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Elimination of Lower Order Harmonics in Multilevel Inverters Using Genetic Algorithm

Prashanth L Gopal, F.T Josh

Abstract- ***This project presents the Genetic optimization method for harmonic elimination in a cascaded multilevel inverter and an optimal solution for eliminating pre specified order of harmonics from a stepped waveform of a multilevel inverter topology with equal dc sources. The main challenge of solving the associated non linear equation which are transcendental in nature and therefore have multiple solutions is the convergence of the relevant algorithm. The main objective of selective harmonic elimination pulse width modulation strategy is eliminating low-order harmonics by solving nonlinear equations. The performance of cascaded multilevel inverter is compared based on computation of switching angle using Genetic Algorithm as well as conventional Newton Raphson approach. A significant improvement in harmonic profile is achieved in the GA based approach. A nine level cascaded multi level inverter is simulated in MATLAB/Simulink and a hardware model has been fabricated to validate the simulation results.***

Keywords-Genetic Algorithm (GA), Multilevel inverters, Selective harmonic elimination (SHEPWM).

I. INTRODUCTION

Today, there are many applications for multilevel inverters, such as flexible ac transmission system (FACTS) equipment high voltage direct current lines, and electrical drives. There are three conventional structures for multilevel inverters such as diode clamped multilevel inverter model, flying capacitor multilevel inverter model and cascaded multilevel inverter model with separate dc sources. To improve inverter performance and output quality, the methods suggest are, sinusoidal or sub harmonic natural pulse width modulation (SPWM), selective harmonic elimination PWM (SHE-PWM), space-vector modulation (SVM), optimized harmonic-stepped waveform (OHSW) and optimal minimization of Total Harmonic Distortion (OMTHD). The second approach is using a low-pass filter in the output of inverters to eliminate higher-order harmonics. The third approach is using multilevel structures in order to reduce harmonics and THD.

Multilevel inverter uses selective harmonic elimination strategy. In this method, the objective is to eliminate low-order harmonics, while the fundamental harmonic is satisfied. If this goal cannot be obtained then the highest possible harmonics optimization is desired.

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In this approach, by solving the equations, $(S-1)$ low order harmonics from the fifth order can be eliminated and the fundamental component is satisfied. Solving of SHE-PWM nonlinear equations is a major problem in obtaining switching angles. Several methods have been suggested which can be categorized into two sets. The first group is based on satisfying the equations. The Newton–Raphson(N–R) method is one of these. The disadvantage of iterative methods is their dependence on an initial guess and divergence problems are likely to occur for large numbers of inverter levels. Also, they can only find one set of solutions. In addition, using the MATLAB function f solve, all roots can be obtained based on the Gauss–Newton method. A mathematical approach based on theory of resultant is proposed in this method can only find all possible solutions for those feasible Modulation index M solutions that exist. It is complicated and time consuming and requires new expression when voltage level or input dc voltage is changed. Also, the Homotopy algorithm is used to determine one set of solutions. Since the first group does not suggest any optimum solutions for infeasible modulation index, the second group of methods have been applied based on evolutionary algorithms. These methods cannot only find solutions, where low-order harmonics can be completely eliminated, but they can also find solutions for infeasible modulation index. The second group introduces optimum angles so that the equations are minimized. These methods are simple and can be used for problems with any number of levels. They are free from derivations. GA is one of the methods that have been used in this approach. In addition, particle swarm optimization, bacterial foraging algorithm and ant colony methods have been introduced. GA is widely used and is simpler and more applicable. In this paper, the Genetic algorithm (GA) is applied to minimize low-order harmonics, as well as to satisfy the desired fundamental component. Results including the probability of reaching to a global solution and the effect of running times are compared with those obtained by GA. Results confirm the effectiveness of GA. Experimental results are presented to confirm the simulation results.

II. MULTILEVEL INVERTERS

Multilevel inverter technology have become more attractive For their use in high voltage and high power applications. In Multilevel inverters the desired output voltage is achieved by Suitable low combination of multiple low dc voltage sources.

Used at the input side. As the number of dc sources increases The output voltage will be pure closer to sinusoidal waveform.

ADVANTAGES

- They can generate output voltages with extremely low distortion and low $\frac{dv}{dt}$.
- They draw input current with very low distortion.
- They generate smaller common-mode (CM) voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated.
- They can operate with a lower switching frequency

APPLICATION

- Flexible ac transmission system (FACTS) equipment.
- High voltage direct current lines.
- Electrical drives

III. SELECTIVE HARMONIC ELIMINATION PWM

For a multilevel inverter, switching angles at fundamental frequency are obtained by solving the selective harmonic elimination equations in such a way that the fundamental voltage is obtained as desired and certain lower order harmonics are eliminated As these equations are nonlinear transcendental in nature, there may exist simple, multiple or even no solutions for a particular modulation index. Earlier works Show that if iterative numerical techniques are implemented to solve the transcendental equations, only one solution set is obtained even there may exist multiple solution sets; other suggested approaches such as resultants method, theory of symmetric polynomial produce all possible solution sets, but these methods are more computationally complex**.**

This has been proposed in the project" Selective harmonic elimination technique for a multilevel inverter"., The semiconductor devices must be switched on and off to synthesize multilevel output ac voltage using different levels of dc inputs in such a way that desired fundamental is obtained with minimum harmonic distortion. The commonly available switching technique is selective harmonic elimination (SHE) method at fundamental frequency, for which transcendental equations characterizing harmonics are solved to compute switching angles. It is difficult to solve the Selective Harmonic Equations, as these are highly nonlinear in nature and may produce simple solutions, multiple solutions, or even no solutions for a particular value of modulation index. A big task is how to get all possible solution sets where they exist using simple and less computationally complex method. Once these solution sets are obtained, the solutions having least Total Harmonic Distortion are chosen. Iterative numerical techniques have been implemented to solve the Selective Harmonic Equations producing only one solution set, and even for this a proper initial guess and starting value of modulation index for which solutions exist are required.

Solving SHE-PWM nonlinear equations is a major problem in obtaining switching angles. Several methods have been suggested which can be categorized into two sets The first group is based on satisfying the equations. The Newton–Raphson (N–R) method is one of these. In addition, using the MATLAB function f solve, all roots can be obtained based on the Gauss–Newton method.

IV. DIFFICULTIES IN NEWTON-RAPHSON

- Dependence on an initial guess
- Divergence problem are likely to occur for large number of inverter levels

In the paper "Elimination of low order harmonics in multilevel inverters using genetic Algorithm". The selective harmonic elimination pulse width modulation (SHE-PWM) switching strategy has been applied to multilevel inverters to remove low order harmonics. Naturally, the related equations do not have feasible solutions for some operating points associated with the modulation index (M). However, with these infeasible points, minimizing instead of eliminating harmonics is performed. Thus, harmful harmonics such as the 5th harmonic still remains in the output waveform. Therefore, it is proposed in this paper to ignore solving the equation associated with the highest order harmonics. A reduction in the eliminated harmonics results in an increase in the degrees of freedom. As a result, the lower order harmonics are eliminated in more operating points. A 9-level inverter is chosen as a case study. The genetic algorithm (GA) for optimization purposes is used. Simulation results verify the proposed method. Today, there are many switching strategies which are applied to multilevel inverter topologies. Some of these switching strategies are mentioned in. Selective harmonic elimination pulse width modulation (SHE-PWM) is the most famous switching strategy. The aim of this method is the eliminating low order harmonics, if it is possible, or at least to minimize them. The nature of these equations is nonlinear. Some iterative methods such as: the Newton-Raphson (N-R) have been used to solve the equations.

V. BASIC SWITCHING STRATEGIES

There are several switching strategies which are applied to multilevel inverter topologies such as:1) sinusoidal pulse width modulation (SPWM). 2) selective harmonic elimination pulse width modulation (SHEPWM); 3) minimization of total harmonic distortion (MTHD). In MTHD, without any emphasis on special harmonics, all harmonics in the same weight (i.e. THD) are minimized . In SHEPWM, the low order harmonics are eliminated. There are some advantages and disadvantages to these three techniques which are reported in the literature. In this paper, the SHEPWM technique is developed.

Fourier series expansion of the output voltage waveform is

$$V(\omega_t)=\sum_{n=1}^{\infty} V_n \sin(n\omega t) \qquad (1)$$

where, Vn is the amplitude of the harmonics. The angles are limited to between zero and 90 ($0 \leq \Theta \leq 90$). Because of an odd quarter-wave symmetric characteristic, the harmonics with an even order become zero. Subsequently, Vn becomes:

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$$Vn=\frac{4Vdc}{n\pi}\sum_{i=0}^{s}\cos(n\theta i) \qquad (2)$$

VI. PROPOSED METHOD BASED ON THE REDUCTION OF ELIMINATED HARMONICS

As previously mentioned, the elimination of low order harmonics involves solving nonlinear transcendental equations. These equations are not solvable for some intervals of M (the third region). However, some loads such as electrical drives need to work in a wide range of M even in the third region. In these points, the desired harmonics cannot be completely eliminated. Instead, the minimization of harmonics leads to the presence of harmful harmonics such as the 5th order harmonic.

In this paper, the SHE-PWM switching strategy is developed to improve the quality of the low order harmonics in a wide range of modulation indexes. Normally, the equations related to SHE-PWM do not have feasible solutions for all of the values of M. This leads to the presence of harmful harmonics such as: the 5th harmonic. It is suggested to reduce the number of eliminated harmonics. As a result, the 5th harmonic becomes zero for more values of M. Also, the equations are satisfied for all quantities of M. The objective of SHE-PWM is to eliminate the lower order harmonics while remaining harmonics are removed with filter. In this paper, without loss of generality, a 9-level inverter is chosen as a case study to eliminate its low-order harmonics (fifth and seventh). It is needless to take the triplen harmonics into consideration, since they will vanish in three-phase applications. So, to satisfy fundamental harmonic and eliminate fifth and seventh harmonics, three nonlinear equations with three angles are provided in

$$V_1=\frac{4Vdc}{\pi}[\cos(\theta 1)+\cos(\theta 1)+\cos(\theta 3)] \qquad (3)$$

$$V_5=\frac{4vdc}{5\pi}[\cos(5\theta 1)+\cos(5\theta 2)+\cos(5\theta 3)] \qquad (4)$$

$$V_7=\frac{4vdc}{7\pi}[\cos(7\theta 1)+\cos(7\theta 2)+\cos(7\theta 3)] \qquad (5)$$

$$V_9=\frac{4vd\,c}{9\pi}[\cos(9\theta 1)+\cos(9\theta 2)+\cos(9\theta 3)] \qquad (6)$$

VII . GENETIC ALGORITHM

A genetic algorithm is a computational model that solves optimization problems by imitating genetic processes and the theory of evolution. It imitates biological evolution by using genetic operators referred to as reproduction, crossover, mutation etc. The GA is simple and applicable to problems with any number of levels, without the extensive derivation of analytical expressions, for both eliminating and minimizing harmonics. This algorithm is chosen for the optimization goals

In conventional SHE-PWM, two sets of modulation indexes (M) are specified. In the first set, the equations have feasible solutions, whereas in the second set there are not any analytical solutions. Therefore, when using these optimizing methods, the low order harmonics are minimized as much as possible but not removed completely. As a result, low order harmonics such as: the 5th harmonic still remain in the output voltage. There are S switching angles associated with S cells. These angles are considered as variables or degrees of freedom. Thus, S equations can be satisfied. S-1 equations are devoted to eliminating the (S-1) low order harmonics starting from the 5th order for 3-phase applications or from the 3rd order for single phase applications. Also, one equation is dedicated to satisfying the fundamental component. The Modulation index (M) is defined as a symbol of the fundamental component. In some Ms, which are focused on here, there are no feasible solutions, whereas some loads need to work in whole range of Ms.

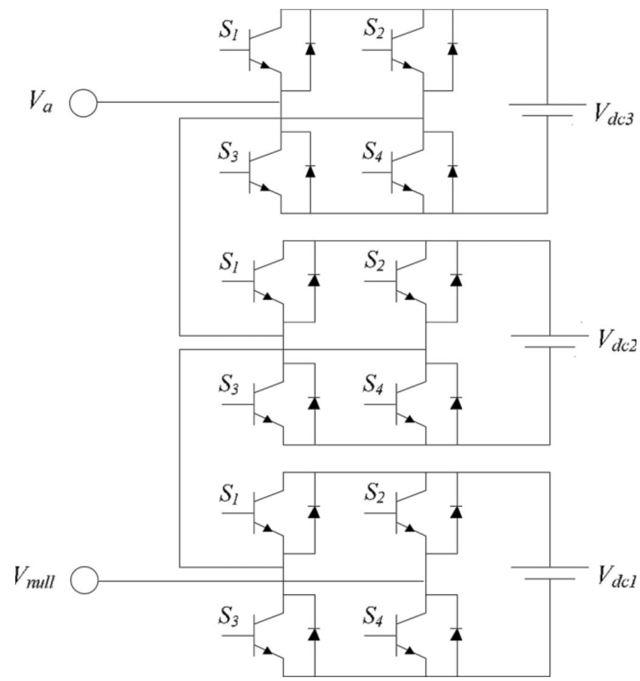

Fig.1. Cascaded multilevel inverter with dc sources

VIII. FLOW CHART OF GENETIC ALGORITHM

The structure of a simple GA consists mainly of three operators. A selection operator, a crossover operator which acts on a population of strings to perform the required reproduction and recombination, and a mutation operator which randomly alters character values, usually with a very low probability. The effect of these random alterations is to maintain diversity within the population, thereby preventing an early convergence of the algorithm to a possibly false peak.

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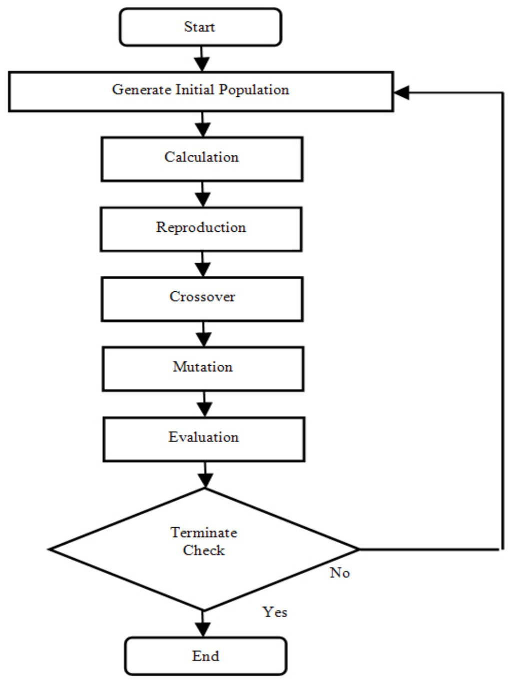

A. Chromosome Representation

In this study, each chromosome is taken as a possible solution for the problem, then each chromosome is developed based on single dimensional arrays with a length of S, where S is the number of angles.

B. Initialization of the Population

For any GA it is necessary to initialize the population. The most common method is to randomly generate solutions for the entire population. All of the experiments discussed in this paper employ a completely random seeding of the initial population. Population size depends only on the nature of the problem and it must achieve a balance between the time complexity (consume for computing the fitness function and the genetic operators) and the search space measure. In this paper, the population size is set at 200.

C. Reproduction

The degree of conformity of each object is calculated and an individual is reproduced under a fixed rule depending on the degree of conformity. Here, some individuals with a low degree of conformity will be screened, while individuals with a high degree of conformity will increase.

D. Cross Over

New individuals are generated by the method of intersection that has been set up.

E. Mutation

This is performed by an operation determined by the installed mutation probability or mutation, and then a new individual is generated.

F. Evaluation Fitness

The fitness value is a measure of the appropriateness of a solution with respect to the original objective and the "amount of infeasibility". The fitness function is formed by adding a penalty to the original objective function or fundamental component functionFor each solution (or each chromosome) the fitness function is calculated as

$$ʃ=\min_{\Theta i}\{(100^{V}{}_{1}^{*}-{}^{V}{}_{1}/V_{1}^{*})^{4} + \sum_{s=2}^{S} 1/h_s(50^{V}{}_{hs}/V1)^{2}\} \quad (7)$$
where $i=1,2,\ldots,s$
subject to $0\leq \Theta_i \leq \pi/2$

IX. GENETIC ALGORITHM IN SOLVING SHEPWM PROGRAM

```
Clear all; close all; clc;
Function v=gamulti(x)
% initialise for 2 objectives
i=1:1:7;
x(i)=0:7:pi/2
v=zeros(3,1);
% compute first objective
For i=1:1:7
V(1) =[cos(Θ1)+cos(Θ2)+cos(Θ3);
V(2)  =[cos(5Θ1)+cos(5Θ2)+cos(5Θ3);
V(1)  =[cos(7Θ1)+cos(7Θ2)+cos(7Θ3);
End
```

$$F=\min_{\Theta i}\{(100^{V}{}_{1}^{*}-{}^{V}{}_{1}/V_{1}^{*})^{4} + \sum_{s=2}^{S} 1/h_s(50^{V}{}_{hs}/V1)^{2}\}$$

X. IMPLEMENTATION OF THE GENETIC ALGORITHM FOR SOLVING SHEPWM TECHNIQUE

For achieving the switching angle, the GA program is written using MATLAB software. The size of population of GA is 200. The no. of variables is the no. of decision variables. In addition, the number of iterations for each run is 200 and assumed as a termination criterion. Constructed

$$ʃ=\min_{\Theta i}\{(100^{V}{}_{1}^{*}-{}^{V}{}_{1}/V_{1}^{*})^{4} + \sum_{s=2}^{S} 1/h_s(50^{V}{}_{hs}/V1)^{2}\} \quad (8)$$
where $i=1,2,\ldots,s$
subject to $0\leq \Theta_i \leq \pi/2$

where V_1^{*}= The desired fundamental harmonic,
S = The no. of switching angles
h_s = Order of s_{th} viable harmonic at the output of a three-phase multilevel inverter e.g., $h_2=5$ and $h_3=9$

In this section, switching angles are found such that low-order harmonics (fifth and seventh) are eliminated and the magnitude of the fundamental harmonic reaches to its desirable value, i.e.,V_1^{*}.

If the fundamental harmonic violates its set point by more than 1%, the first term of fitness it by a power of 4. Because of the use of the power of 4, corresponding penalties for any deviations under 1% get a negligible value. The second term of neglects harmonics under 2% of fundamental. But, when any harmonic exceeds this limit, the objective function is subject to a penalty by power of 2. Finally, each harmonic ratio is weighted by inverse of its harmonic order, i.e.,1/*hs*. By this weighting method, reducing the low-order harmonics gets higher importance.

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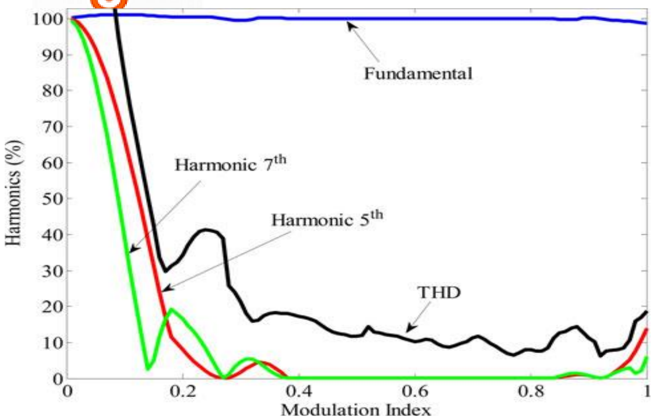

Fig.2. Percentages of fundamental, low-order harmonics and THD

The algorithm is run 1, 2, 5, and 10 times and the best solution based on the minimum fitness function is selected. Fig. 4.1 shows the amount of fitness function with respect to the range of modulation index (0–1) with step 0.01, when the program is run once and 10 times.

For feasible points, the program can successfully arrive at the solutions, as it is indicated by objective values less than 10^{-2}. For some modulation indices, more than one solution may exist. The program encounters with one of them. The probability of converging to global minimum for 10 times run is greater than 1 time run.

PARAMETERS OF GA

POPULATION SIZE
NO. OF ITERATIONS IN EACH RUN
NO. OF RUNS
RUNNINING TIME
CODE COMPLEXITY

XI. SIMULATION RESULTS AND ANALYSIS

The MATLAB code is written for achieving switching angle, the GA program is written using MATLAB/Simulink software. The size population of GA is mentioned. In addition, the number of iterations for each run is also mentioned and assumed as a termination criterion.

XII. MATLAB SIMULATION TOOL R2010A

MATLAB is a high-performance language for technical computing. It integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation algorithm development data acquisition modeling, simulation and prototyping data analysis, exploration and visualization scientific and engineering graphics application development, including graphical user interface building MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems.

XIII. SIMULATION CIRCUIT AND WAVEFORMS

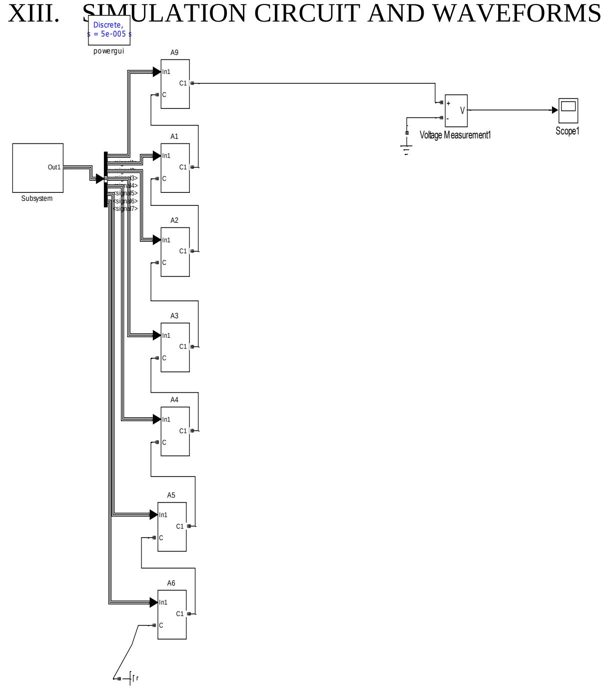

Fig.3 Implemented Circuit In Matlab

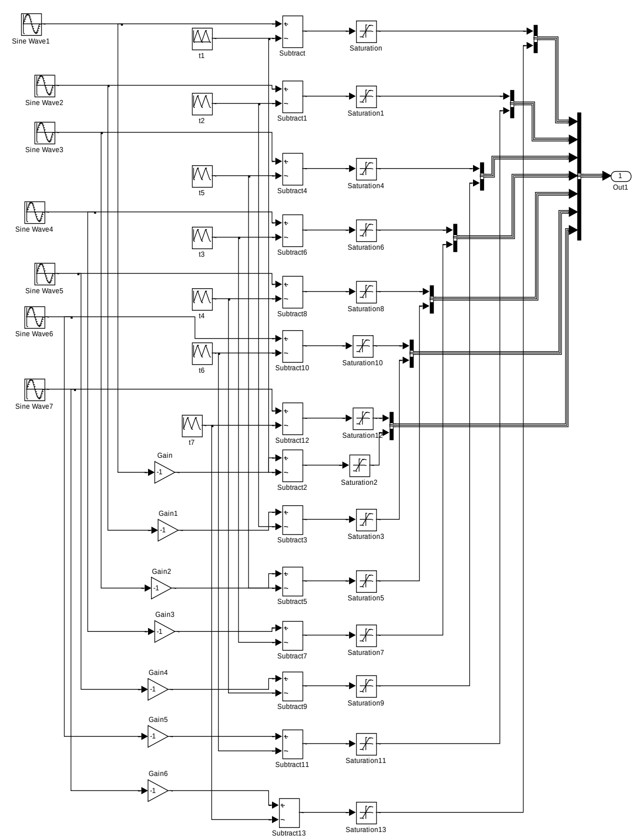

Fig. 4. Subsystem Of Circuit

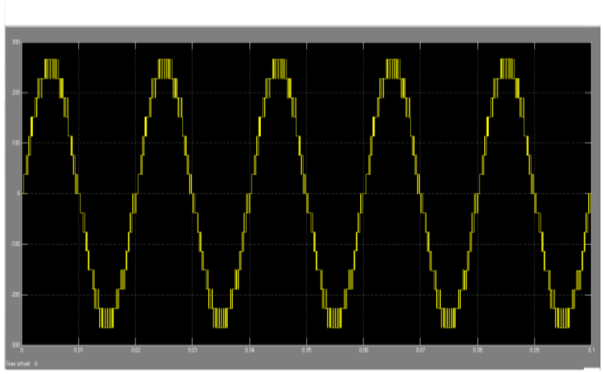

Fig.5. Phase Voltage Waveform

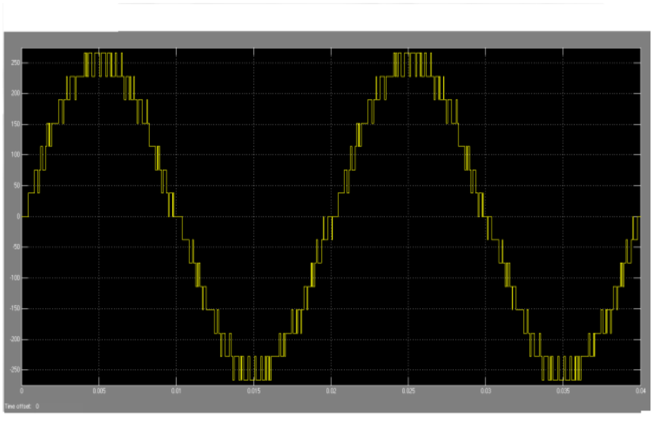

Fig.6. Line voltage waveform

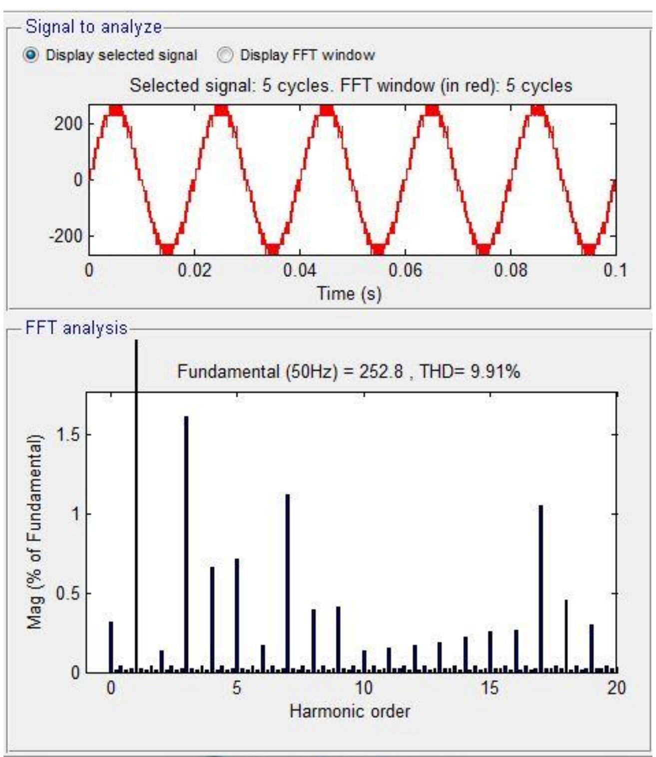

Fig.7. Harmonic Spectrum of Output Voltage Plotted With FFT Analysis of Simulink

XIV. CONCLUSION

In this project, elimination of low-order harmonics using SHEPWM strategy is investigated. GA is applied to solve the equations. Simulation results obtains the accuracy and ability of GA for convergence objectives. Also, solutions have near probability to attain global minimum for 1, 2, 5, and 10 times runs. Normally, the equations related to SHEPWM do not have feasible solutions for all of the values of M. This leads to the presence of harmful harmonics such as the 5th harmonic. It is suggested to reduce the number of eliminated harmonics. As a result, the 5th harmonic becomes zero for more values of M. Also, the equations are satisfied for all quantities of M. Finally,to verify GA solutions, experimental results are presented which gives the accuracy of the proposed method.

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