GA Optimized Weighted Random Pulse Width Modulation Approach for the Elimination of Harmonic Distortion for Multilevel Inverters

Kiran T. S, Bisharathubeevi A, K. N. Pavithran

Abstract: *This paper proposes an optimized weighted random pulse width modulation (WRPWM) scheme for multilevel power converters, for the elimination of harmonic distortion present at the output of the converter. In weighted random pulse width modulation, the PWM signal is generated by comparing random binary numbers with the fundamental reference signal. The proposed optimized WRPWM strategy provides an improved performance over traditional random pulse width modulation schemes for multilevel inverters. A binary valued Genetic algorithm (GA) is employed for the optimization process. The total harmonic distortion (THD) is taken as the performance index for optimization. Simulation results of optimized WRPWM scheme for a three-level and five-level inverters are presented in this paper.*

Index Terms: *Genetic Algorithm (GA), Random pulse width modulation (RPWM), Total Harmonic Distortion (THD), Weighted Random Pulse Width Modulation (WRPWM).*

I. INTRODUCTION

The multilevel power converter technology is a promising technology for high power electric applications. Because of their capability of high voltage operation, high efficiency, and low electromagnetic interference, the multilevel power converters have received more and more attention in today's industry [8][9]. For a multilevel inverter the desired output is synthesized by several sources of DC voltages. By increasing number of DC voltage sources a nearly sinusoidal voltage can be achieved at the output of the inverter. This results in low switching losses, power losses and less electromagnetic interferences etc. These types of inverters are widely used as input supply for induction motors in industrial applications.

Harmonics in multilevel inverters produces a number of undesirable effects in power systems. Harmonics in the power system increases current in the system. High levels of harmonic distortions may cause several harmful effects such as increased size of transformer, motor or generator heating, maloperation of electronic equipment, incorrect reading on meters etc. In induction motors it produces acoustic noise, electromagnetic interference, power loss, switching loss, thermal noise etc. So the elimination of harmonics in power systems is very important. To control the output voltage and eliminating the harmonic distortions present at the output of the inverter, several random pulse width modulation (RPWM) strategies have been developed [1][2]. Three basic RPWM strategies are: 1) Random carrier frequency technique, 2) Random pulse position technique, and 3) Random switching technique [3][4][5]. In random carrier frequency technique, the switching frequency is randomly changed from cycle to cycle [3]. The switching pulses are randomly placed in individual switching intervals in random pulse position technique [4]. In the third technique, the switching signals are generated by comparing random binary number with the reference signal of desired frequency [5]. These methods are used for randomizing the switching pattern of the inverter.

An optimized weighted random switching PWM scheme is proposed in this paper which has several advantages. In weighted random switching, the PWM signal is generated by comparing random binary numbers with fundamental reference of desired frequency [5]. A binary valued genetic algorithm is used to optimize the random switching sequences. Genetic algorithm is used to select an optimum random switching sequence, which ensures minimum harmonic distortion, from a lot of random sequences. The THD is used as performance index for optimization. Simulation results shows that optimized random multilevel provides an improved performance over conventional random multilevel inverters.

II. PRINCIPLES OF WEIGHTED RANDOM PWM TECHNIQUE

Random pulse width modulation techniques are mainly used for spreading the harmonic energy content at the output of the inverter. This spreading of harmonic energy is achieved through randomization of the switching pattern of the inverter.

In weighted random PWM technique the switching PWM signal is generated by comparing a sequence of random binary numbers with the reference sinusoidal voltage of desired frequency. For an n level inverter, (n-1) level shifted random carrier waves are required for the comparison [1]. The weighted random PWM scheme for a two level inverter is shown in Fig 1. Each comparison gives 1 if the modulating signal is greater than that of random carrier wave and gives 0 otherwise.

Revised Manuscript Received on 13 April 2018.

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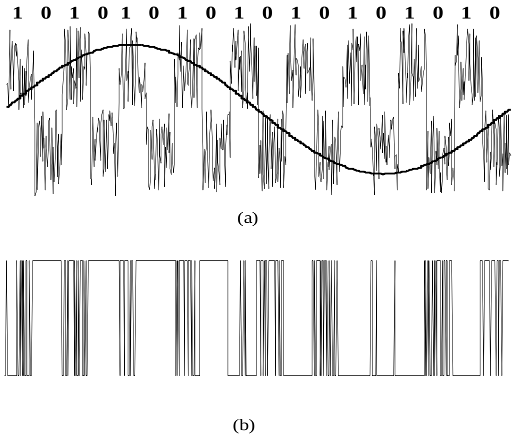

Fig.1 Principles of Weighted Random PWM (a) Modulation Waveform and Carrier Waveform (b) PWM Output

A. Weighted Random PWM for Three Level Inverters

For three-level inverters, switching PWM signal is generated by comparing two level shifted random carrier waves with a fundamental reference sinusoidal signal as shown in Fig.2. Here each comparison gives 1 if the reference signal r(t) is greater than the random carrier, 0 if greater than, and -1 otherwise.

$$z(t) = \begin{cases} 1, & if \quad r(t) \geq x_1(t) \\ 0, & if \quad r(t) \geq x_2(t) \\ -1, & otherwise \end{cases} \quad (1)$$

Where $x_1(t)$ and $x_2(t)$ are the two random carrier signals.

In weighted random technique, the continuous random carrier waves are generated corresponding to a pattern of binary values. Binary number one is used to represent one cycle of two simultaneous random waves, which are in same phase and zero for one cycle of the inverted random waves. Placing alternate binary values will result in two level shifted random carrier waves which can be used to generate switching PWM for multilevel inverters.

In multilevel inverters, the improper switching action of the switching devices present inside the inverter will produce harmonic components at the output of the inverter. These harmonics will produce several problems like acoustic noise, electromagnetic interference, power loss etc. in motors. Therefore it is important to estimate the total effect of these harmonics. The summation of all harmonics in a system is known as Total Harmonic Distortion (THD). Total harmonic distortion is the ratio of the sum of the powers of all harmonic frequencies above the fundamental frequency to the power of fundamental frequency.

$$THD = \frac{\sum Harmonicpowers}{Fundamentalharmonicpower} = \frac{P_2 + P_3 + ... + P_n}{P_1} \quad (2)$$

The weighted random PWM output of a three-level inverter is shown in Fig.2 (b) and the corresponding normalized harmonic spectrum is shown in Fig.3. THD of the corresponding PWM is found to be 0.7913.

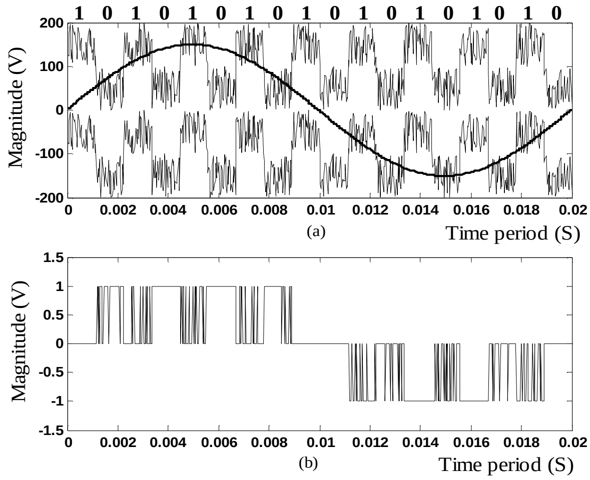

Fig 2. (a) Weighted Random PWM Reference and Carriers (b) PWM Output

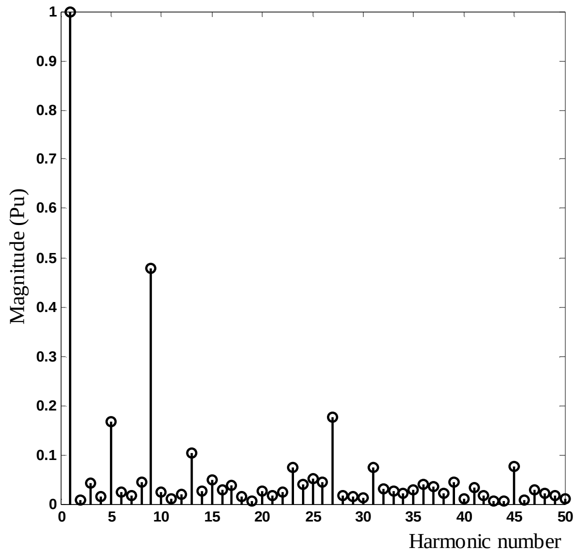

Fig 3.Normalized Harmonic Spectrum (THD=0.7913)

In order to reduce the total harmonic distortion of random PWM inverter, the principle proposed in this paper is to use random carrier waves generated by a random pattern of binary values. The shape of the carrier is varied in accordance with the instantaneous binary values. Fig.4 shows the modulating waveform, the level shifted random carrier waveforms and random PWM output for a three-level inverter, where the carrier wave is generated using a sequence of 100000001111111010. The corresponding normalized harmonic spectrum of the inverter is shown in Fig 5.

The THD of the corresponding PWM is found to be 0.4128. Figure shows that the weighted random PWM technique can provide lower THD values when compared to conventional random PWM technique.

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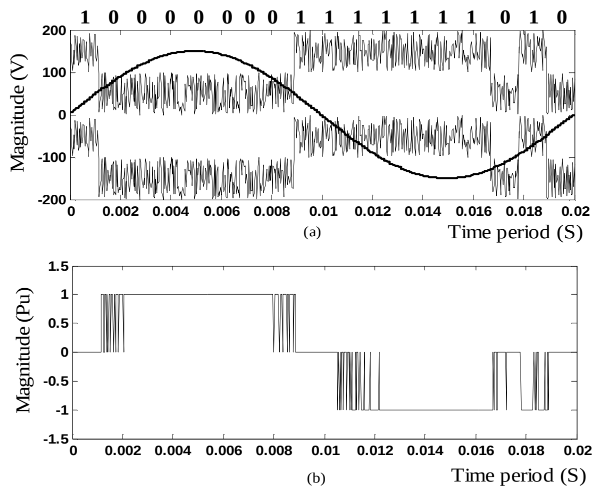

Fig. 4 (a) Random PWM Reference and Carriers (b) PWM Output

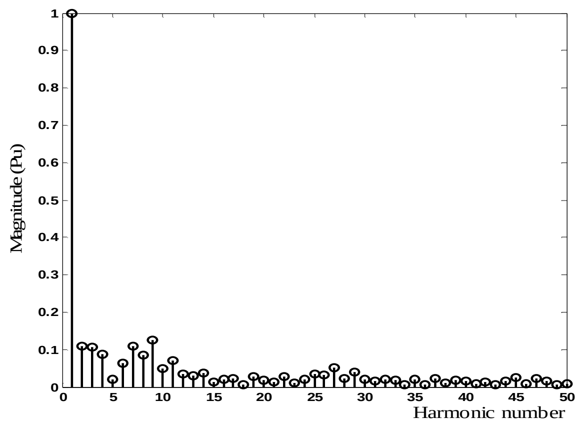

Fig 5. Normalized Harmonic Spectrum (THD=0.4128)

B. Optimized WRPWMFor Three-Level Inverter Based On GA

The main issue associated with the conventional random PWM is that the instantaneous harmonic distributions corresponding to each of the random carrier sequences are different at every sinusoidal cycle. Hence the power quality of inverter output is not optimum at all time. In order to optimize the random PWM, a binary-valued genetic algorithm (GA) is employed with THD as the objective function [10, 11]. GA is used to select a random carrier sequence from a lot of random sequences that can achieve a minimum THD value at all time.

The steps involved in GA for optimizing PWM using THD as the objective function is as shown in Fig.6.

The procedures of binary valued GA for optimizing random PWM are summarized as follows:

1: Randomly initialize population:

The process begins with the generation of random population of N chromosomes.

2: Determine fitness of population:

The fitness values for each chromosome in the population are generated and evaluated with a linear ranking method. In this paper THD is taken as fitness value.

3: New population:

Two strings with minimum THD value are selected as parent structures to form new offspring for the next generation by the process called reproduction. Mutation and cross over processes are used to exchange the information among the chromosomes.

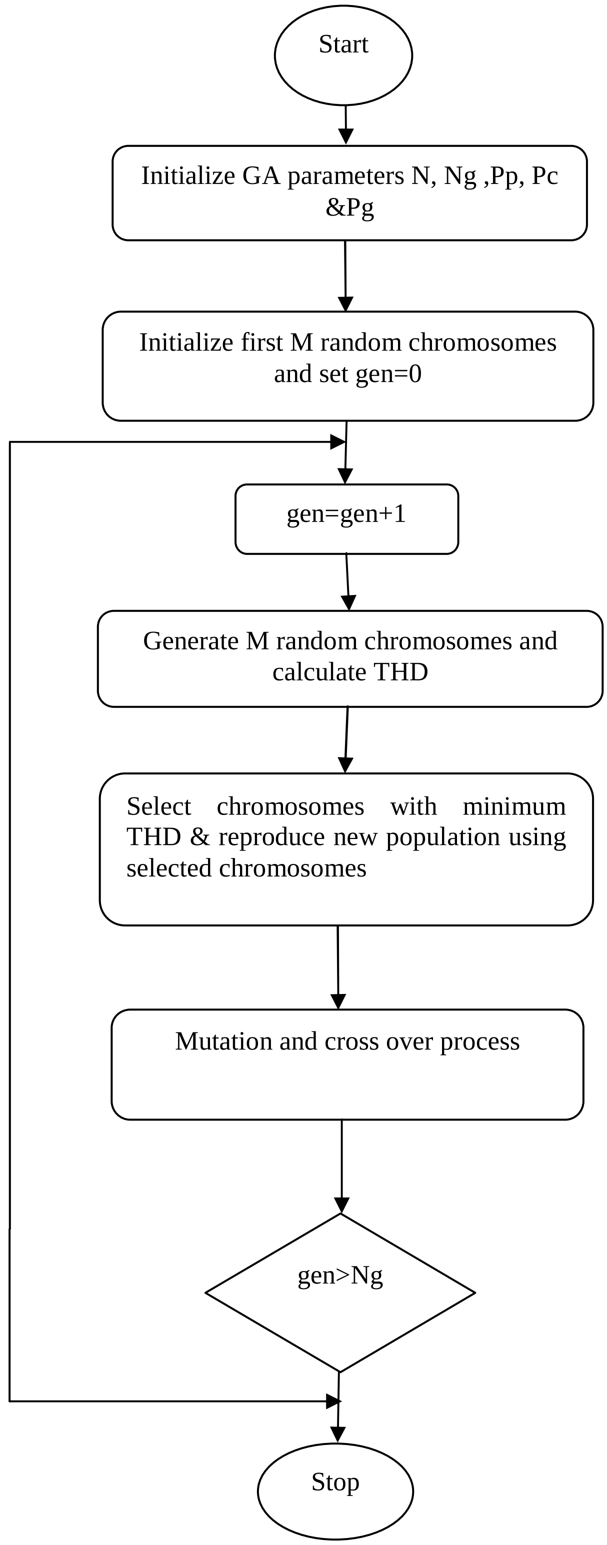

Fig 6. GA operation flowchart to optimize a random PWM Inverter

4: Replace old with new population

Newly generated populations are used for further run of algorithm.

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5: Test the problem

If the end condition is satisfied, stop and return the best solution in current population.

6: Repeat:

Continue Step 1 – 4 until the carrier sequence with minimum THD is achieved.

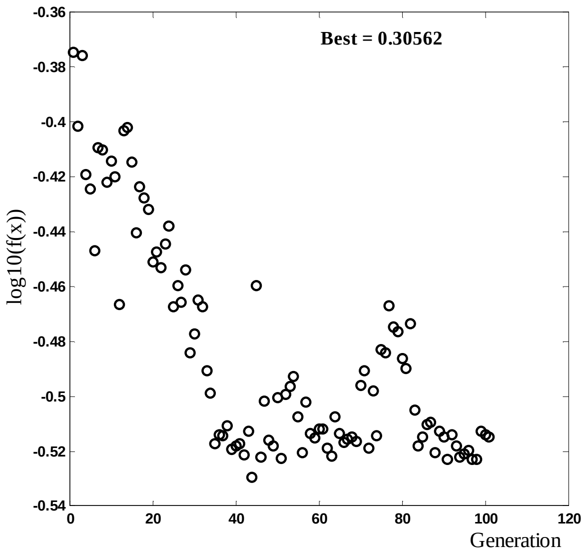

Fig.7. Optimization result of Three-level PWM Output Voltage

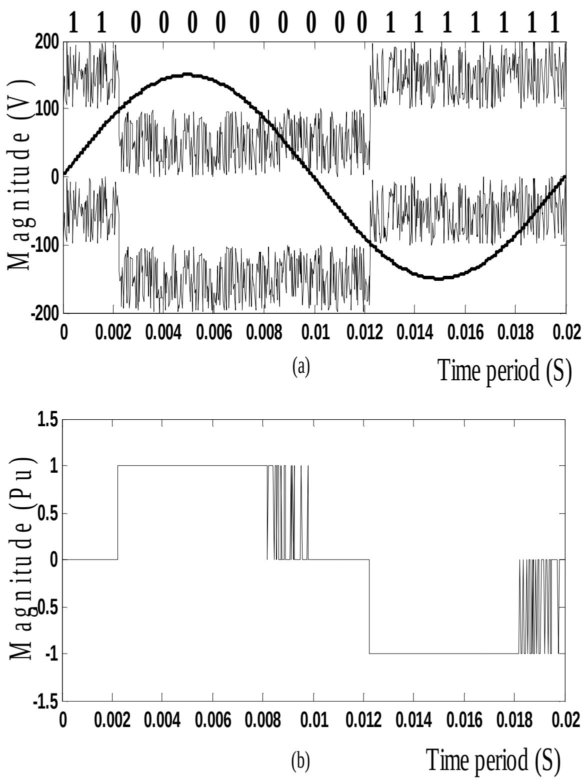

Fig. 8(a) Optimized PWM reference and carriers (b) PWM Output

The simulation results for the random PWM inverter with the optimized carrier sequence and its corresponding PWM output are shown by Fig.7 and Fig. 8 respectively. THD of the optimized PWM output voltage has decreased to 0.30562. The optimized carrier sequence 110000000001111110 is generated at the hundredth population. The corresponding normalized harmonic spectrum of optimized PWM output voltage is shown in Fig 9.

C. Optimized WRPWM for Five-Level Inverters

A five-level inverter scheme requires four level shifted random carriers for the comparison with a fundamental modulating sinusoidal signal.

$$z(t)=\begin{cases}2, & \text{if } r(t)\geq x_1(t)\\ 1, & \text{if } r(t)\geq x_2(t)\\ 0, & \text{if } r(t)\geq x_3(t)\\ -1, & \text{if } r(t)\geq x_4(t)\\ -2, & \text{otherwise}\end{cases} \qquad (3)$$

Where $x_1(t)$, $x_2(t)$, $x_3(t)$ and $x_4(t)$ are the four random carrier signals which are generated corresponding to random binary numbers and r(t) is the modulating signal of desired frequency. The conventional PWM and weighted random PWM and the corresponding normalized harmonic spectrum are shown in Fig.10, Fig.12 and Fig.13 respectively. The THD of the conventional PWM is 0.2887 and that of weighted random PWM is 0.2587. Fig. 14 shows the optimization results using GA gives an optimal THD of 0.2044.

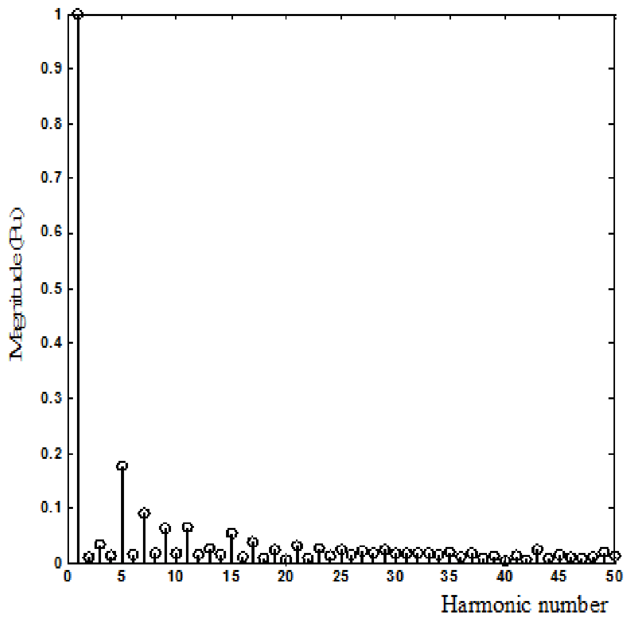

Fig. 9.Normalized Harmonic Spectrum (THD=0.3056)

D. Optimized WRPWM for n-level Inverter

An n level inverter employs n-1 random carrier waves with the sinusoidal modulating signal. With the technique proposed in this paper, we can construct continuous random carrier wave corresponding to a pattern of binary values. By placing alternate binary values we can generate a level shifted random carrier wave as needed for an n-level inverter.

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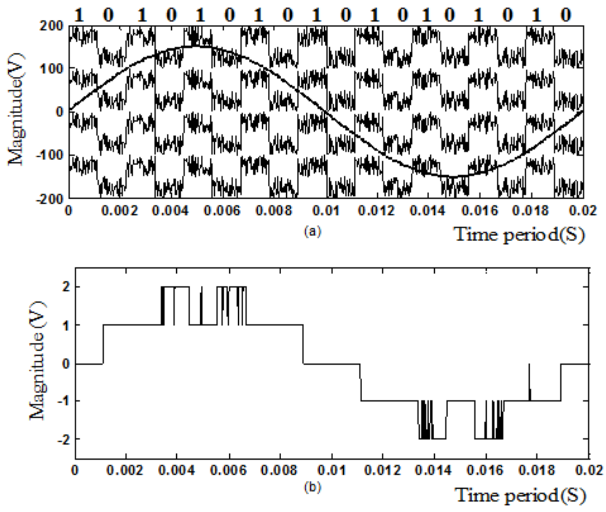

Fig. 10(a) Reference and Carriers Waves for 5 level Inverter (b) PWM Output

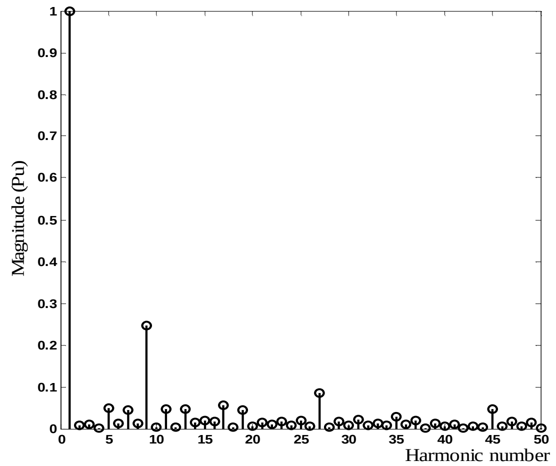

Fig. 11.Normalized Harmonic Spectrum (THD=0.2887)

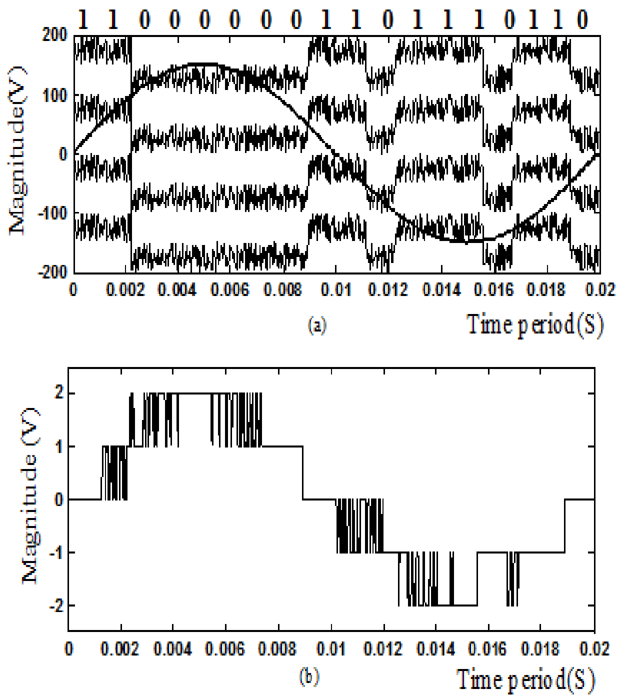

Fig. 12. (a) Random PWM Reference and Carriers (b) PWM Output

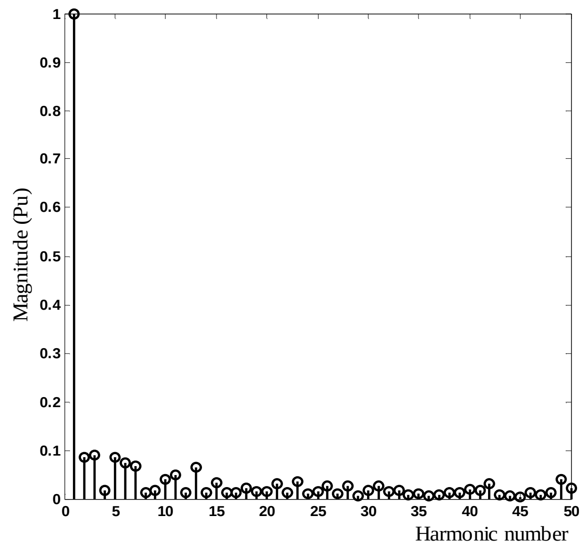

Fig 13.Normalized Harmonic Spectrum (THD=0.2587)

III. RESULTSAND DISCUSSIONS

MATLAB software is used to run the binary-valued GA in this paper. In simulation studies, the following GA program parameters gave satisfactory results:

- *Initial population size (N): 4*
- *Maximum number of generations (Ng):100*
- *Probability of crossover (Pc): 0.9*
- *Probability of mutation (Pp): 0.05*
- *Generation Gap (Gp):6*
- *Precision of binary representation: 3*
- *Performance index: the THD of PWM inverter output voltage.*

When applied to both three-level and five-level inverters these values provide an acceptable optimization with high rate of convergence. Hence these values are maintained in the optimization process.

For three-level inverter, an optimized random carrier is generated using Genetic Algorithm, and from which optimized PWM and its corresponding spectrum with THD 0.30562 for modulation index (m) = 0.75 are generated and are shown in Fig.7, Fig.8 and Fig.9 respectively. The optimized random carrier, PWM and its corresponding normalized spectrum with THD 0.2044 for same modulation index for a five-level inverter is shown in Fig.14, Fig.15 and Fig.16 respectively. The simulation result shows that optimized weighted random PWM provides lower THD values when compared with conventional random PWM technique. Fig.17 and Fig.18 shows the variation of THD with the entire range of linear modulation indices for sine-triangle, random and optimized strategies of three-level and five-level inverters.

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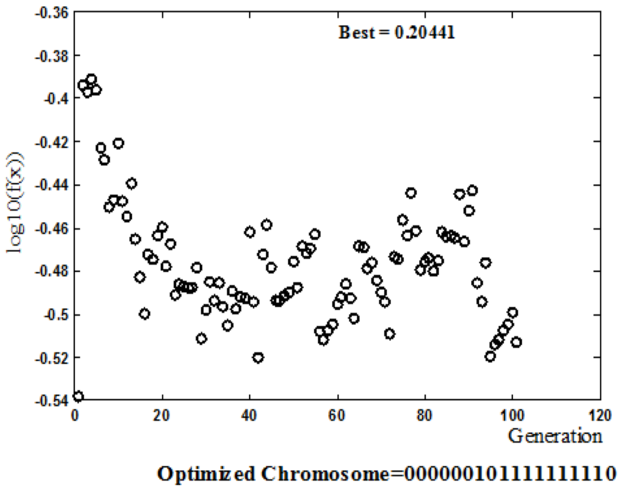

Fig.14. Optimization Result of Five-Level PWM Output Voltage

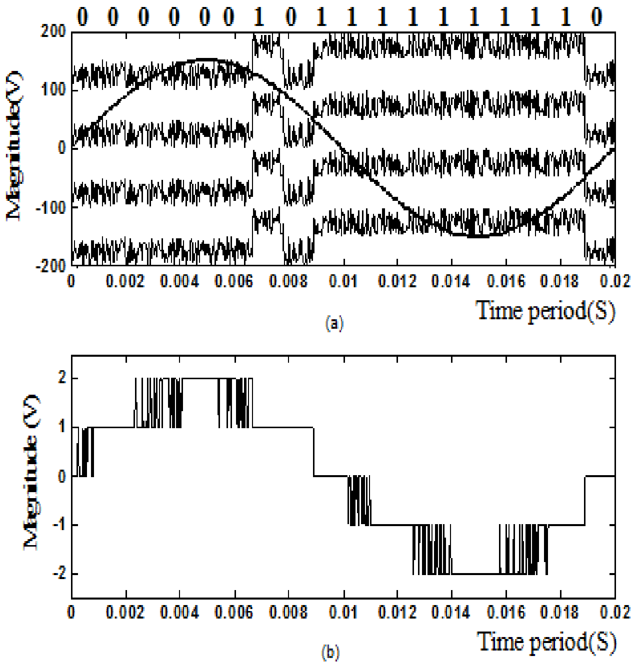

Fig. 15(a) Optimized PWM reference and carriers (b) PWM Output

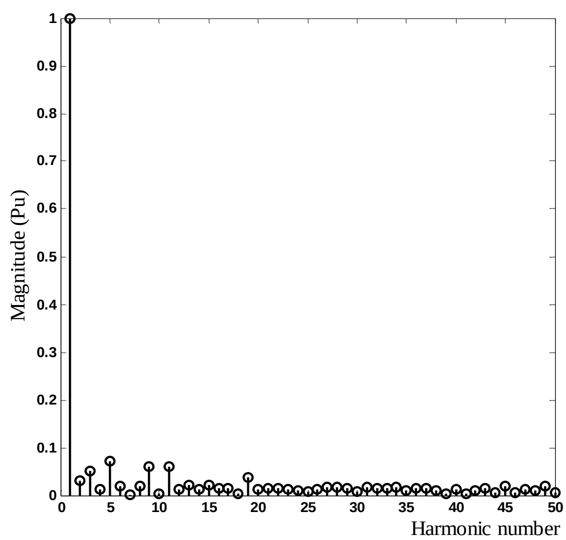

Fig 16.Normalized Harmonic Spectrum (THD=0.2044)

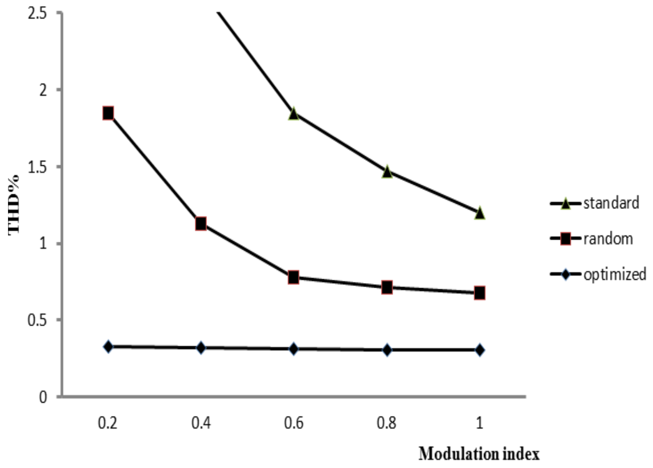

Fig. 17. Variation of THD with Modulation Index for Three-Level Standard, Random and Optimized PWM

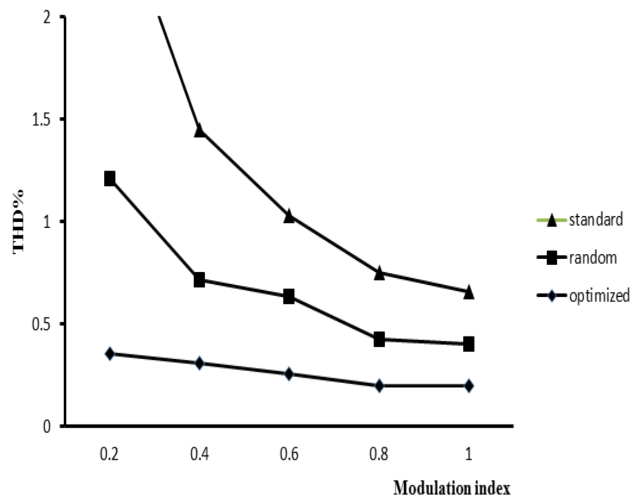

Fig 18.Variation of THD with Modulation Index for Five-Level Standard, Random and Optimized PWM

IV. CONCLUSION

An optimized weighted random PWM strategy for multilevel inverter is proposed in this paper. In weighed random technique the PWM signal is generated by comparing random binary numbers with the fundamental reference signal. In this proposed random PWM scheme the switching sequences are optimized using a binary valued genetic algorithm. Optimization of a three-level and five level inverters are presented. The simulation results shows that optimized PWM based on GA provide better performance than conventional PWM for multilevel inverters.

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