] and diode clamped [3] consists of only onesource. The main disadvantage of this type of multilevel inverter is,it uses more number of clamping diodes and capacitors, which makes the system bulky and complex.

The cascaded multilevel inverter comes under multiple source multilevel inverters which do not require any clamping diodes or capacitors. So the cost of the system becomes less and manufacturing can be made easily.Now a day'smultilevel inverter is being popular due to its limitations while comparing with the two-level inverters in terms of handling high power conversions. The intriguing feature of the multilevel inverter structures is their ability to scale up the KVA rating and also to improve the harmonic performance greatly without having to resort to PWM techniques. The cascaded scheme includes generalized multilevel inverter, mixed multilevel inverter and hybrid multilevel inverter.

In this paper, a new multicarrier PWM with Selective Harmonic Elimination technique is proposed for Hybrid Multilevel inverter. In this technique, trapezoidal waveform is used as a reference wave instead of sine waveform. The performance of Hybrid Multilevel inverter using the above technique is validated through simulation and experimental results.

Seven Level Cascaded Hybrid Multilevel Inverter Topology

In multilevel inverter, the high-frequency switches are being combined to generate the positive and negative polarities. The project proposes a hybrid CHB multilevel inverter. It uses a simple cascaded H-bridge structure and developed.The project proposes a hybrid CHB multilevel inverter. It uses a simple cascaded H-bridge structure and was developed. This topology consists of a full-bridge with four bidirectional switch. The new topology used will offer lower component count and reduced layout complexity. In order to get a complete output of multilevel inverter, the high frequency side is being connected with the low frequency side which is in the form of full-bridge inverter and will decide the output voltage polarity.

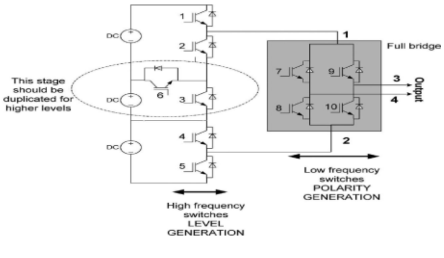


Figure 1: Proposed Hybrid CHB MLI topology

Fig.1 is the proposed hybrid CHB MLI circuit consists of ten MOSFET's and three DC sources. The basics of the proposed topology are that left sidefrequency generates theoutput in levels and the right side frequency circuitwill give theoutput either in positive or negative. If the output polarity is positive then the output level will be in the same direction and if the polarity is in negative then the output level will be in the opposite direction

Modes of Operation

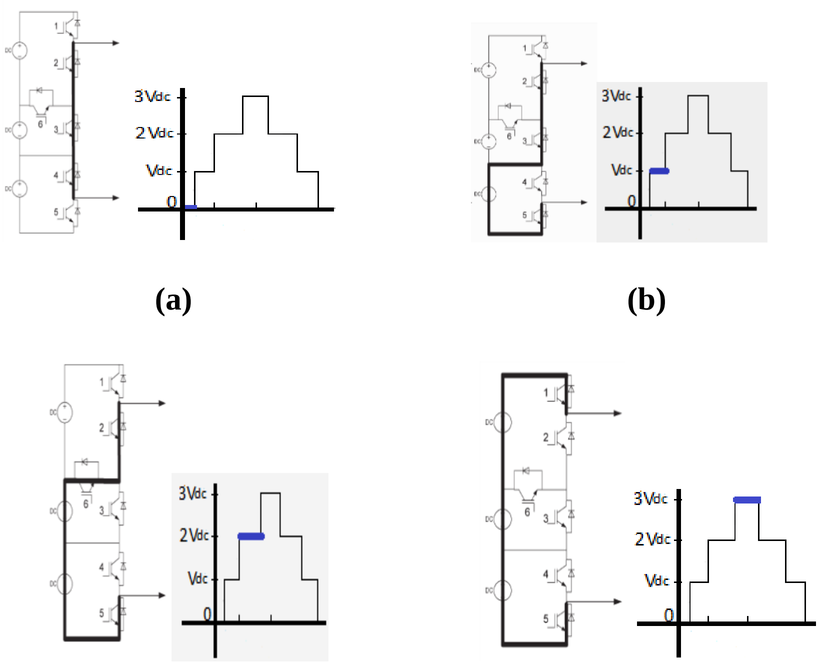
This topology has four modes of operation to generate seven levels. The various switching combinations for different stages are explained below and are given in Fig.2.

a) **Stagei**: During this mode of operation the switches 2, 3 and 4 are turned ON. The source is disconnected from load. So the output voltage across the load will be zero.

b) Stage ii: During this mode of operation the switches 2, 3 and 5 are conducting. So V_{dc} of the supply is connected across the load. Therefore the voltage across the load will be V_{dc}. This mode of operation can be achieved by the switching combination 2,4and 6.

c) Stageiii: During this mode of operation the switches 2, 6 and 5 are turned ON. Two times of V_{dc} is connected with load. So the output voltage is $2*V_{dc}$. This mode can also be obtained by turning on the switches 1 and 4.

d) **Stageiv:** During this mode of operation the switches 1 and 5 are turned ON. So all the three voltage sources are connected with the load. The output voltage across the load will be equal to $3*V_{dc}$.



(a) **(b)**

(c) **(d)**

Figure 2: Switching States of the Hybrid Multilevel Inverter

Pulse Width Modulation and Trapezoidal Reference Wave Technique

Pulse width modulation is a method for generating an analog signal using a digital source. A pulse width modulation signal consists of two main components that define its behavior: a duty cycle and a frequency.Pulse width modulation signals are used for a wide variety of control applications. Their main use is for controlling DC motor but it can also be used to control valves,pumps, hydraulics and other mechanical parts.A single sine wave (reference) is compared with each triangular wave (carrier) to determine the output voltage. Three types of PWM techniques are discussed as below,

a) Phase disposition method (PD):

In this technique all the carrier waves are in phase with each other.

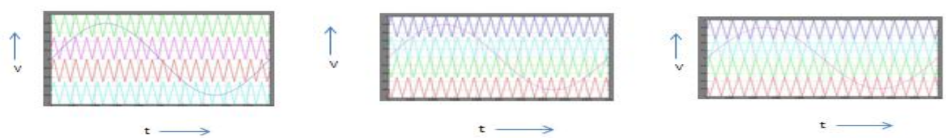
b) Phase apposition disposition method (POD):

In this technique all carrier waves are compared and results that above the zero referenceare in phase and all carrier waves below the zero reference are 180 degree out of phase.

c) Alternative phase apposition disposition method (APOD):

In this technique all carrier signals are shifted by 180 degree with other carrier waves. This method results are almost similar to that of POD method.

For carrier waves based modulation technique, different carrier waves displacement produces different types of pulse width modulation patterns, which is named asPOD, PDand APOD.



(a) (b) (c)

Figure 3: PWM technique types (a) (PD) (b) (POD) (c) (APOD)

Fig. 4 shows that trapezoidal waves are used as reference waves instead of sine wave in multicarrier pulse width modulation method in order to reduce the harmonics. Trapezoidal wave is formed by the combination of slope and the horizontal line. The shape of the trapezoidal wave is mainly due to the slope angle.

The harmonics magnitude for trapezoidal reference wave technique is calculated on the basis of some rules. The α values should be chosen between 0 degree and 90 degree. After finding the firing angle (α) value, the equations are evaluated using Fourier analysis. In terms of quarter-symmetry, the Fourier coefficients are calculated by,

$$\begin{cases} A_n = \frac{4}{\pi}\int_0^{\pi/2} F(\theta)\sin(n\theta)\,d\theta & (1) \\ Q=\frac{1}{\alpha}\quad 0 < \quad < \alpha & (2) \end{cases}$$

$1\ \alpha < \Theta < 90^0$

Q represents trapezoidal waveform,

Equations (1) and (2) can be written as,

$$A_n = \frac{4}{\pi}\left[\left[\frac{-\theta\cos(n\theta)}{n}\right]_0^{\alpha} + \frac{1}{n}\int_0^{\pi/2}\cos(n\theta)\right] + \frac{4}{\pi}\int_{\alpha}^{\pi/2} 1\sin(n\theta)\,d\theta \quad (3)$$

By simplifying Equation (3), we can get that, $A_n = \frac{4}{n^2\pi}\times\frac{\sin(n\alpha)}{\alpha}$

When the slope angle is selected with respect to 90□ then the harmonics will get reduce and are increased when the slope angle is selected with respect to 0□ [6]. By eliminating the lower order harmonics (i.e. 3^{rd} and 5^{th} harmonic)in the output.

(i)Case 1: Third Order Harmonic Elimination

For n=3,

Equation (4) becomes,

$$A_n = \frac{4}{n^2\pi}\times\frac{\sin(n\alpha)}{\alpha}$$

$$A_3 = \frac{4}{3^2\pi}\times\frac{\sin(3\alpha)}{\alpha}$$

In order to eliminate the third order harmonics, the magnitude A_3 will be equated to zero. Substituting $A_n = 0$, the above equation will become,

$$0 = \frac{4}{3^2\pi}\times\frac{\sin(3*\alpha)}{\alpha}$$

$$\alpha = \frac{180}{n},\ \alpha = \frac{180}{3} = 60°$$

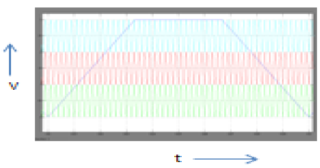


Figure 4: Shape of trapezoidal wave for 3^{rd} order Harmonic Elimination

(ii) Case 2: Fifth Order Harmonic Elimination

For n=5,

Equation (4) becomes,

$$A_n = \frac{4}{n^2\pi} \times \frac{\sin(n\alpha)}{\alpha}$$

$$A_5 = \frac{4}{5^2\pi} \times \frac{\sin(5\alpha)}{\alpha}$$

In order to eliminate this harmonic, the magnitude A_5 will be equated to zero. Substituting $A_n = 0$, the above equation will becomes,

$$0 = \frac{4}{5^2\pi} \times \frac{\sin(5 * \alpha)}{\alpha}$$

$$\alpha = \frac{180}{n}, \ \alpha = \frac{180}{5} = 36°$$

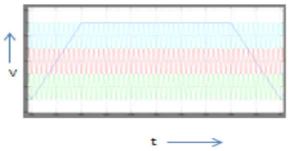


Figure 5: Shape of trapezoidal wave for 5th order Harmonic Elimination

(iii) Case 3: Seventh Order Harmonic Elimination

For n=7,

Equation (4) becomes,

$$A_n = \frac{4}{n^2\pi} \times \frac{\sin(n\alpha)}{\alpha}$$

$$A_7 = \frac{4}{7^2\pi} \times \frac{\sin(7\alpha)}{\alpha}$$

In order to eliminate the third order harmonics, the magnitude A_7 will be equated to zero. Substituting $A_n = 0$, the above equation will become,

$$0 = \frac{4}{7^2\pi} \times \frac{\sin(7 * \alpha)}{\alpha}$$

$$\alpha = \frac{180}{n}, \ \alpha = \frac{180}{7} = 25.71°$$

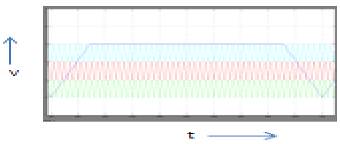


Figure 6: Shapeof trapezoidal wave for 7th order Harmonic Elimination

The slope angle is calculated for third, fifth and seventh order harmonic elimination is calculated.

Simulation Results

This project proposes a new Hybrid multilevel inverter. It uses a simple cascaded H-bridge structure and developed. This topology includes H-bridge which consists of four bidirectional switches, which reduces the circuit complexity andoffers less number of components, when compared with other types of multilevel inverter. The new topology achieves almost a 40% reduction in the number of components required.

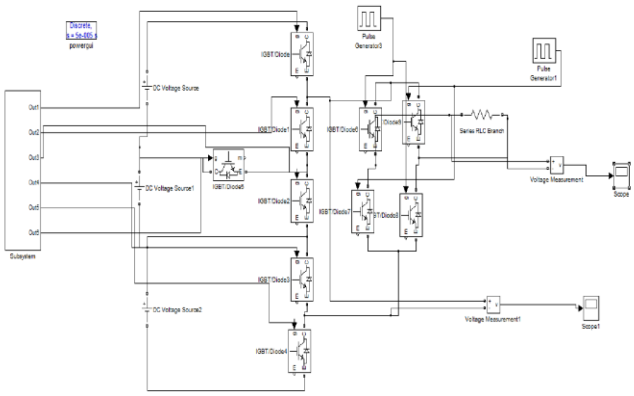


Figure 7: Simulation schematic diagram of 7-level MLI

PWM technique is used to drive the circuit where the comparison of the magnitude is done by the reference wave which is the sine wave over the carrier waves which is the triangular waves and hence the respective output levels are generated. The control signals are generated and the output voltage is evaluated by using the MATLAB/SIMULINK platform. Output voltage can be controlled using the modulation index and output frequency can be controlled by adjusting the frequency. The simulation results are illustratedas below. Results based on switching losses analysis and its respective THD analysis for techniques PD,POD, APOD on voltage level of seven are also performed for the reversing voltage multilevel inverter.

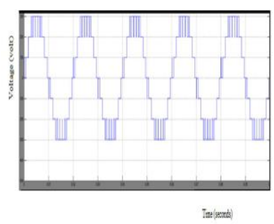


Figure 8: Output waveform of 7-level inverter

Table 1 shows the Total harmonic distortion which is the measure of the entire harmonics present in the circuit is calculated for the 7-level inverter.

Table 1: Thd Analysis

TECHNIQUES	7-LEVEL
PD	17.49%
POD	17.82%
APOD	18.64%

The simulation for the hybrid multilevel inverter has been developed using MATLAB/SIMULINK platform. Each input DC supply has the value of 100V. Switching frequency 1 kHz. In this hybrid multilevel inverter ten switches are used. Six switches are operating under the high frequency and the remaining switches are operating under the low frequency i.e. line frequency. The seven level output voltage and the corresponding FFT analysis for third, fifth and seventh order harmonic elimination is shown in the following figures.

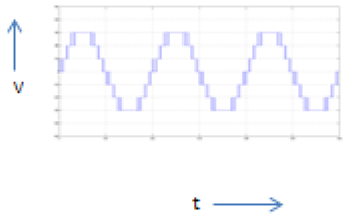


Figure 9: Seven-level Output Voltage for 3rd order Harmonic Elimination

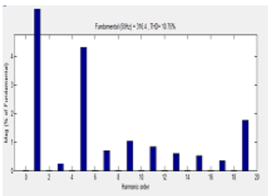


Figure 10: FFT analysis for 3rd order Harmonic Elimination

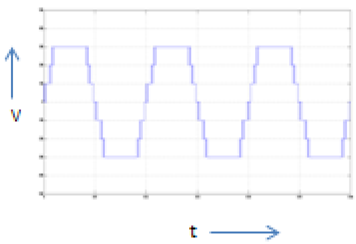


Figure 11: Seven-Level Output Voltage for 5thorder Harmonic Elimination

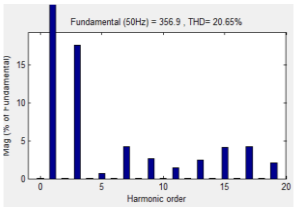


Figure 12: FFT analysis for 5th order Harmonic Elimination

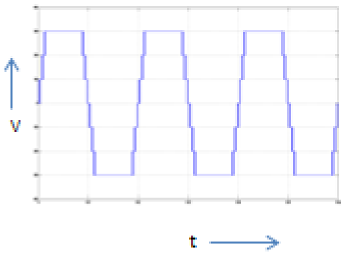


Figure 13: Seven-level output voltage for 7th order Harmonic Elimination

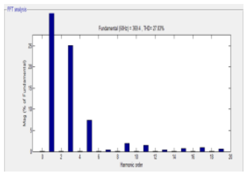


Figure 14: FFT analysis for 7th order Harmonic Elimination

Table 2 shows the comparison of the Total harmonic distortion(THD) and Slope angle in degree.

Table 2: Slope Angle Vs. Harmonic Order

Harmonic Order	Slope Angle (degree)
Third	60
Fifth	36
Seventh	25.71

Thus the third, fifth and seventh order harmonics have been eliminated using the proposed multicarrier PWM with selective harmonic elimination technique.

Experimental Results

The block diagram given in Fig. 15 explains the Hardware setup which consists of power supply, DC source, Microcontroller, Driver circuit and the power switches. The hybrid cascadedmultilevel inverter is validated experimentally by using the proposed multicarrier modulation with Selective Harmonic Elimination technique, a prototype of seven-level inverter has been built usingIRF460 MOSFET as shown in Fig.16.The gating signals are generated using PIC16F877A Micro controller. The seven level inverter output is as shown in Fig.17 and 18 respectively. THD was measured using Power quality analyser and is shown in Fig.19 and it is found to be 18%.

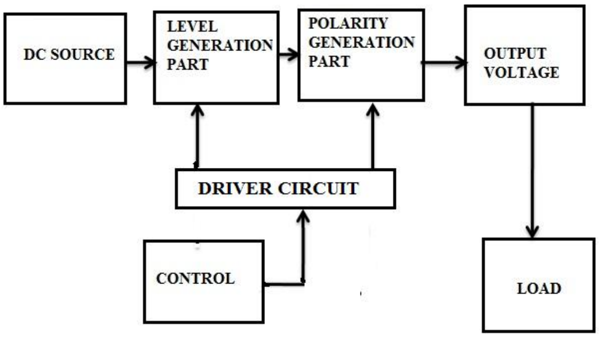


Figure 15: Block Diagram of hardware

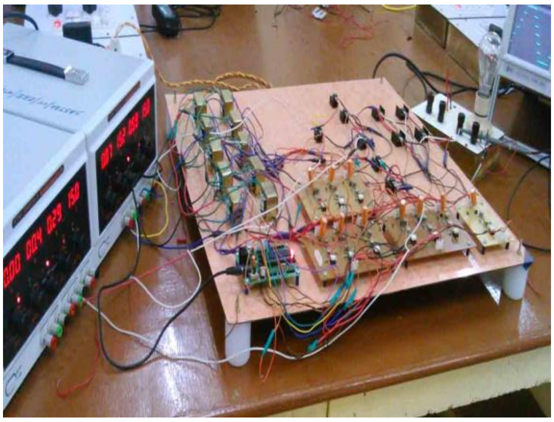


Figure 16: Hardware Setup

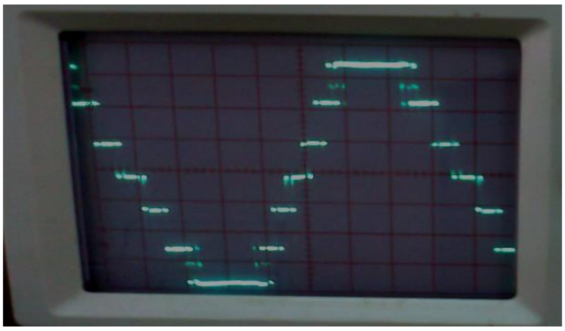


Figure 17: Seven level output voltage

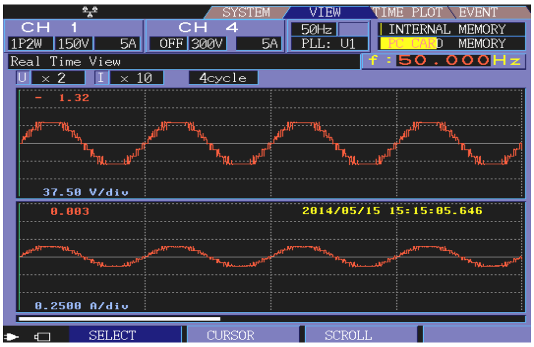


Figure 18: Output voltage and current

Figure 19: THD Measurement using Power Quality Analyzer

Conclusion

In this work, a multicarrier PWM with Trapezoidal technique was developed for Hybrid Multilevel Inverter. This hybrid multilevel inverter topology will reduce the number of components used compared with a normaltwo-level conventional inverter. Modes of operation, control signals, and operating principle for the proposed inverter were studied. The total harmonic distortion (THD) for the hybrid multilevel converter with the proposed PWM technique has been discussed. The behavior of the inverter has been analyzed with the simulation results and experimental results.

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