# GA Based Optimization and Critical Evaluation SHE Methods for Three-level Inverter

**J.Baskaran, S.Thamizharasan, R.Rajtilak**

***Abstract: The Selective Harmonic Elimination Pulse-Width Modulation (SHE-PWM) has been an inclusive research area in the field of Power Converters. This technique offers a tight control of the harmonic spectrum of a given voltage waveform generated by a power electronic converter along with a low number of switching transitions. It involves the solution of non-linear transcendental equation sets representing the relation between the amplitude of the fundamental wave, harmonic components and the switching angles. This paper reports solutions to the Selective Harmonic Elimination (SHE) method based on novel usage of Artificial Intelligence (AI) technique such as Genetic algorithm (GA) for single-phase three-level inverter. This paper uses Matlab GA Toolbox to generate the gate pulse pattern to eliminate the required order of harmonics present in the demanded fundamental output voltage.***

***Index Terms: SHE-PWM, SPWM, GA Toolbox.***

## I. INTRODUCTION

The problem of eliminating harmonics in switching converters has been the focus of research for many years. If the switching losses in an inverter are not a concern (i.e., switching on the order of a few kHz is acceptable), then the sine-triangle PWM method and its variants are very effective for controlling the inverter output voltage [1]. This is because the generated harmonics are beyond the bandwidth of the system being actuated and therefore these harmonics do not dissipate power. On the other hand, for systems where high switching efficiency is of utmost importance, it is desirable to keep the switching frequency much lower. In this case, another approach is to choose the switching times (angles) in such a way that a desired fundamental output is generated and specifically chosen harmonics of the fundamental voltage are suppressed [1]–[5]. This is called as harmonic elimination or programmed harmonic elimination as the switching angles are chosen (programmed) to eliminate specific harmonics. The common characteristic of the SHE-PWM method is that the waveform analysis is performed using Fourier theory [6] - [9]. Sets of non-linear transcendental equations are then derived, and the solution is obtained using an iterative procedure, mostly by Newton-Raphson method [2]-[4]. This method is derivative-dependent and may result in local optima; however, a judicious choice of the initial values guarantees convergence [6]. Another approach uses Walsh functions [6] where solving linear equations, instead of non-linear transcendental equations, optimizes the switching angles. In references [2] and [4] these transcendental equations are converted into polynomial equations where the resultant theory is applied to determine the switching angles to eliminate specific harmonics.

Genetic Algorithm (GA) is not customary in the field of power electronics but it was first introduced by *M. J. Schutten* and *D. A Torrey*, for the control of power converters in the year 1995 [10]. Following the same, *B. Ozpineci et al.*, used GA for optimizing the pulses in a pulse density modulated high frequency ac-ac converter [11]. GA has been later applied in the field of inverters by *A. I. Maswood et al.* to generate SHE-PWM switching patterns in the year 2001 [12]. In 2004, *B. Ozpineci* used the same technique of SHE in multilevel inverters and proved the competence of GA with numerical methods [13].

## II. PROBLEM FORMULATION

The SHE-PWM technique is currently used to synthesize an output voltage waveform of a full-bridge inverter. In this work, a three-level SHE-PWM pulse pattern generated by a full-bridge inverter is considered. A full-bridge voltage source inverter, which comprises four switches and a dc source, is depicted in Fig.1. Three states of an output voltage waveform such as positive, negative and zero can be obtained. Fig.2 shows a generalized three-level SHE-PWM waveform, which synthesized using the inverter circuit shown in Fig.1.

The output waveform is chopped 'N' number of times per quarter cycle. Each switch is therefore switched '2N' times per half cycle to generate such a voltage waveform. The H-bridge inverter discussed above has three states of operation. Consider the generalized three-level SHE-PWM waveform shown in Fig.2. Let N be the number of switching angles per quarter-cycle.

By applying Fourier series to the above waveform, the output voltage is given by,

$$Vo = a_0 + \sum_{n=1}^{\infty} a_n \sin(n\omega t) + b_n \cos(n\omega t)$$

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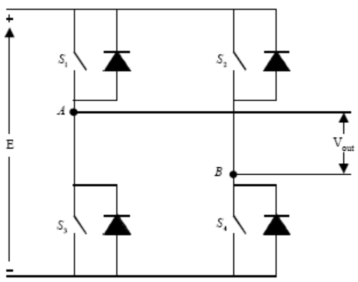


**Fig.1 A full-bridge voltage source inverter**

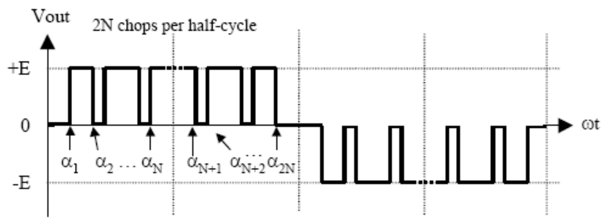


**Fig.2 Generalized three-level SHE PWM waveform**

The output voltage waveform is assumed to be odd quarter wave symmetry, whose amplitude equals E. Because of odd quarter wave symmetry, the dc component and the even harmonics are equal to zero.

Therefore,

$$a_n = \frac{2}{T}\int_0^T E\sin(n\omega t)d(\omega t)$$

$$a_n = \frac{4}{\pi}\int_0^{\frac{\Pi}{2}} E\sin(n\omega t)d(\omega t) \text{ for odd values of n} \quad (1)$$

and

$$b_n = 0 \text{ for all n} \quad (2)$$

For all $n$, from equations (1) and (2), the Fourier series is given as,

$$Vo = \sum_{n=1}^{\infty} a_n \sin(n\omega t) \quad (3)$$

Substituting ωt = α in equation (1) gives the following.

$$a_n = \frac{4}{\pi}\int_0^{\frac{\Pi}{2}} f(\alpha)\sin(n\alpha)d(\alpha) \quad (4)$$

For the waveform shown in Fig.2, the equation (4) is evaluated and given as,

$$a_n = \frac{E*4}{\pi}\left[\int_0^{\alpha_1}\sin(n\alpha)d(\alpha) + \int_{\alpha_1}^{\alpha_2}\sin(n\alpha)d(\alpha) + \int_{\alpha_2}^{\alpha_3}\sin(n\alpha)d(\alpha) + \int_{\alpha_3}^{\frac{\pi}{2}}\sin(n\alpha)d(\alpha)\right] \quad (5)$$

$$a_n = \frac{4*E}{n\pi}\left[\cos(n\alpha_1) - \cos(n\alpha_2) + \cos(n\alpha_3)\right] \quad (6)$$

The output voltage of the unipolar waveform shown in Fig.2 is expressed as,

$$V_{out}(\omega t) = \sum_{n=1}^{\infty}\left\{\frac{4*E}{n\pi}\left[\cos(n\alpha_1) - \cos(n\alpha_2) + \cos(n\alpha_3)\right]\right\} \quad (7)$$

Where, $\alpha_1$, $\alpha_2$, $\alpha_3$ are the inverter switching angles with the condition $\alpha_1 < \alpha_2 < \alpha_3 < \Pi/2$, $n$ is the odd number, for our work we are taken n=3.

From (7), the amplitude of the fundamental and odd-harmonic component of the three-level inverter output voltage are calculated and given in equations (8) and (9). The lowest order harmonics are dominant and need to be eliminated from the inverter output voltage waveform. The inverter switching angles are calculated such that the lowest order harmonics are eliminated.

$$h_1 = \frac{4*E}{\pi}\left[\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3)\right] \quad (8)$$

and

$$h_n = \frac{4*E}{n\pi}\left[\cos(n\alpha_1) - \cos(n\alpha_2) + \cos(n\alpha_3)\right] \quad (9)$$

The fundamental amplitude of an inverter output voltage waveform is controlled using the modulation index given in equation (10). For a three-phase system the lowest non-triplen harmonics are need to be eliminated from the phase voltage. For three-level inverter, three angles ($\alpha_1$, $\alpha_2$, $\alpha_3$) are used to control the fundamental and eliminate the two lowest order harmonics such as $3^{rd}$ and $5^{th}$.

The Modulation Index $M = \frac{h_1}{E}$ (10)

$$\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) = M\frac{\pi}{4}$$
$$\cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) = 0$$
$$\cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) = 0 \quad (11)$$

These equations are nonlinear and transcendental in nature. Conventional techniques use Newton-Raphson method to solve the SHE problem. This method is derivative-dependent time consuming and involves more mathematical calculations. In order to reduce the computational burden and time, AI technique such as Genetic Algorithm (GA) is used to solve the objective function of SHE problem.

## III. GA TOOLBOX

Genetic Algorithm (GA) is a method used for solving both constrained and unconstrained optimization problems based on natural selection, the process that drives biological evolution. GA repeatedly modifies a population of individual solutions. At each step, GA selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" towards an optimal solution. GA uses three main rules at each step to create the next generation from the current population:

- *Selection rules* select the individuals, called *parents* that contribute to the population at the next generation.
- *Crossover rules* combine two parents to form children for the next generation.
- *Mutation rules* apply random changes to individual parents to form children.

**Calling the function 'ga' at the Command Line**

To use GA at the command line, call the GA function ga with the syntax

*[x fval] = ga (@fitnessfun, nvars, options)*

where

- *@fitnessfun* is a handle to the fitness function.
- *nvars* is the number of independent variables for the fitness function.
- *options* is a structure containing options for the genetic algorithm. If you do not pass in this argument, ga uses its default options.

The results are given by

- *x* — Point at which the final value is attained
- *fval* — Final value of the fitness function

Using the function ga is convenient if you want to

- Return results directly to the MATLAB workspace
- Run the genetic algorithm multiple times with different options, by calling ga from an M-file.

**Using GA Tool**

The Genetic Algorithm tool is a graphical user interface that enables you to use the genetic algorithm without working at the command line. To open it, enter *gatool.* at the MATLAB command prompt. The tool opens as shown in the Fig.3.

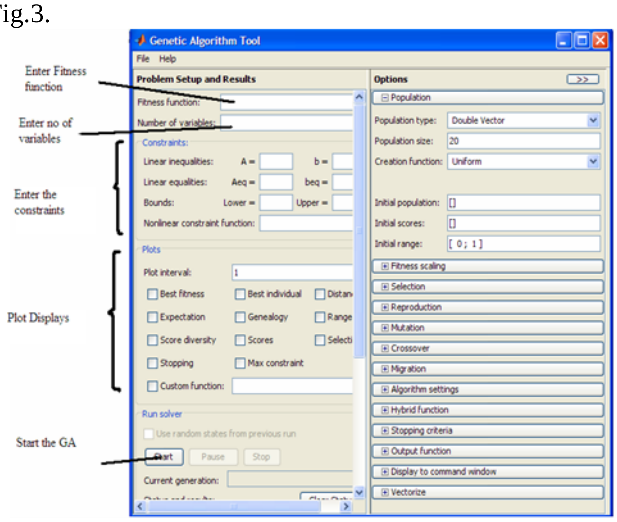


**Fig.3 GA Toolbox**

To use the GA tool, the following information is entered,

- **Fitness function** — The objective function is to minimize. Enter the fitness function in the form @fitnessfun, where fitnessfun.m is an M-file that computes the fitness function.
- **Number of variables** — The length of the input vector to the fitness function.

Enter constraints or a nonlinear constraint function for the problem in the **Constraints** pane. If the problem is unconstrained, leave these fields blank.

To run the GA, click the **Start** button. The tool displays the results of the optimization in the **Status and results** pane. We can change the options for the genetic algorithm in the **Options** pane.

## IV. SIMULATION RESULTS AND DISCUSSIONS

A program was developed using the software package MATLAB 7.1 and using GA Toolbox, the solutions are found.

Simulation parameters:

$$V_{dc} = 100V$$
$$M_a = 0.8$$

The angles obtained after solving the equation by using Genetic algorithm are,

$$\alpha_1 = 31.39^o,\ \alpha_2 = 54.54^o,\ \alpha_3 = 69.32^o$$

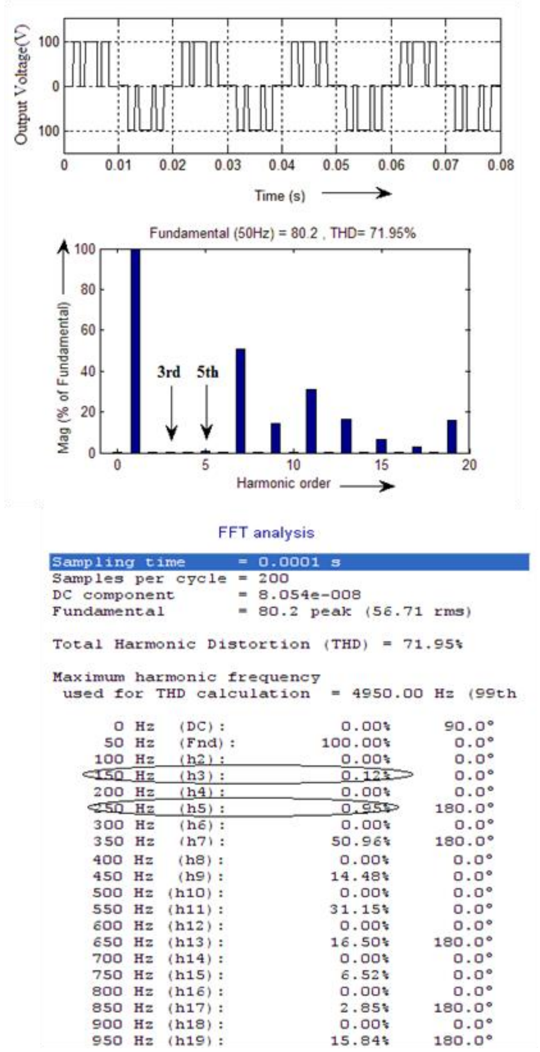


**Fig.4 Output voltage and harmonic spectrum**

Fig.4 shows the harmonic spectrum for the three-level inverter output voltage waveform in which the 3rd and 5th order harmonics are completely eliminated and the values are also shown.


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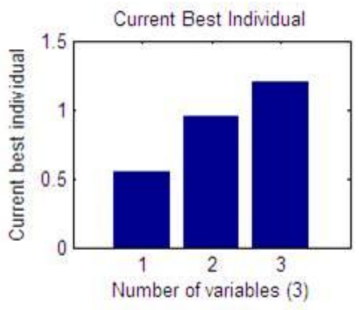
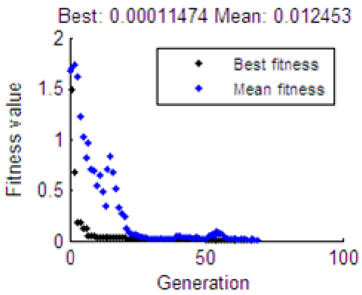



(a)




**(b)**

**Fig.5 GA Results**

Fig.5 (a) shows the best function value in each generation versus iteration number and (b) shows the vector entries of the individual with the best fitness function value in each generation.

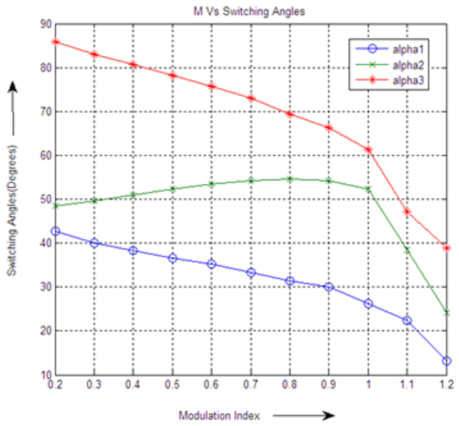



**Fig.6 Switching angles for various modulation indices**

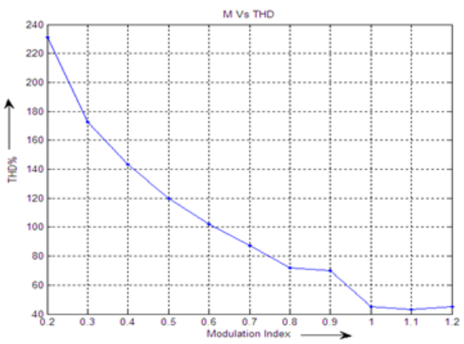



**Fig.7 THD values for various modulation modulation indices**

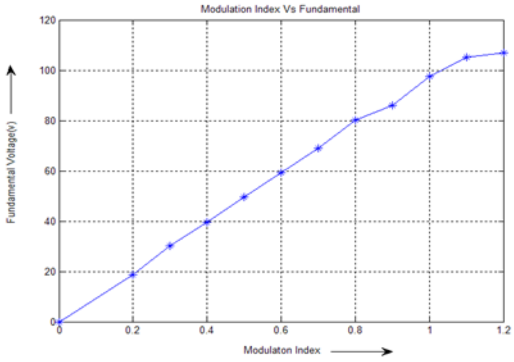



**Fig.8 Fundamental voltages for various modulation indices**

Fig. 6 to Fig.8 shows the various results for SHE-PWM case. To compare the performance of the SHE-PWM with that of SPWM, the same number of pulses per half cycle is taken and the results are validated as shown in the Fig.9 to Fig.11

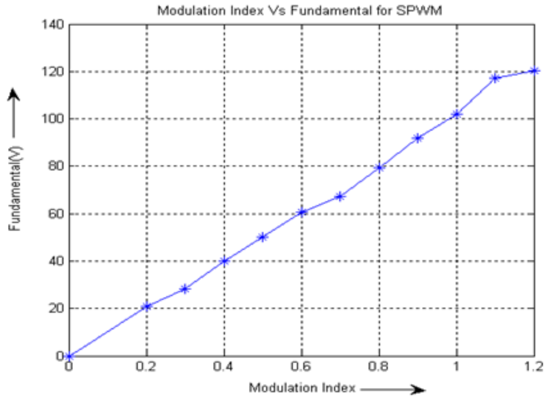



**Fig.9 Fundamental voltages for various modulation indices**

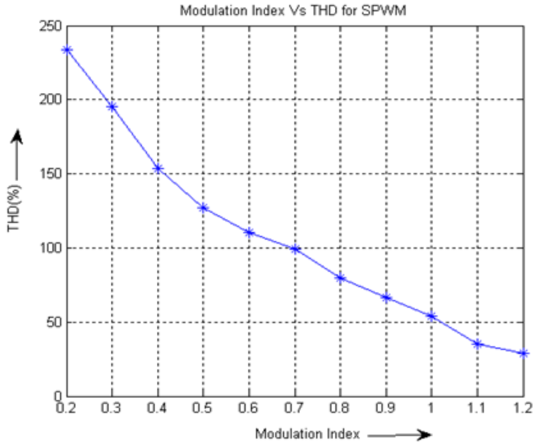



**Fig.10 THD values for various modulation indices**

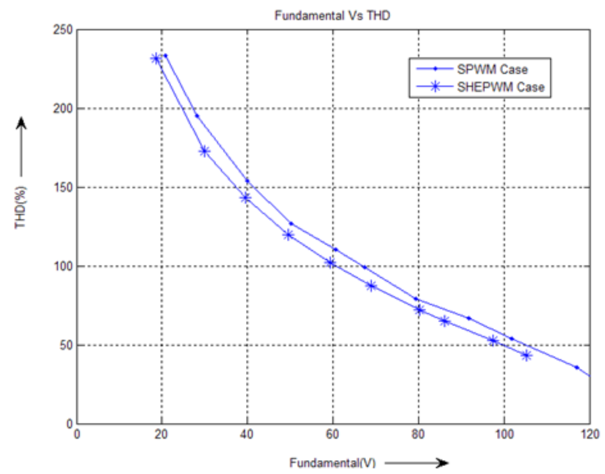



Fig.11 Fundamental Vs THD for both SHE-PWM and SHPWM

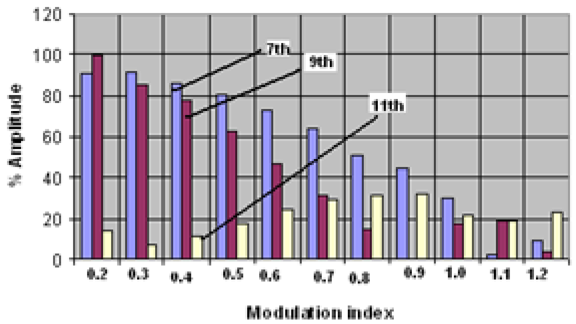



Fig.12 Modulation indices Vs Amplitude of uneliminated harmonics (7, 9, 11) (SHE-PWM case)

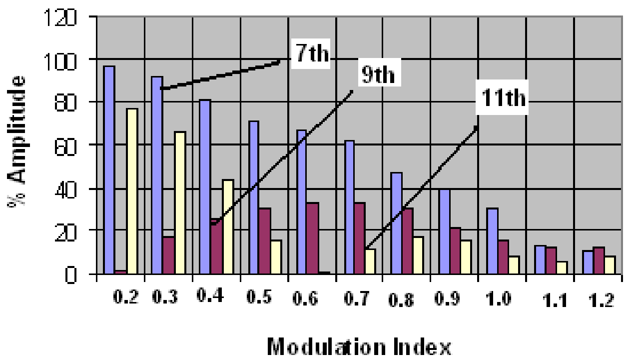



Fig.13 Modulation indices Vs Amplitude of uneliminated harmonics (7, 9, 11) (SPWM case)

Fig.12 and Fig.13 show the amplitudes of uneliminated harmonics such as 7th, 9th and 11th order for various modulation indices for SHE-PWM and SPWM case.

## V. HARDWARE RESULTS

The prototype for the single-phase three-level inverter is built and operated with the calculated angles.

The switch is IRF 840 MOSFET with $V_{DS}$ =500V, $I_D$(max) =8A, $R_{ds(on)}$ =0.850Ω.

The capacitor value is 5000μF

Input DC voltage is 100V

The load used is an R load with resistance=110 Ω

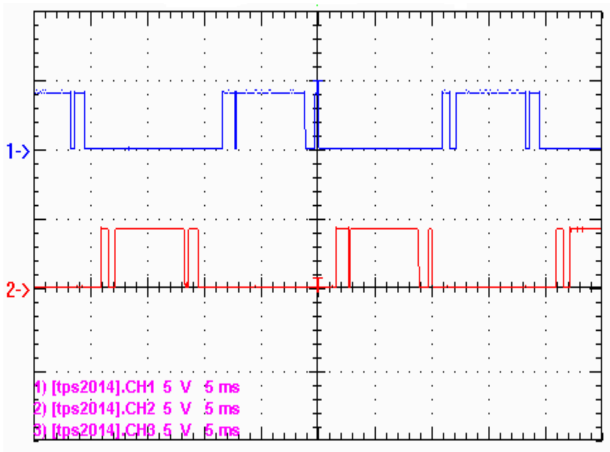



Fig.14 Experimental results of switching angles

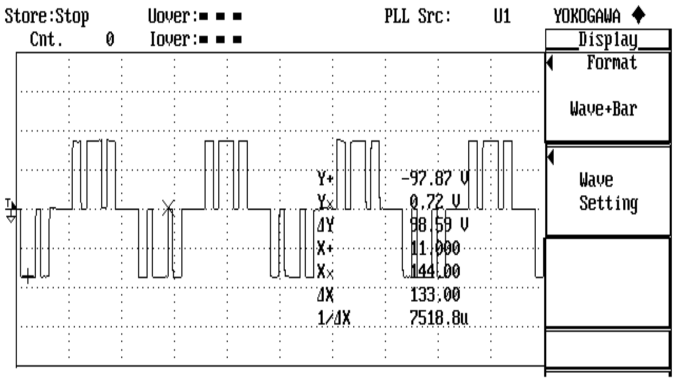



Fig.15 Experimental results of output voltage waveform

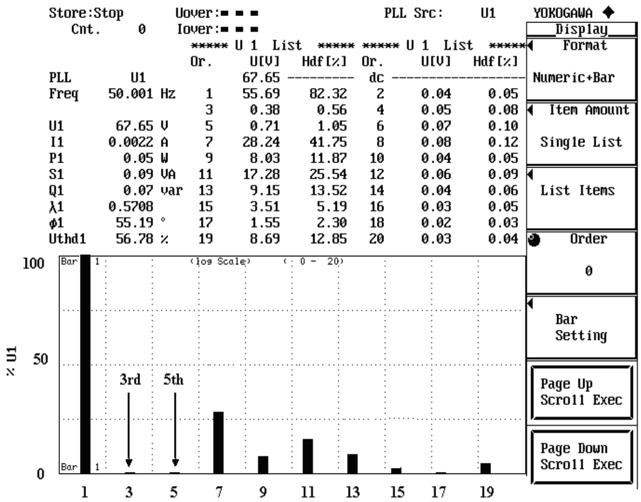



Fig.16 Experimental results of Harmonic spectrum

## VI. CONCLUSION

A GA method to generate optimal switching angles to eliminate certain order of harmonics is introduced in this paper. It is observed that the genetic algorithm works efficiently for harmonic elimination problem. The simulated and experimental results depict the same in which the 3rd and 5th order harmonics are completely eliminated.

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