Selective Harmonic Elimination PWM Method using Seven Level Inverters by Genetic Algorithm Optimization Technique

[1]R.Vijayakumar
Department of Electrical and Electronics Engineering
Christ College of Engineering and Technology
Puducherry, India

[2]Dr. Alamelu Natchiappan
Department of Electrical and Electronics Engineering
Pondicherry Engineering College
Puducherry, India

[3]C. Devilalitha
Department of Electrical and Electronics Engineering
Christ College of Engineering and Technology
Puducherry, India

[4]R. Mazhuventhi
Department of Electrical and Electronics Engineering
Christ College of Engineering and Technology
Puducherry, India

***Abstract*—This paper proposes a method for optimization of the harmonic performance of inverters under selective harmonic elimination PWM modulation (SHEPWM) control. SHEPWM method is used to optimize harmonic stepped waveform for multi-level inverters using Genetic algorithm. 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. The genetic algorithm obtains the being optimal solution set of switching angles for each obligatory harmonic profile. Optimized SHEPWM sequences obtained for various operating points under different sampling frequencies are exposed to result in significant reduction of major harmonics while upholding the waveform quality inside prescribed limits.**

Keywords—Selective Harmonic Elimination PWM Method (SHEPWM), Genetic Algorithm (GA), Cascaded H-Bridge Multilevel Inverter, Optimization Technique.

I. INTRODUCTION

The two general group are mainly involved in all applications are electrical drives for all AC motors when dc supply is used and in systems including high voltage direct current transmission systems, customer power & flexible ac transmission systems(FACTS) devices and interconnection of distributed generation units to a grid. Modulation Strategy classified according to several switching algorithm such as Pulse width modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM), Space Vector Modulation (SVM), Selective Harmonic Eliminated Pulse Width Modulation (SHEPWM) or Programmed Waveform Pulse Width Modulation (PWPWM) are applied widely to control and obtain switching angle to achieve the desired output voltage. In the recent era, a novel kind of inverter named multilevel inverter has been introduced. It can be used in high power and high voltage applications. Advantages of this multilevel approach include good power quality, good electromagnetic compatibility (EMC), low switching losses, and high voltage capability [1]. In order to extend the desired fundamental component of voltage, all of several switching methods create harmonics and hence, it is of attention to select the finest method to succeed minimum harmonics and total harmonic distortion (THD) [2]. However, PWM techniques are not able to eliminate lower order harmonics totally [3]. Alternative approach is to select the switching angles consequently that specific higher order harmonics such as the 5th, 7th, 11th, and 13th are suppressed in the output voltage of the inverter. This method is known as selective harmonic elimination (SHE) or programmed PWM techniques in practical literature [6]. A fundamental issue related with such method is to attain the arithmetic solution of nonlinear transcendental equations which include trigonometric terms and obviously existing several solutions [5]. This set of nonlinear equations can be solved by iterative techniques such as the Newton-Raphson method. SHEPWM provides highest power quality at fundamental switching frequency in comparison to other existing PWM methods like space vector modulation and carrier based PWM technique [7]. The applications of SHEPWM are power quality improvement, motor drives and high voltage DC transmission system & distributed system [8]. Genetic algorithm is used to solve the equation and determine the optimized switching angle [10]. It solves the problem with multiple solutions compared to Differential Evolution algorithm. It is method which is very easy to understand and practically does not demand the knowledge of mathematics [9].

In this paper, a harmony Genetic Algorithm (GA) approach will be presented. The problem can be solved with an easier formulation and with any number of levels without wide derivation of analytical expressions. It is also faster and more precise than other optimization techniques [11].

II. CASCADED MULTILEVEL INVERTERS

A novel scheme for an *m*-level ($m \geq 3$) cascaded multilevel hybrid inverter is proposed. In the proposed method, a simple algorithm of founding switching sequence is applied that leads

ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

to lowest change in voltage. An actual hybrid multilevel inverter must safeguard that the total harmonic distortion (THD) in the voltage output waveform is small sufficient [13]. This paper proposes a new algorithm for the hybrid multilevel inverter with uneven or varying voltage steps under the selective harmonic elimination PWM modulation. The algorithm results in the minimum THD of output voltage of the cascaded multilevel inverter with unequal voltage steps. A new expression of THD is existing to shorten the derivation [12].

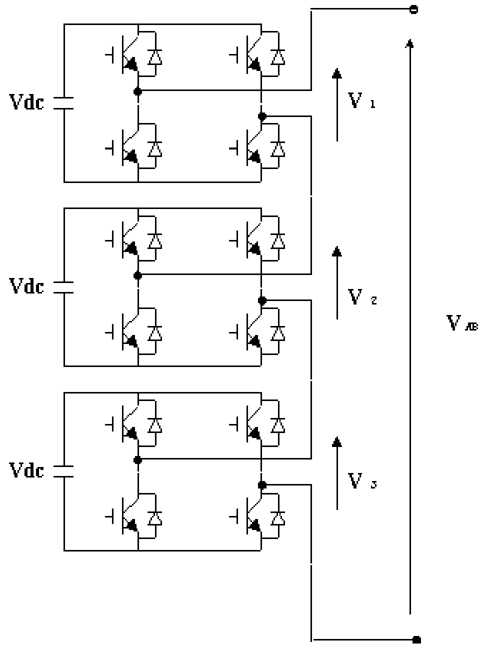

Fig. 1. M-level Cascaded H-Bridge Multilevel Invereter

A single H-bridge is a three-level converter. The four switches S_1, S_2, S_3 and S_4 are controlled to generate three discrete outputs V_{out} with levels V_{dc}, 0 and -V_{dc}. When S_1 and S_4 are on, the output is V_{dc}; when S_2 and S_3 are on, the output is $-V_{dc}$; when either pair S_1 and S_2 or S_3 and S_4 are on, the output is 0.

In this paper, seven level cascaded H-Bridge multilevel inverter used. It's obtaining the higher voltage level and increases the voltage level of the inverter using reduced number of switches. Easy to reduces total harmonic distortion [15].

The Fourier series of a 7 level unit dc source is shown in figure,

$$f(t) = f_{\theta 1}(t) + f_{\theta 2}(t) + f_{\theta 3}(t) \quad (1)$$

$$= \sum_{h=1}^{\infty} [\cos(h\theta_1) + \cos(h\theta_2) + \cos(h\theta_3)] \quad (2)$$

$$= \frac{4V_{dc}}{\pi} \sum_{h=1}^{\infty} \left[\sum_{i=1}^{3} [\cos(h\theta_i)] \frac{\sin(h\omega t)}{h} \right] \quad (3)$$

Where

V_{dc} = Voltage source for each cell that is unity

θ_i = the switching angle

h = harmonic order

III. Conventional Method

In conventional method, additional number of switches used to attain the switching angle and used to rises the output voltage level. For seven level inverters, fifth and seventh harmonics are lessening by using switching angle. In this method, low harmonics are allowable; an extensive solution space is available [14].

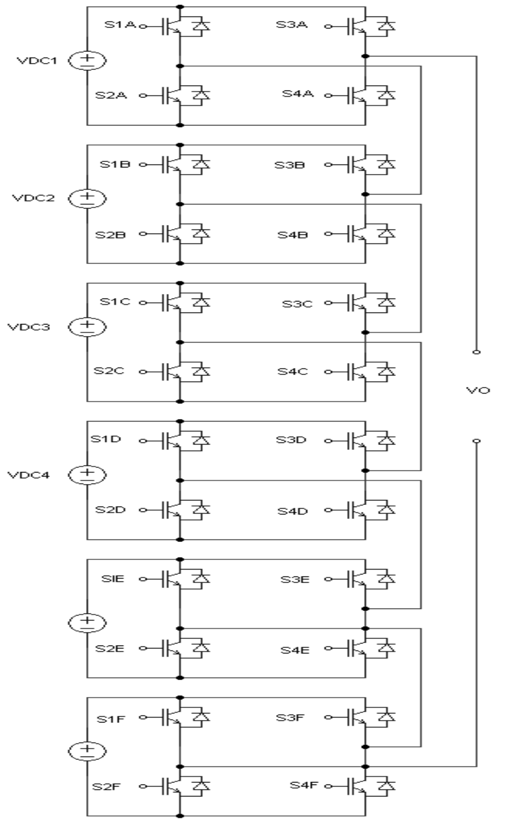

Fig. 2. Seven Level H-Bridge Multilevel Inverter

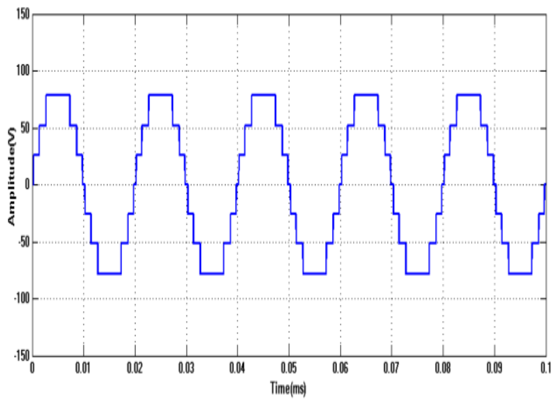

Fig. 3. Seven Level Output Voltage Waveform

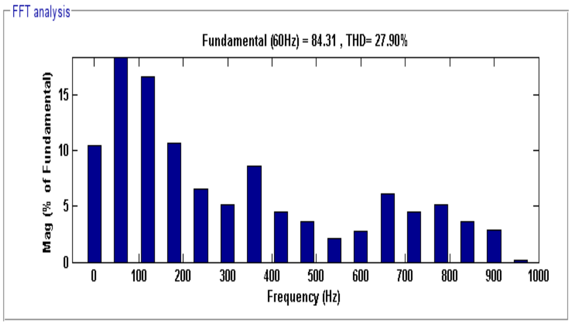

Fig. 4. Total Harmonic Distortion For Conventional Method

Numerous set of solution are available by definite modulation indices. Possible to evaluation THD's for each solution set and its gives the lower THD. Figure shows seven level voltages waveform for modulation index [17].

IV. Control and Modulation Techniques of Multilevel Converters

A. *Multilevel SPWM*

Multilevel SPWM usually needs multiple carriers. Each DC source needs its own carrier. Several multi-carrier techniques have been developed to reduce the distortion in multilevel converters, based on the classical SPWM with triangular carriers. Some methods use carrier disposition and others use phase shifting of multiple carrier signals. This common SPWM method is the extension of bi-level SPWM. One reference signal is used to compare to the carriers.

The advantage of the method is it is very simple. But it has two disadvantages. The first is the method cannot completely eliminate the low order harmonics. Therefore the low order harmonics cause loss and high filter requirements. The second is the high switching frequency causes high switching loss and low efficiency.

B. *Space Vector PWM Modulation*

The space vector PWM modulation technique is popular for bi-level PWM converter control. It can be extended to multilevel converters. Space vectors for the traditional three-, five-, and seven-level converters. These vector diagrams are universal regardless of the topology of multilevel converter. Therefore it can be used for diode-clamped, capacitor-clamped, or cascaded converters.

These advantages make it popular for converter control. But one disadvantage is as the number of levels increases, redundant switching states and the complexity of selecting switching states increase dramatically. Another disadvantage is it cannot completely eliminate the low order harmonics.

C. *Selective Harmonic Elimination*

The popular selective harmonic elimination method is also called fundamental switching frequency method which is based on the harmonic elimination theory developed by Patel *et al.* As shown in Figure. , a multilevel converter can produce a quarter-wave symmetric stepped voltage waveform synthesized by several DC voltages [16].

By applying Fourier series analysis, the output voltage can be expressed as

$$V(t)=\sum_{n=1,3,5...}^{\infty}\frac{4}{n\pi}(V_1\cos(n\theta_1)+V_2\cos(n\theta_2)+...+V_s\cos(n\theta_s))\sin(n\omega t) \quad (4)$$

Where *s* is the number of DC sources, and V_1, V_2 ... V_s is the level of DC voltages. The switching angles must satisfy the condition $0<\theta_1<\theta_2<\cdots<\theta_s<\frac{\pi}{2}$. However, if the switching angles do not satisfy the condition, this method no longer exists. If $V_1=V_2=...=V_s$, this is called equal DC voltages case. To minimize harmonic distortion and to achieve adjustable amplitude of the fundamental component, up to *s*-1 harmonic contents can be removed from the voltage waveform. In general, the most significant low-frequency harmonics are chosen for elimination by properly selecting angles among different level converters, and high-frequency harmonic components can be readily removed by using additional filter circuits [18]. To keep the number of eliminated harmonics at a constant level, all switching angles must satisfy the condition $0<\theta_1<\theta_2<\cdots<\theta_s<\frac{\pi}{2}$, or the total harmonic distortion (THD) increases dramatically.

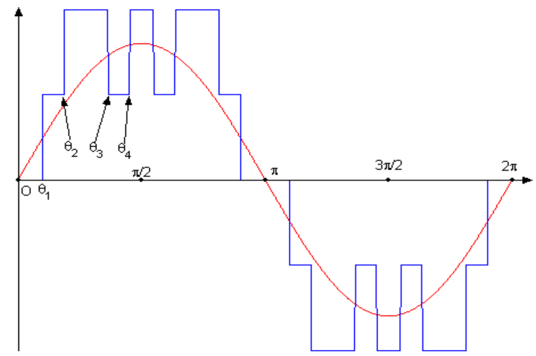

Fig. 5. Output Waveform of Virtual Stage PWM Method

By applying Fourier series analysis, the output voltage can be expressed as

$$V(t)=\sum_{n=1,3,5...}^{\infty}\frac{4}{n\pi}(V_1\cos(n\theta_1)\pm V_2\cos(n\theta_2)\pm V_3\cos(n\theta_3)\pm...\pm V_s\cos(n\theta_s))\sin(n\omega t) \quad (5)$$

Based on the harmonic elimination theory, if one wants to eliminate the n^{th} harmonic, then

$$\cos(n\theta_1)+\cos(n\theta_2)+\cos(n\theta_3)+...+\cos(n\theta_s)=0 \quad (6)$$

$$V_1\cos(\theta_1)\pm V_2\cos(\theta_2)\pm V_3\cos(\theta_3)\pm\ldots\pm V_s\cos(\theta_s)=m$$
$$V_1\cos(5\theta_1)\pm V_2\cos(5\theta_2)\pm V_3\cos(5\theta_3)\pm\ldots\pm V_s\cos(5\theta_s)=0$$
$$\vdots$$
$$V_1\cos(n\theta_1)\pm V_2\cos(n\theta_2)\pm V_3\cos(n\theta_3)\pm\ldots\pm V_s\cos(n\theta_s)=0 \quad (7)$$

$$\cos(\theta_1)+\cos(\theta_2)+\cos(\theta_3)=\frac{\pi V_1}{4V_{dc}} \quad (8)$$

$$\cos(5\theta_1)+\cos(5\theta_2)+\cos(5\theta_3)=0 \quad (9)$$

$$\cos(7\theta_1)+\cos(7\theta_2)+\cos(7\theta_3)=0 \quad (10)$$

To simplify the expression, (3.4) can be written as

$$\cos(\theta_1)+\cos(\theta_2)+\cos(\theta_3)=m \quad (11)$$

Where

$$m=\frac{\pi V_1}{4V_{dc}} \quad (12)$$

Is defined here as the modulation index. So

$$V_{1_{\max}}=\frac{4}{\pi}sV_{dc} \quad (13)$$

Where s is the number of DC sources.

By applying the resultant method, the solution of fundamental frequency switching angles for 5-, 7-, 11- and 13-level can be obtained. In this thesis, the THD is computed throughout the nth as

$$THD=\sqrt{\frac{V_5^{\,2}+V_7^{\,2}+\cdots+V_n^{\,2}}{V_1^{\,2}}} \quad (14)$$

For all the cases except indicated. The even and triple harmonics are not computed in THD because they do not appear in the line-line voltages.

For the 7-level multilevel converters, the harmonic equations are:

$$\begin{aligned}&\cos(\theta_1)+\cos(\theta_2)+\cos(\theta_3)=m\\&\cos(5\theta_1)+\cos(5\theta_2)+\cos(5\theta_3)=0\\&\cos(7\theta_1)+\cos(7\theta_2)+\cos(7\theta_3)=0\end{aligned} \quad (15)$$

The above equations are non-linear transcendental equation in nature, known as SHEPWM equation. Consequently, multiple solutions are possible. This solution of these equations is achieved by means of evolutionary process method (Genetic algorithm) and to obtain switching angles to overcome the problems.

V. GENETIC ALGORITHM

A. Introduction

Genetic Algorithm is direct, parallel, stochastic method for global search and optimization. It is the part of group of evaluatory algorithm. It is a search technique used in computing to find true or approximate solution to optimization and search problem. The selection principle is applied by using criteria, giving an evaluation for the individual with respect to the desired solution. Algorithm is started with set of solution called generation. Solution of one generation is used to form a new population. This is motivated by a hope, that the new generation will be better than the old one. Solutions which are selected according to their fitness are more suitable and there are the more chances they have to reproduce.

B. Flow chart

The genetic Algorithm is classified into three types of operation. There are encoding, cross over, selection and mutation. The evaluation usually starts from a population of randomly generated individuals and happen in generation. In each generation, the fitness of every individuals in the generation is evaluated, multiple individuals are selected from the current generation based on their fitness value, and modified (recombined and possibly mutated) to form a new generation. The new generation is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced or a satisfactory fitness level has been reached for the generation. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached.

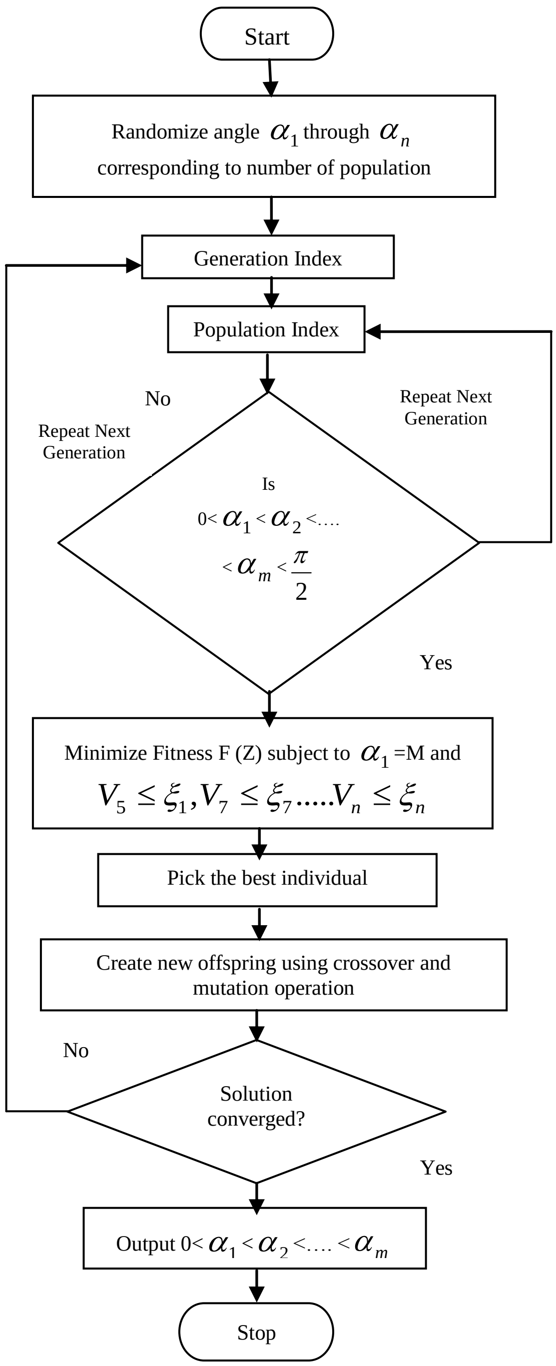

Fig. 6. Genetic Algorithm Flow Chart

VI. FORMULATING THE PROBLEM

The genetic algorithm approach is similar way for any application. Genetic algorithm works to be set only a few parameters. The formulating a problem and GA are applied. Binary and floating point sequence will select and attain the number of switching angle in an individual. The number of variable are considered as the number of switching angle in individual. The switching angle and its given to the H-bridge cascaded multilevel inverter a seven level inverter requires five h-bridge inverter and each population will have three switching angle. First initialize the population of the interface and set size of the population. The rate of convergence is rises by using higher population and also increases the execution time. Each population contains some switching angles. The population is initialized with randomly preferred angle between 0 to 90 degree and it's considering the quarter wave symmetry of output voltage. The genetic algorithm is to evaluate the fitness value of each individual. The objective of the function is to minimize specified harmonics. The most important thing for GA to evaluate the fitness values of individual in each population. The switching angle expression can be formulated as

$$f_\theta(\theta_1, \theta_2, \theta_3) = 100 * \frac{|V_5| + |V_7|}{V_1} \quad (16)$$

For each generation, the output voltage waveform in multilevel inverter which is produced using switching angle in the population and the required harmonic magnitude is attaining using FFT techniques. Fitness value is calculated for each individuals using

$$FitnessVal(\theta_1, \theta_2, \theta_3) = -100 * \frac{|V_5| + |V_7|}{V_1} \quad (17)$$

Genetic algorithm is set to run a definite number of generations to estimate the solution. Subsequently first generation, fitness values are used to attain the novel generation. Then it goes through the crossover and mutation process which creates new generation the similar cycle starting from fitness value estimation. By using MATLAB source code, it can find the optimal switching angles solution for a cascaded multilevel inverter with any number of output voltage levels and for the elimination of desired any number of harmonics.

VII. SIMULATION RESULTS

The SHEPWM technique strategy of single phase cascaded seven level inverter using genetic algorithm and switching angle variation technique are simulated with the use of MATLAB R2012a. For seven level inverters, reduced number of switches using H-bridges is needed for simulation. MOSFET switches are used as power switches. Figure 5 shows the simulation circuit for seven level inverter using PWM technique.

In order to validate the computational results as well as the simulations results are presented for a single phase 7- level cascaded H-bridge inverter. The circuit configuration is shown in the Fig. 6 the inverter uses MOSFETs as the switching devices, and the nominal dc-link voltage for each H-bridge is considered to be 138V. The gate control signals are generated by a dedicated unit is provided to the each H-bridge.

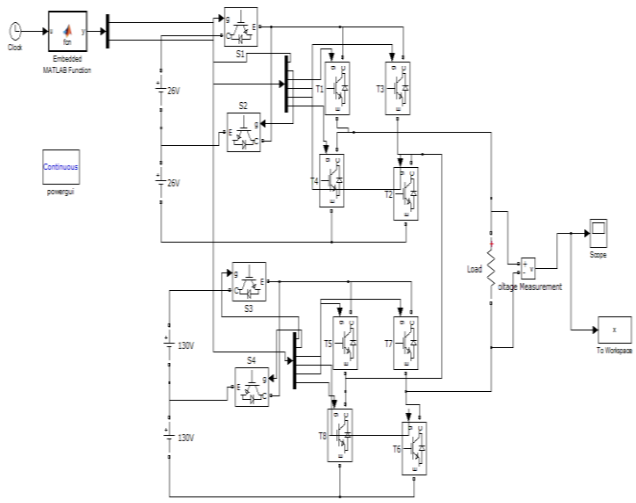

Fig. 7. Simulation Diagram of the Single Phase Cascaded H-Bridge Multilevel Inverter using Genetic Algorithm

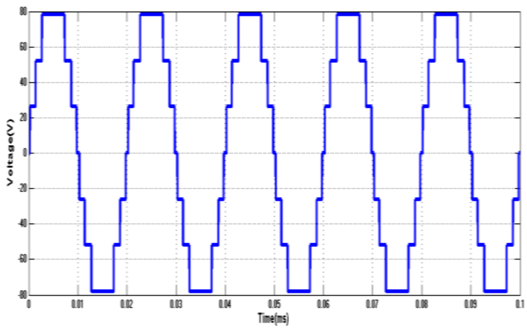

Fig. 8. Output Voltage Waveform of Proposed System (Seven Level)

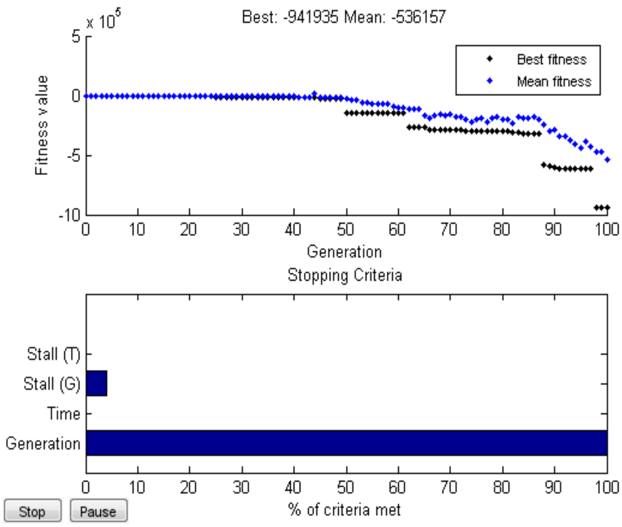

Fig. 9. Fitness Value and Generation Stopping Criteria Of Genetic Algorithm

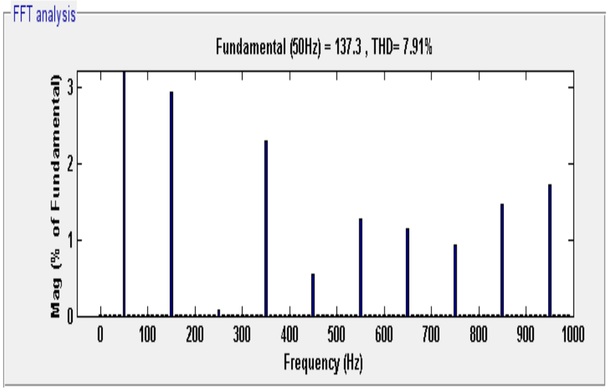

Fig. 10. Voltage Total Harmonic Distortion Plot For Proposed Method

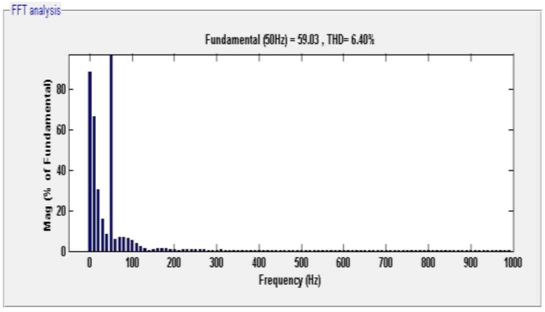

Fig. 11. Current Total Harmonic Distortion Plot For Proposed Method

VIII. CONCLUSION

The selective harmonic elimination PWM method at fundamental frequency switching arrangement has been simulated using the Genetic Algorithm that creates all possible solution sets when they exist. In comparison with other suggested methods, the proposed technique has several advantages such as: it can produce all probable solution sets for any numbers of multilevel inverter without considerable calculation burden; speed of convergence is fast etc. The proposed technique was successfully simulated for attaining the optimum switching angles for 7-level Cascaded H-Bridge Multilevel Inverter. An extensive analysis for 7- level inverter has been presented and it is shown that a significant amount of THD reduction can be achieved if all possible solution sets are computed.

REFERENCES

[1] M.S.A. Dahidah and V.G. Agelidis, “Selective harmonic elimination PWM control for cascaded multilevel voltage source converters: A generalized formula,” *IEEE Trans. on Power Electronics*, 2008, vol.23, no. 4, pp.1620 – 1630.

[2] Mohamed azab, “Particle Swarm Optimization-Based Solutions For Selective Harmonic Elimination In Single-Phase PWM Inverters”, *International Journal of Power electronics*, Vol. 2, No. 2, 2010, Inderscience Enterprises Ltd- UK.

[3] Reza Salehi, Naeem Farokhnia, Mehrdad Abedi, and Seyed Hamid Fathi “Elimination of Low Order Harmonics in Multilevel Inverters Using Genetic Algorithm” *Journal of Power Electronics*, Vol. 11, No. 2, March 2011.

[4] V. G. Agelidis, *et. al*., "Multiple Sets of Solutions for Harmonic Elimination PWM Bipolar Waveforms: Analysis and Experimental Verification," *IEEE Trans. Power Electron.*, vol. 21, no. 2, pp.415–421, March 2006.

[5] H.S. Patel and R.G. Hoft, "Generalized techniques of harmonicelimination and voltage control in thyristor inverters: Part II- voltage control technique," *IEEE Trans. Ind. Applicat.*, 1974, vol. IA-10, no.5, pp. 666-673.

[6] L. M. Tolbert, J. N. Chiasson, K. McKenzie, and Z. Du, "Elimination of harmonics in a multilevel converter with non equal DC sources, " in *Proc. IEEE Appl. Power Electron. Con*!,Miami, FL, Feb. 9-13, 2003, pp. 589-595.

[7] Kh. El-Naggar and T. H. Abdelhamid, "Selective harmonic elimination of new family of multilevel inverters using genetic algorithms", *Elsevier Journal of Energy Conversion and Management*, vol. 49, issue 1, pp. 89-95, Jan. 2008.

[8] J. Rodriguez, J. Lai and FZ. Peng, "Multilevel converters: a survey of topologies, controls, and applications", *IEEE Trans. Industrial Application*, vol. 49(4), pp. 724–738, Aug. 2002.

[9] P. Lezana, J. Rodriguez and D. A. Oyarzun, "Cascaded multilevel inverter with regeneration capability and reduced number of switches", *IEEE Trans. on Industrial Electronics*, vol. 55, no. 3, pp. 1059-1066, Mar. 2008.

[10] Ovaska SJ, Bose T and Vainio O., "Genetic algorithmassisted design of adaptive predictive filters for 50/60 Hz power systems instrumentation", *IEEE Trans. Instrument Measurement*, vol. 54(5), pp. 2041-2048, 2005.

[11] D. G. Holmes and T. A. Lipo, *Pulse Width Modulation for Power Converters*. Piscataway, NJ: IEEE Press, 2003.

[12] S. Kouro, J. Rebolledo, and J. Rodriguez, "Reduced switching-frequencymodulation algorithm for high-power multilevel inverters," *IEEE Trans.Ind. Electron.*, vol. 54, no. 5, pp. 2894–2901, Oct. 2007.

[13] W. Fei, X. Du, and B. Wu, "A generalized half-wave symmetry SHE-PWM formulation for multilevel voltage inverters," *IEEE Trans. Ind. Electron.*, vol. 57, no. 9, pp. 3030–3038, Sep. 2010.

[14] Y. Liu, H. Hong, and A. Q. Huang, "Real-time algorithm for minimizing THD in multilevel inverters with unequal or varying voltage steps under staircase modulation," *IEEE Trans. Ind. Electron*., vol. 56, no. 6, pp. 2249–2258, Jun. 2009.

[15] B. Ozpineci, L. M. Tolbert, and J. N. Chiasson, "Harmonic optimization of multilevel converters using genetic algorithms," *IEEE Power Electron. Lett.*, vol. 3, no. 3, pp. 92–95, Sep. 2005.

[16] H. Taghizadeh and M. Tarafdar Hagh, "Harmonic elimination of multilevel inverters using particle swarm optimization," in *Proc. IEEE Int.Symp. Ind. Electron.*, 2008, pp. 393–396.

[17] A. I. Maswood, Shen Wei and M. A. Rahman, *"A Flexible Way to Generate PWM-SHE Switching Patterns Using Genetic Algorithm,'' Conference Proceedings of IEEE (APEC)*, 2001, pp. 1130-1134.

[18] R. Salehi, N. Farokhia, M. Abedi, and S.H. Fathi, *"Elimination of Low Order Harmonics in Multilevel Inverters Using Genetic Algorithm,''* Journal of Power Electronics, volume 11, no. 2, Mar. 2011, pp.132-139.