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REAL TIME GA AND ANN BASED SELECTIVE HARMONIC ELIMINATION IN 9 LEVEL UPS INVERTER

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Abstract

High quality power is very much critical and essential for medical, research and industrial applications to bring good quality results with accurate evaluation. Hence all the sensitive equipments and critical loads need to be provided with high quality and reliable power, where Uninterruptible Power Supplies (UPS) are mainly used to supply reliable power to these loads. Inverter is the main component of a UPS. In the recent times, by the advanced usage of semiconductor devices and non linear loads, harmonics are unavoidable. So the actual challenge for UPS is, under a non linear condition of load, it has to maintain a high quality sinusoidal output voltage. In this paper, the inverter of UPS is replaced by a nine level cascaded H bridge multilevel inverter with equal DC sources and harmonics can be eliminated by the optimal selection of switching angle by using Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM) technique along with a hybrid technique to optimize and minimize the Total Harmonic Distortion(THD). The proposed hybrid technique utilizes the Genetic Algorithm (GA) and Neural Network (NN). The switching angles are calculated offline using Genetic Algorithm. Then the NN is trained by these switching angles and the real time switching angles are found out by Neural Network. The proposed technique is tested over a nine level cascaded H-bridge inverter and the resultant fundamental and harmonic voltages are analysed. Then, simulation is carried out in Matlab/Simulink environment and the results indicate that the switching angles obtained using this method results in efficient harmonic minimization.

Keywords:

Genetic Algorithm, Neural Network, Harmonics, Switching Angle, UPS

1. INTRODUCTION

Power quality is an important problem in all levels of electricity consumers. Both non-linear loads and sensitive equipments are in the common place in the industrial and the domestic environment and because of this, a heightened awareness of power quality is developing [1]. Efficient use of electrical energy is becoming more of a concern. Harmonics have been shown to have deleterious effects on many types of equipments. Electronic power converters have become one of the major sources of harmonics in the industrial environment [2]. Non sinusoidal current supplied to non linear loads results in non sinusoidal voltage. Hence, harmonic distortion results reduce the power quality. So, various techniques such as application of harmonic filters, modification of circuit configurations, selection of high pulse converters and transformer connections are used. Active power filters were developed for power factor correction and harmonic compensation [3]. Uninterruptible power supplies (UPS) are devices which are placed between power system and critical load, and they do a good job in protecting their own load but they are the major power system polluters and often cause problems for neighbouring loads. Therefore, the need for new and innovative circuits exists that can be placed at end-user [4].

In this regard, the multilevel inverter, as UPS inverter is taken with equal dc source, so that equal magnitude of dc input voltage can be added to get required output voltage. In this proposed method, adaptive hybrid Genetic Algorithm (GA) is applied for the minimization of THD of a 9 level cascaded multilevel inverter with equal dc source. The objective function derived from the SHE problem is minimized, to compute the switching angles while lower order harmonics are controlled within allowable limits. The switching instants can be found using Genetic Algorithm (GA) and the Artificial Neural Network (ANN) is trained with these switching instants and tested over a nine level cascaded multilevel inverter with equal dc sources. Hence, the real time switching angle can be given by neural network which has the advantage to extrapolate and interpolate and also requires no need of look up tables since neural network maps the switching angle online, it requires less computational time compared to other evolutionary algorithms. In this paper, the literature review is discussed in section 2, UPS system is described in section 3, multilevel inverters and SHE-PWM are described in section 4, the proposed methodology, Genetic Algorithm and Artificial Neural Network are discussed in section 5, the algorithm and flowchart for genetic algorithm is discussed in section 6, neural network training in section 7, implemented model and the results are discussed in section 8 and the conclusion in section 9.

2. RELATED WORKS

In literature, the different multilevel converter structures have been described as diode clamped (neutral-clamped), cascaded H-bridges converter, and capacitor clamped (flying capacitors) [5]. Harmonic elimination methods applied in multilevel inverter reported in literature are Optimal Minimization of Total Harmonic Distortion (OMTHD), Sinusoidal PWM (SPWM), Space Vector Pulse Width Modulation (SVPWM), Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM), etc [6]. Out of the above methods, SHE-PWM provides a firm control on a given voltage waveform’s harmonic spectrum that is generated by a power electronic converter along with a minimum number of switching transitions [7]-[8]. It involves the solution of nonlinear transcendental equation sets representing the relation between the amplitude of the fundamental wave, harmonic components and the switching angles.

There are different methods to solve these equations in literature. This group of methods is deterministic approach based on conventional optimization technique which satisfies the equation. Newton-Raphson method and other iterative methods are among these and have some drawbacks like no optimal solution, problem of divergence and needs initial guess [7]. The theory of resultant is also one among them in literature which is a mathematical approach. In this method, for the feasible modulation index only, we can find the solutions. It is time consuming and complicated and when input dc voltage or voltage levels are changed, it requires new expression [9]. Instead of solving non-linear transcendental equations, linear equations are solved in Walsh function which is one of the other approaches, which results in a set of algebraic matrix equation and gives the switching angles. Optimal calculation of switching angle in this method is time consuming and complex [10] [11] [12].

Another group of methods where the different probabilistic optimization approach are based on evolutionary algorithms are used to minimize THD. They are Genetic algorithm (GA) [8], Particle Swarm optimization (PSO) [13], Harmony Search algorithm (HSA) [14], Differential Evolution Approach [15], Ant Colony Optimization [16] and Bee Algorithm [17] in literature. The advantages of these methods are successful in locating the optimal solution and derivative free, but they are usually slow in convergence and it requires much computational time. GA gives better performance in THD minimization and takes less computational time compared with PSO [18], [19]. Some of the related research works in literature are explained in detail in [20]. For three phase UPS inverters, a seven level multilevel inverter and nine-level multilevel inverter are implemented with PSO in [21] and [22].

3. UPS SYSTEM DESCRIPTION

Uninterruptible Power Supplies (UPS) are electronics based power backup systems, capable of providing short term supply of high quality and stabilized electrical power, without interruption to operations [23]. The most important role of any UPS is to supply short-term power when there is a failure in source input power. The key problems of UPS system are harmonic insertion and irregular output waveforms on both sides and should be dealt with instantly [24].

Pulse Width Modulation (PWM) inverter, Diode rectifier, dc-link capacitor, input/output filter, battery and battery charger, battery on/off switch, and load transformer are the main components of UPS. The topology can function in two distinct modes, namely, normal (or) charging modes and backup modes [25]. There are three types of UPS topology: Line interactive UPS, Off-line UPS and Online UPS [26]. So, in this paper, we have considered the UPS which has the inverter of nine-level cascaded H bridge inverter that has equal DC sources. That is responsible for generating the harmonics affected voltage waveforms.

4. MULTILEVEL INVERTER

The Multilevel Inverter has a distinct structure that allows high voltage and power levels without using transformers. These are particularly designed for applications, where low THD is required. These are power electronic devices that are constructed to produce an expected AC voltage from many levels of DC voltages. Based on this research, it is found that good performance is exhibited by multilevel inverters, when they are used in UPS.

The important and desirable features of multilevel inverter can be summarized as their lower switching frequency, lower switching losses, high voltage rating and lower electromagnetic interfaces (EMI) than conventional two level inverters [27]. The three main multilevel converter structures are: Diode clamped (neutral-clamped), Cascaded H-bridges converter and Flying capacitors (capacitor clamped) [5].

4.1 CASCADED H BRIDGE MULTILEVEL INVERTERS

The Cascaded Multilevel Inverters (CMLI) are created by a series connection of 2 or more single phase H-bridge inverters and they are particularly desired because of their modularity and simplicity of control [27]. The basic idea of this inverter is made by the series connection of H-bridge inverters in order to get a sinusoidal output voltage. The output voltage is the summation of the generated voltage in each cell. The total number of output voltage levels is $2n+1$, and the number of cells is represented by 'n'.

The total harmonic distortion is minimized based on the selection of the switching angles. Only standard components of low-voltage can be used to obtain output voltage with medium levels, using this structure. This model enables less voltage stress on power electronic devices and reduced switching losses, and there by results in the smaller voltage steps of the output voltage, which in turn, again results in low harmonic components, better electromagnetic compatibility and hence high power quality. The inverter model is depicted in Fig.2. Here, four single phase H-bridge converters are connected in series for nine-level inverter and that is shown in Fig.2 and the output is shown in Fig.1. The formula for harmonic output voltage of inverter is given as,

$$h_n = \frac{4}{n\pi}\sum_{k=1}^{m}\left[V_k \cos\left(n\alpha_k\right)\right] \tag{1}$$

where, V_{dc} is input DC voltage, α_k is switching angle for the k^{th} H-bridge, and V_h is voltage of the h^{th} order harmonic that is generated by the inverter. The hybrid technique that selectively eliminates the odd harmonics is detailed in the following sections.

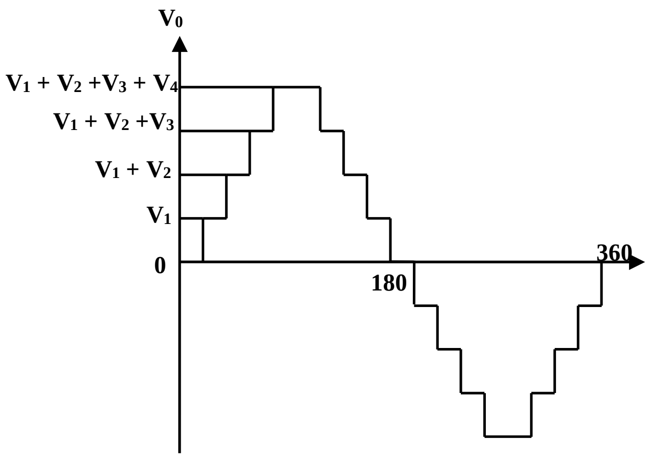

Fig.1. Output voltage waveform of a 9 level inverter

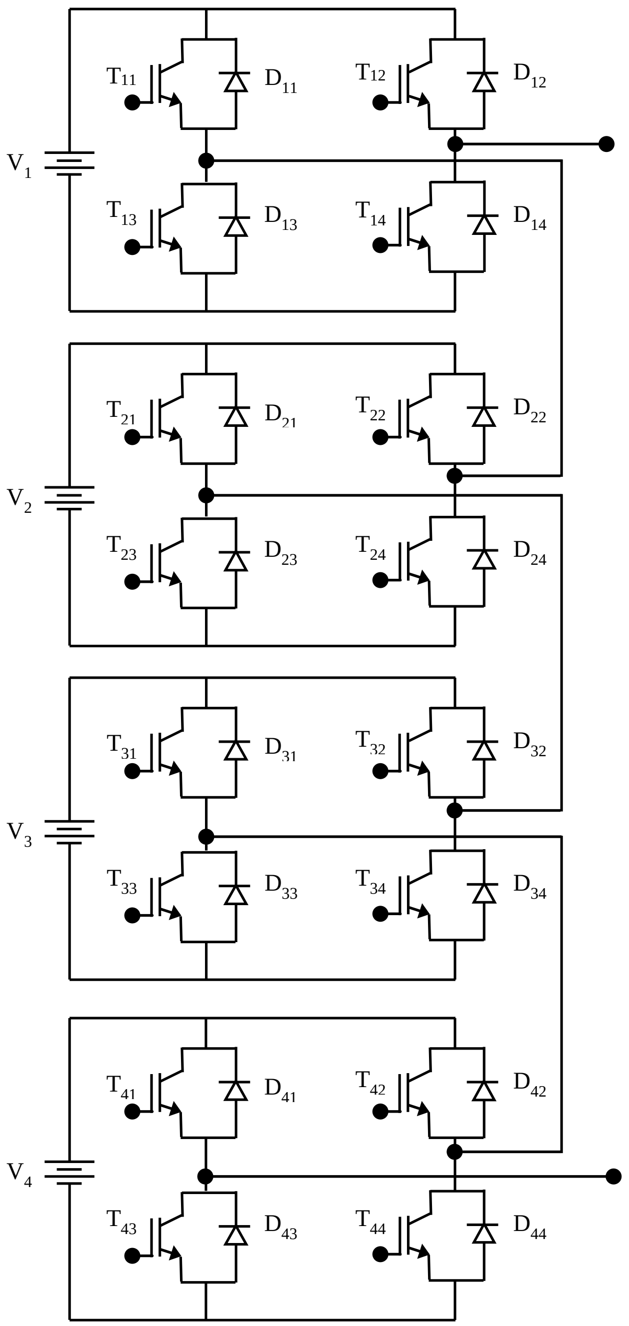

Fig.2. 9 level cascaded multilevel inverter

4.2 SELECTIVE HARMONIC ELIMINATION

In Selective Harmonic Elimination (SHE) method, mathematical techniques such as iterative methods or mathematical theory of resultant can be applied to calculate the optimum switching angles, so that lower order dominant harmonics are eliminated [28]. The modulation methods with higher switching frequency reduce filter size but increases switching losses. And low switching frequency means low switching losses but it requires large filter size. To reduce the filter size, the number of levels of the inverter is increased, but it increases the cost of the system [29]. The harmonics at the low order frequency gets eliminated by the SHE modulation method and the higher order frequency gets shifted and hence without increasing the switching losses and cost of the system, the filter size too can be reduced.

The output voltage waveform can be expressed in the Fourier form as,

$$V_{an}(wt) = \sum_{i=1,3,5,7,..}^{m} \frac{4V_{dc}}{n\pi} \begin{pmatrix} \cos(n\alpha_1)+ \\ \cos(n\alpha_2)+ \\ \cos(n\alpha_3)+... \end{pmatrix} \cdot \sin(nwt) \tag{2}$$

where,

V_{an} = inverter output voltage

V_{dc} = input DC source

α_1, α_2, α_3 = inverter switching angles.

The set of equations for Genetic Algorithm (GA) are,

$$V_{fund} = \frac{4V_{dc}}{\pi} \begin{pmatrix} \cos(\alpha_1)+\cos(\alpha_2)+ \\ \cos(\alpha_3)+\cos(\alpha_4) \end{pmatrix} \tag{3}$$

$$V_{5th} = \frac{4V_{dc}}{5\pi} \begin{pmatrix} \cos(5\alpha_1)+\cos(5\alpha_2)+ \\ \cos(5\alpha_3)+\cos(5\alpha_4) \end{pmatrix} \tag{4}$$

$$V_{7th} = \frac{4V_{dc}}{7\pi} \begin{pmatrix} \cos(7\alpha_1)+\cos(7\alpha_2)+ \\ \cos(7\alpha_3)+\cos(7\alpha_4) \end{pmatrix} \tag{5}$$

$$V_{11th} = \frac{4V_{dc}}{11\pi} \begin{pmatrix} \cos(11\alpha_1)+\cos(11\alpha_2)+ \\ \cos(11\alpha_3)+\cos(11\alpha_4) \end{pmatrix}. \tag{6}$$

The objective function is formulated as,

$$f(V_{fund}, V_5, V_7, V_9) = V_{fund} - 230 + V_{5+}V_7 + V_9. \tag{7}$$

To eliminate fifth, seventh and eleventh harmonics V_5, V_7 and V_{11} are set to zero in the above equations. To determine the switching angles the following equations must be solved,

$$\cos(\alpha_1)+\cos(\alpha_2)+\cos(\alpha_3)+\cos(\alpha_4) = 4M \tag{8}$$

$$\cos(5\alpha_1)+\cos(5\alpha_2)+\cos(5\alpha_3)+\cos(5\alpha_4) = 0 \tag{9}$$

$$\cos(7\alpha_1)+\cos(7\alpha_2)+\cos(7\alpha_3)+\cos(7\alpha_4) = 0 \tag{10}$$

$$\cos(11\alpha_1)+\cos(11\alpha_2)+\cos(11\alpha_3)+\cos(11\alpha_4) = 0. \tag{11}$$

In the above equations, the modulation index is represented by 'M' that ranges between 0 and 1. The switching angles α_1, α_2, α_3 and α_4 should not be more than $\pi/2$. In literature, Newton Raphson (NR) and theory of resultant method is used to solve the above equations. But, since the above method needs initial guess for solving the equations and also since it is time consuming, these types of nonlinear equations are solved with few types of evolutionary algorithms. The Genetic Algorithm (GA) is programmed to obtain the optimum set of angles to control the multilevel inverter for each value of modulation index.

5. PROPOSED METHODOLOGY

At high level, in this proposed methodology, we have combined the widely accepted Genetic Algorithm and Artificial Neural Network as an adaptive hybrid technique, to improve the result by optimizing the THD and by reducing the harmonics in the above mentioned algorithms.

Here, first the genetic algorithm is used to derive the optimal switching angles and then these resultant switching angles are in turn used to train the neural network. The advantage of using neural network here, is that, it gives the real time switching angles which has the flexibility to interpolate and extrapolate and also there is no need of look up tables to save the pre-calculated values.

For real time applications, a conventional GA is not a better technique since it is very time consuming. This has been observed in the optimization of THD in this proposed model, where in this proposed methodology reduces the running time by 3 times, when compared to the above mentioned algorithms with the current set of constraints which satisfies the Eq.(8) to Eq.(11) with switching angles between 0 and $\pi/2$.

The proposed technique is of a cascaded multilevel inverter prototype, used in a 9-level, 4H-bridge UPS inverter, that is implemented in the working platform of MATLAB (versionR2011A)/Simulink. The 9 level cascaded H bridge inverter Simulink model is shown in Fig.3 to Fig.7.

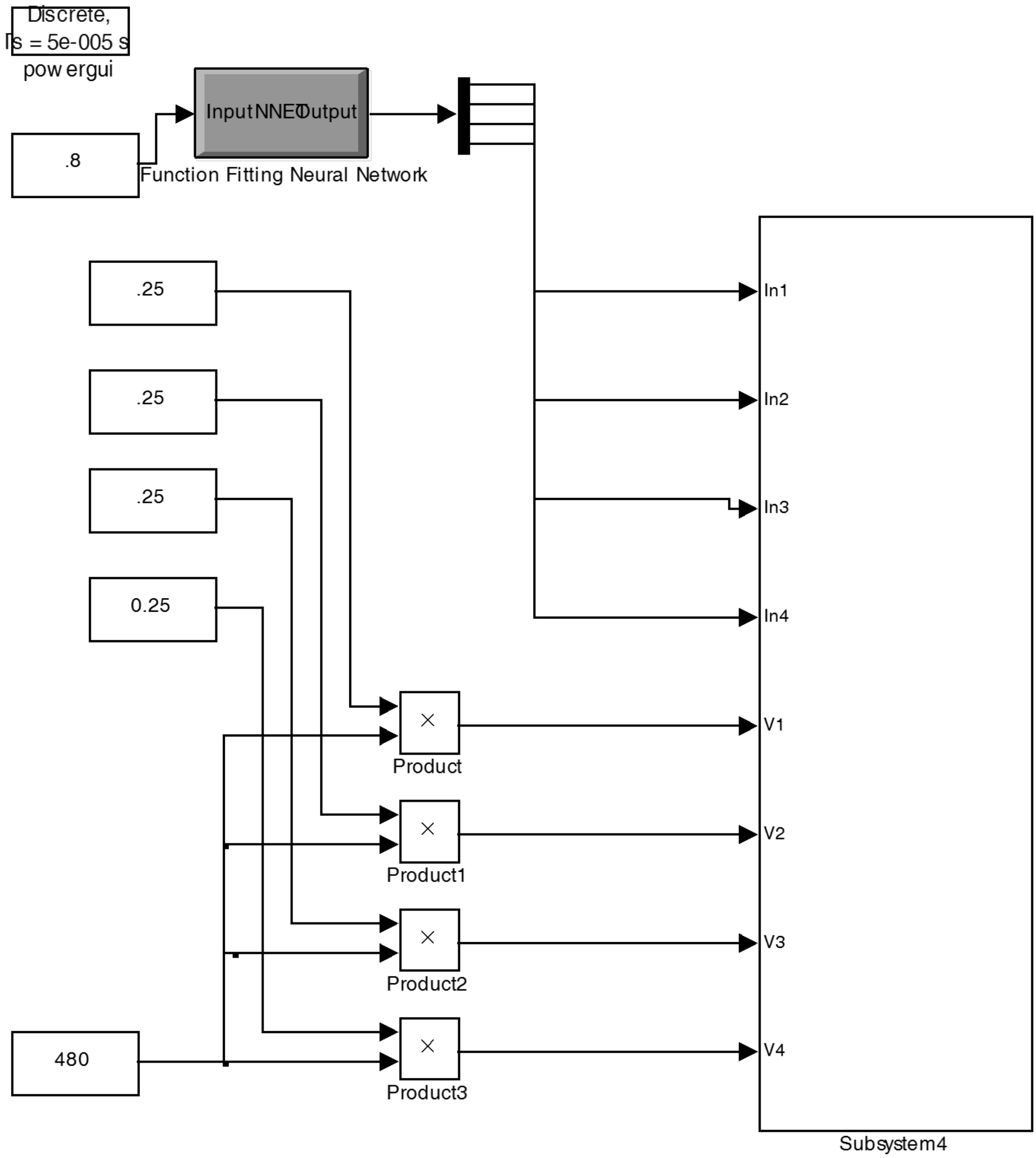

Fig.3. Simulink model of 9 level UPS Inverter (Main Circuit)

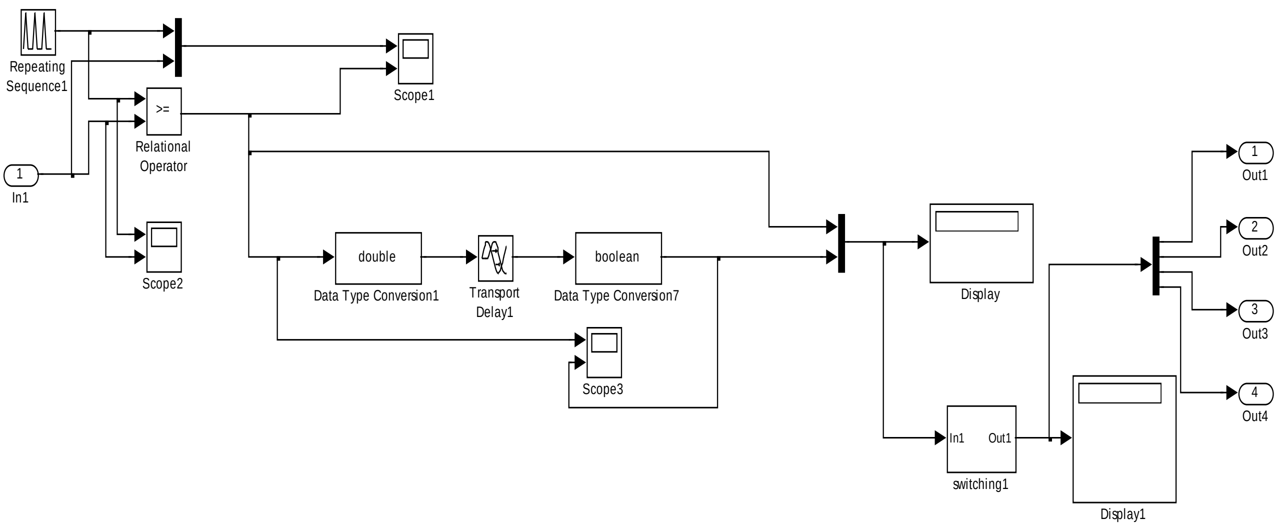

Fig.4. Simulink model of 9 level UPS Inverter (Control Circuit)

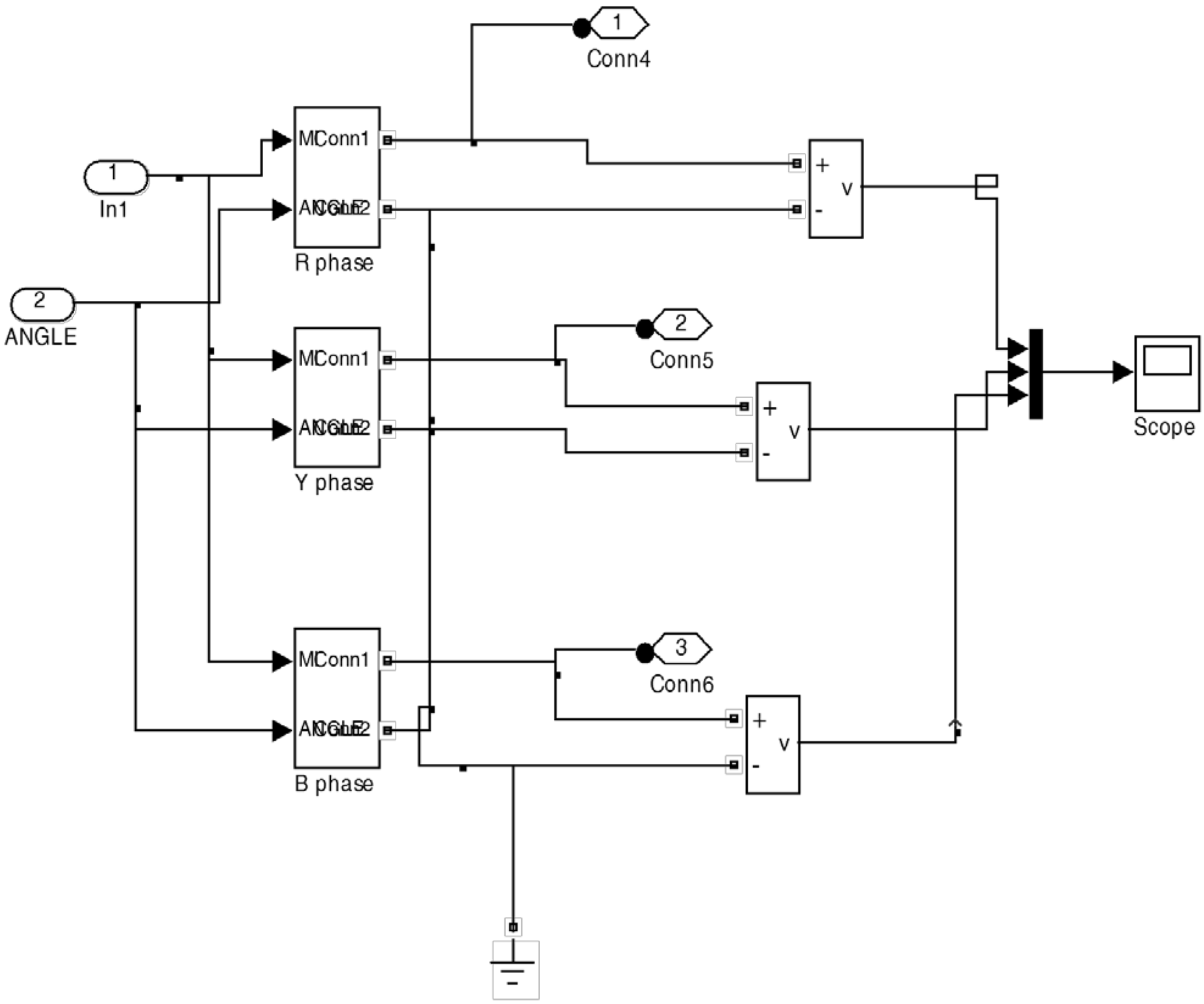

Fig.5. Simulink model of 9 level UPS Inverter (Three Phase Circuit)

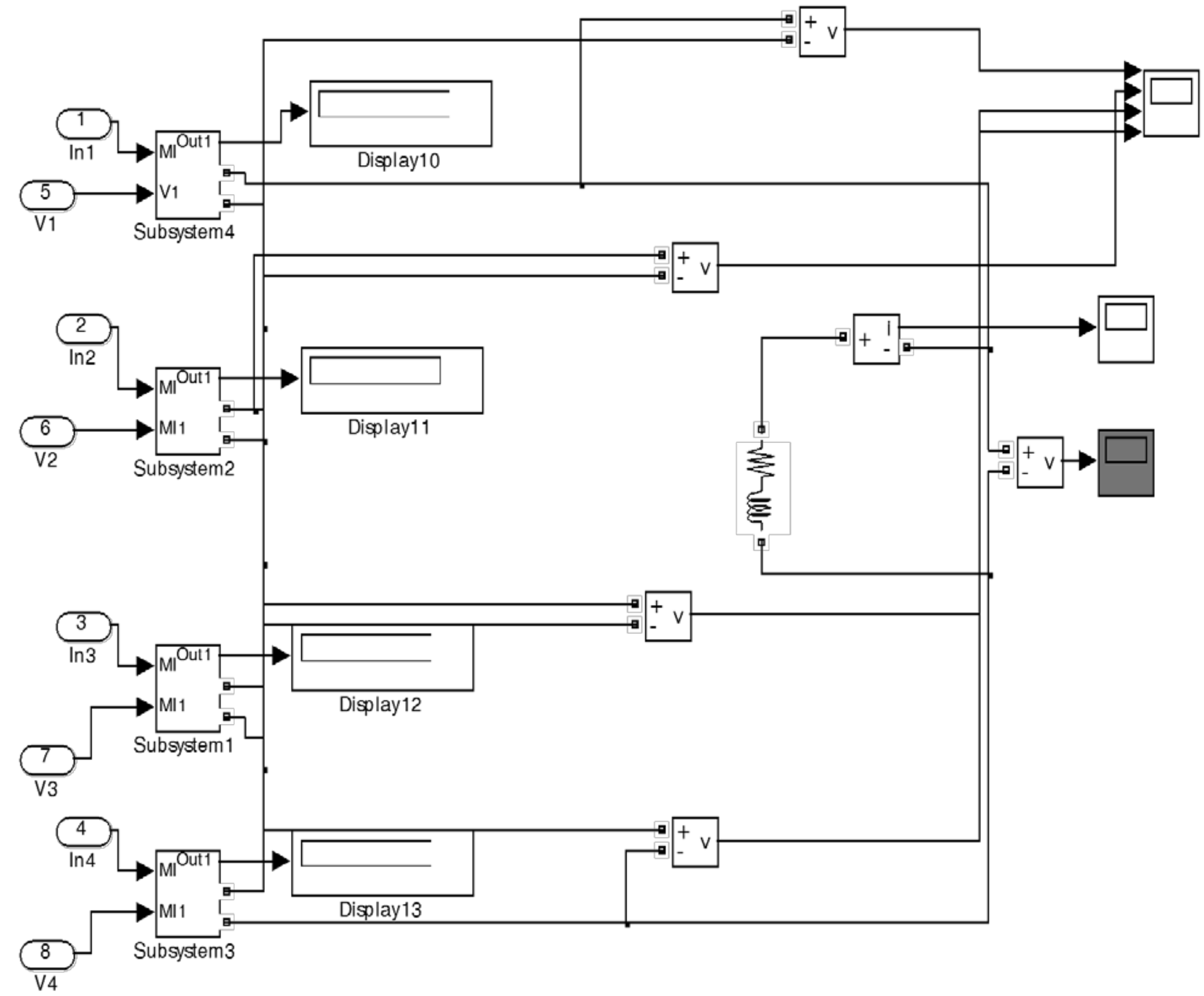

Fig.6. Simulink model of 9 level UPS Inverter (Three Phase Circuit Subsystem)

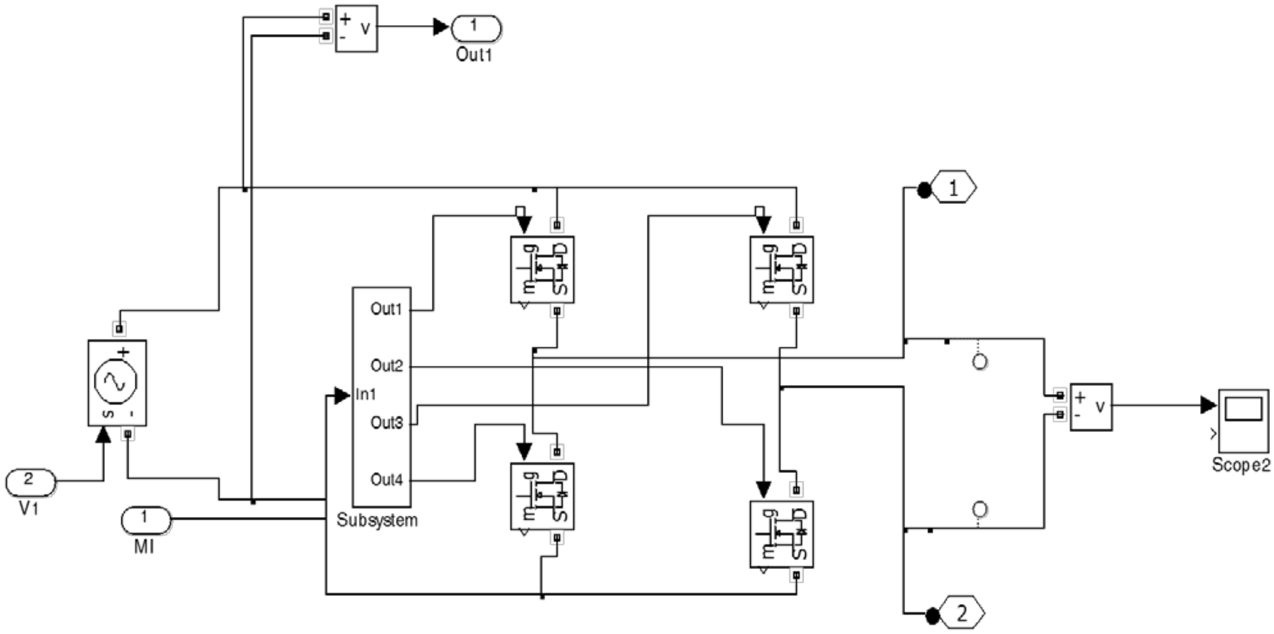

Fig.7. Simulink model of 9 level UPS Inverter (Three Phase Circuit single bridge Subsystem)

6. SHE EQUATION USING GENETIC ALGORITHM

Genetic algorithm is applied to minimize the harmonics in a nine level multilevel inverter with equal voltage sources. The optimum switching angles are obtained from GA. To validate the results of GA, nine-level inverter is simulated in Matlab/Simulink and the harmonic spectrum is analyzed.

6.1 ALGORITHM FOR PROPOSED GA FOR FINDING SWITCHING ANGLES (IMPLEMENTED IN MATLAB R2010A)

The algorithm or the step by step procedure for implementing GA to find the switching angles is as follows,

i) To start with, determine the number of variables for the particular problem, since they represent the genes. In this problem, the number of variables is the four switching angles.

ii) Then set the population size and initialize it. Here the population size used is 100 chromosomes, by taking into account the output voltage waveform with quarter wave symmetry, initialize the population randomly between angles 0 and 90 degree.

iii) To reduce the particular harmonics, the harmonics should be related to fitness function. Here the fitness function is derived by,

$$\text{Fitness Function}=\frac{\sqrt{\sum_{n=5,7,11}\left(\frac{1}{n}\sum_{k=1}^{4}\cos\left(n\alpha_k\right)\right)^2}}{\sum_{k=1}^{4}\cos\left(\alpha_k\right)} \qquad (12)$$

iv) Then this function is iterated till the time the solution is determined. Here the number of iterations is 100 to find the solution.

v) New offspring is determined by fitness values after first iteration by crossover and mutation and then a new population is formed.

vi) The same process is repeated till the solution is found which satisfies the constraints, $\alpha_1 > \alpha_2 > \alpha_3 > \alpha_4$ in the Eq.(8) to Eq.(11).

6.2 FLOWCHART FOR PROPOSED GA

The flowchart for solving the problem in genetic algorithm is given in Fig.8.

7. ADAPTIVE SHE

In our proposed methodology, for training the neural network, the below mentioned ANN structure is used to derive the real time switching angles. The data set was used to train the neural network. The ANN topology proposed is shown in Fig.9. It is a feed forward ANN with a tangent-sigmoid function activation hidden layer and a linear activation function output layer. This ANN takes the modulation index ranging from 0 to 1 and gives the switching angles for the control system.

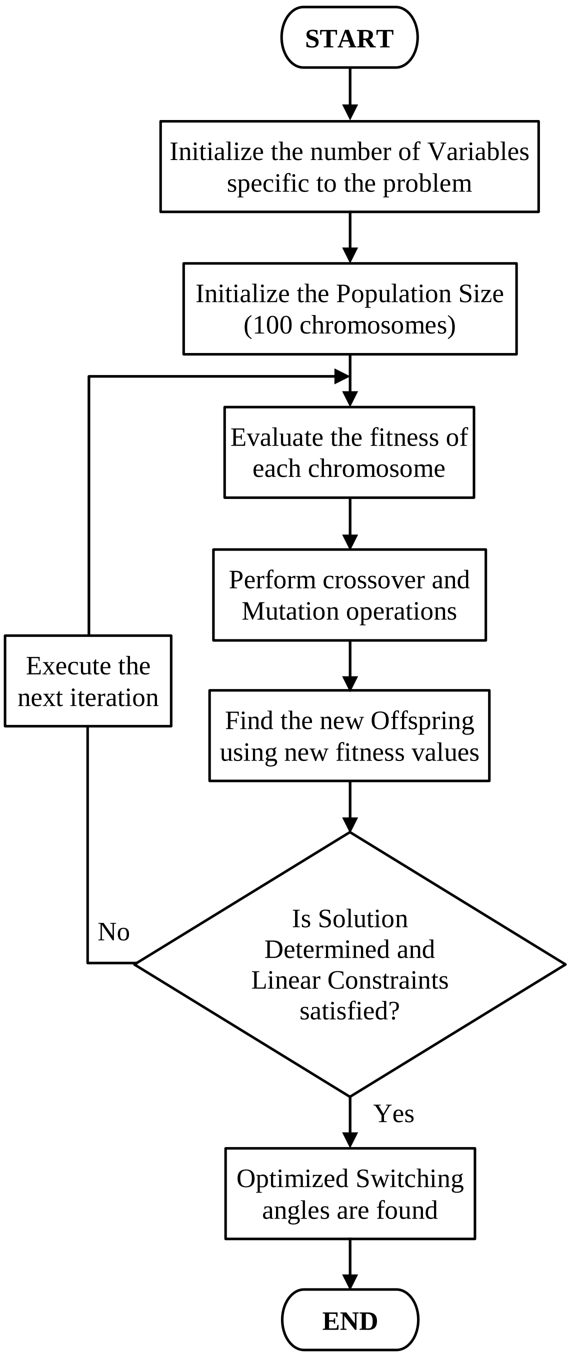

Fig.8. Flowchart of proposed genetic algorithm

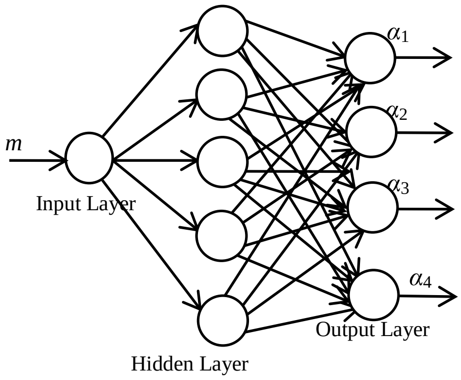

Fig.9. ANN topology

8. RESULTS AND DISCUSSION

The proposed technique is of a cascaded multilevel inverter prototype, used in a 9-level, 4H-bridge UPS inverter that is implemented in the working platform of MATLAB (versionR2011A)/ Simulink. The 9 level cascaded H bridge inverter simulink model are shown in Fig.3 to Fig.7.

In Fig.10, the iteration number is plotted against the best function value of generation, as the best fitness plot. In Fig.11, the numbers of variables are plotted against the current best individual, which is called the best individual plot. In Fig.12, the genealogy of individuals is shown as genealogy plot. The colour-coded lines from one generation to the other are indicated by,

i) Gray lines are marked as mutation children
ii) Dark gray lines are marked as Crossover children.
iii) Black lines are marked as Elite individuals

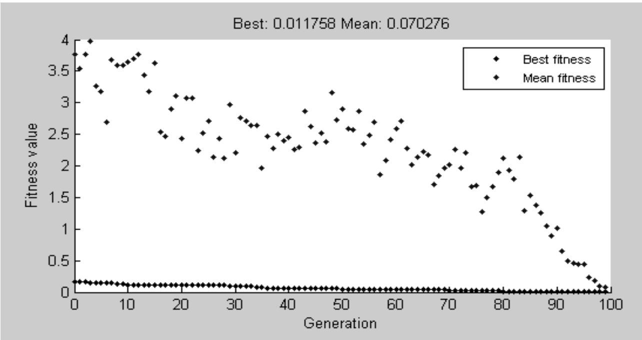

Fig.10. Best Fitness Plot

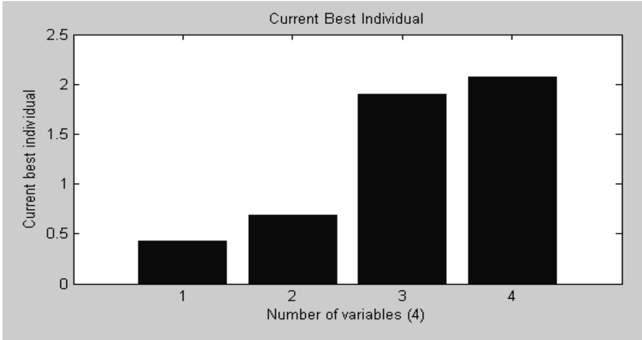

Fig.11. Best Individual plot

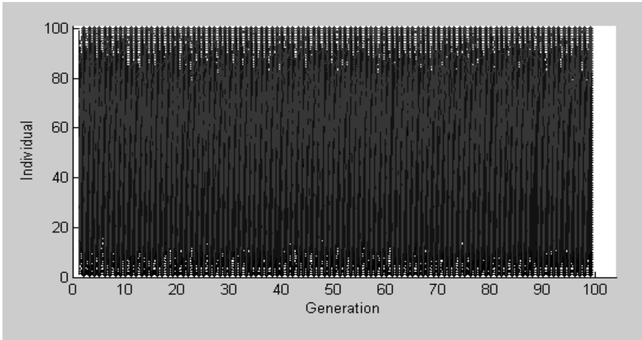

Fig.12. Genealogy plot

In this implementation, harmonics affected voltage waveforms are generated from an H-bridge type of UPS inverter. There are four levels of H-bridge inverter. So, selecting four optimum switching angles α_1, α_2, α_3 and α_4 are essential. The technique is implemented to eliminate the fifth, seventh and eleventh order harmonics. Thus, the THD is minimised in the UPS inverter. The output waveforms of different switching pulses are shown in Fig.13.

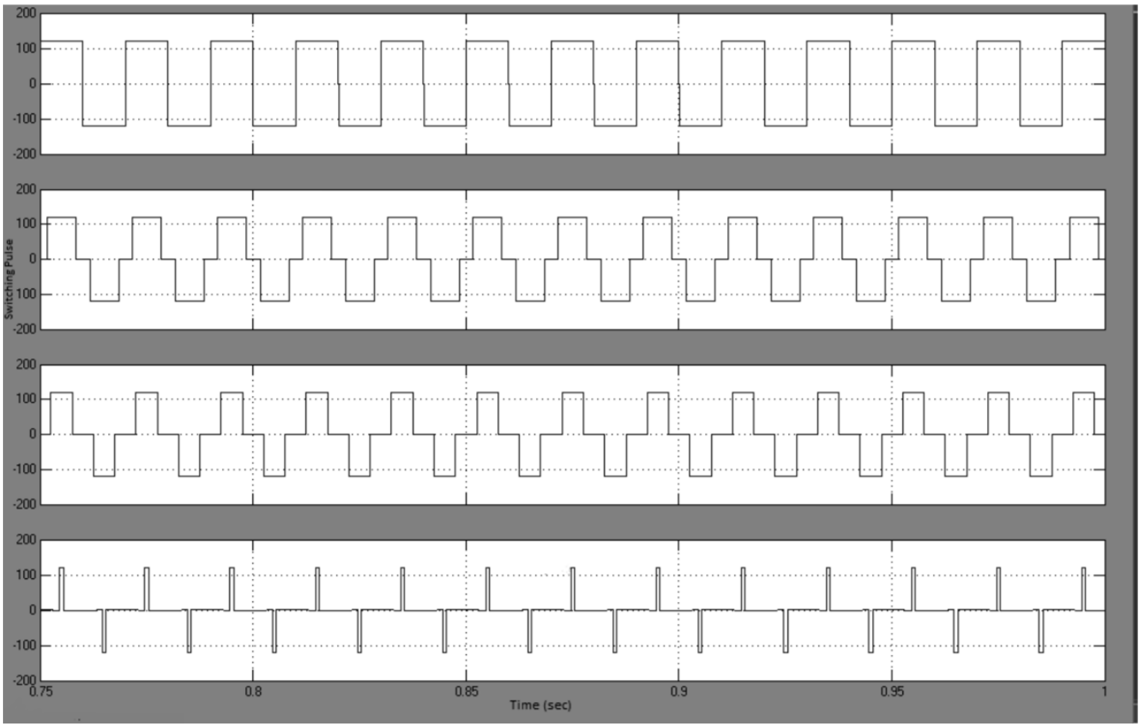

Fig.13. Output waveform switching angle of bridge 4, bridge 3, bridge 2, bridge 1

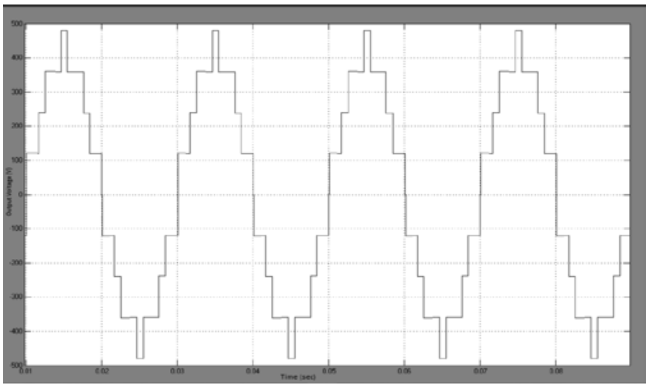

Fig.14. Output voltage waveform of 9 level UPS inverter

The output voltage of the 9-level cascaded multilevel inverter is shown in Fig.14. The output voltage is four times more than the input voltage. The nine levels of the output are obtained, which are both positive and negative polarity.

The output current waveform for nine-level inverter is shown in Fig.15. As RL load is connected, it synthesizes a near sinusoidal waveform.

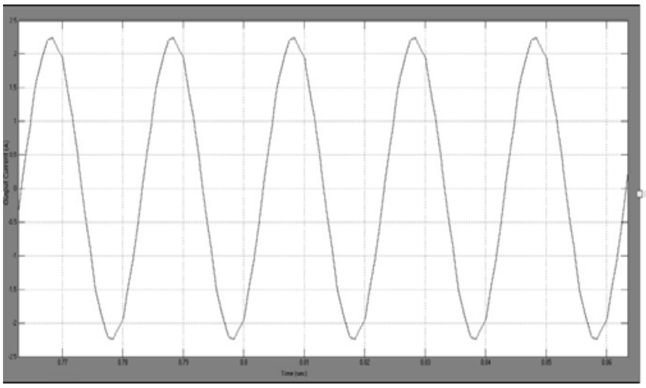

Fig.15. Output current waveform of 9 level UPS inverter

The FFT analysis is done to estimate the THD value. The FFT analysis for the output voltage and current waveform obtained from GA are shown in Fig.16 and Fig.17. It displays the harmonic spectrum of the output voltage and current. In the same figure, a high value of the third and ninth harmonics can be noticed; those harmonics were not minimized due to the fact that they will be cancelled in line voltage for a 3-phase application. The objective in this work is to minimize lower order harmonics, to improve the performance.

9. CONCLUSION

In this paper, an adaptive hybrid technique was proposed to select an optimal switching angle for eliminating the odd harmonic voltages in a UPS 9-level inverter. The hybrid technique is the combination of a Genetic algorithm and neural network. The proposed technique was implemented and its performance in eliminating the 5th, 7th and 11th order harmonic voltages was tested in a 9-level 4-H bridge UPS inverter. Here Genetic algorithm is used to solve the nonlinear transcendental equations obtained from SHEPWM strategy. These equations determine the switching angles which are used to minimize the THD. According to IEEE 519, the allowable limit for current harmonic distortion is 5%. Here the THD value obtained from GA is 1.29% and 5th, 7th and 11th harmonic are less than 3%. The selected lower order harmonics are kept within allowable limits. The solution obtained using GA is used for training the neural network. The trained network is used for online determination of switching angles to minimize the harmonics. A real-time system was implemented using the neural network. This work can be extended further for experimental verification. This method can be extended to any number of levels of Multilevel Inverter.

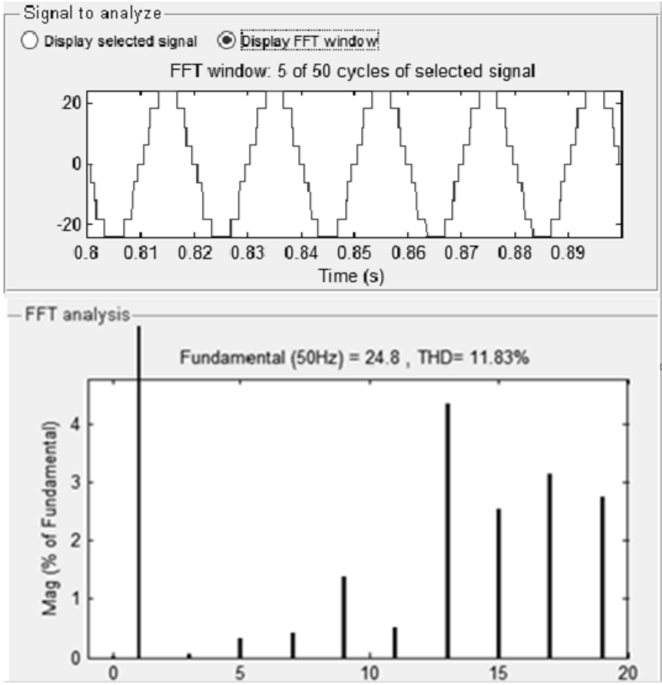

Fig.16. FFT Analysis of output voltage waveform of 9 level UPS inverter

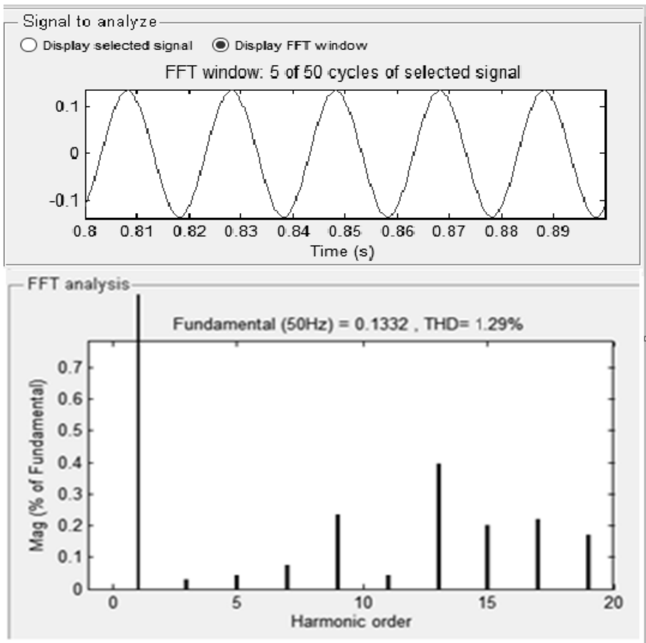

Fig.17. FFT Analysis of output current waveform of 9 level UPS inverter

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