

Non-Traditional Method-Based Solution for Elimination of Lower Order Harmonics in Voltage Source Inverter Feeding an Induction Motor Drive

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Abstract: This paper presents an efficient and reliable Genetic Algorithm-based solution for Specific Harmonic Elimination (SHE) switching pattern. This method eliminates considerable amount of lower order line voltage harmonics in Pulse Width Modulation (PWM) inverter. The determination of pulse pattern for the elimination of some lower order harmonics of a PWM inverter necessitates solving a system of nonlinear transcendental equations. Genetic Algorithm is used to solve nonlinear transcendental equations for PWM-SHE. In this proposed method, harmonics up to 17th are eliminated using Genetic Algorithm without using Dual transformer. Simulations using Matlab 7.0 and PSIM 6.1 are carried out so as to validate the solution.

Keywords: Inverter, Harmonics, Genetic Algorithm (GA), Pulse Width Modulation (PWM), Selective Harmonic Elimination (SHE).

1 Introduction

Pulse width modulation has been the subject of intensive research over the past few decades. Different types of feed forward and feed backward pulse width modulation schemes having relevance for industrial application have been widely discussed [2].

The use of power electronic equipments in industrial and consumer applications has been increased in recent years. Such loads draw nonlinear sinusoidal current and voltage from the source resulting in the harmonics in the networks [10]. They occur frequently in variable frequency drives or any electronic devices using solid state switching to convert AC or DC.

The characteristic harmonics h are based on the number of rectifiers (pulse number) used in the circuit, and can be determined by the equation (1).

$$h = (n \times p) \pm 1 \quad (1)$$

where, n is an integer and p is pulse number of rectifier.

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For 6 pulse rectifier, the characteristic harmonics will be 5th, 7th, 11th, 13th, 17th, etc.

The undesirable lower order harmonics of a square wave can be eliminated and fundamental voltage, known as Specific Harmonic Elimination (SHE), can be subsequently controlled. In SHE method, notches are created on the square wave at predetermined angles so as to eliminate the significant harmonic components and control the fundamental voltage.

Programmed PWM that eliminates lower-order harmonics [1] generates high-quality output spectra, which in turn results in the minimal occurrence of current ripples, thereby satisfying several performance criteria and contributing to overall improved performance. Performance characteristics of a rectifier/inverter power conversion scheme largely depend on the choice of the particular Pulse Width Modulation strategy employed. Programmed PWM techniques optimize a particular objective function, such as selective elimination of harmonics being thus the most effective means of obtaining high performance.

An optimized PWM technique aimed at reducing harmonic distortion and spreading the harmonic energy for high frequency inverters is proposed in [7]. Optimization algorithms are becoming increasingly popular in engineering design activities, whereby the emphasis is put either on maximizing or minimizing a certain goal primarily owing to the availability and affordability of high speed computers. They are extensively used in engineering design problems.

The minimization of objective function used for SHE was done using traditional mathematical techniques such as Conjugate Gradient Descent Method (CGD) [4] and Newton Raphson Method (NR) [8]. These methods need initial values to obtain the objective function and are based on differential information, so they may produce local minimum solution which leads to undesirable pattern.

GA is one of the Non-Traditional programming techniques which provide third solution to the nonlinear mathematical problems. GA is inspired by the mechanism of natural selection, in which sturdier individuals are likely to survive in a competing environment. GA uses a direct analogy of such selection. In [3] GA is applied to eliminate the lower order harmonics in power converter with dual transformer and 12 pulse rectifier. The 3rd and other triple in harmonics can be ignored if the machine has an isolated neutral.

GA and CGD methods are used to find the switching pattern for SHE to eliminate rectifier low input current harmonics without having any initial guesses for the switching pattern. GA is used to provide the initial values [6].

NR and GA are adopted for the reduction of the lower order line current harmonics by developing the 'N' number of pulse per half cycle [9]. GA

technique was used to generate an optimal pulse pattern to suppress 5th and 7th harmonics in PWM inverter [5].

The power circuit for Voltage Source Converter Drive system is given in Fig. 1. DC voltage is obtained by using 6 pulses Voltage Source Rectifier. The rectifier is connected to Voltage Source Inverter through DC link capacitor and DC link Inductor.

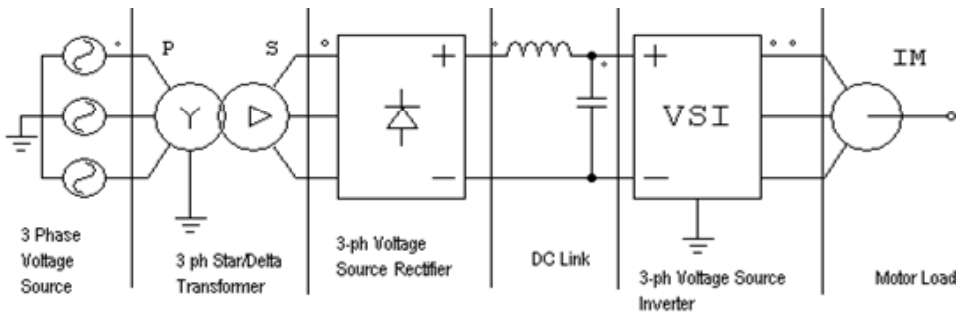


Fig. 1 – Power circuit of Voltage Source Converter Drive System.

This paper presents a new method of line voltage harmonics reduction in PWM converter without dual transformer and using GA. The use of dual transformer and 12 pulse rectifier can be eliminated in the proposed method. The 5th, 7th, 11th, 13th and 17th harmonics are the characteristic harmonics required to be eliminated. The objective is achieved by determining the switching pattern for the three-phase Inverter using GA. Simulation was carried out and validated using Matlab 7.0 and PSIM6.1.

2 PWM-SHE Switching Techniques

The Fourier coefficients of the PWM-SHE switching pattern for a three-phase line to neutral are given by the equation (2),

$$a_n = \frac{4}{n\pi} \left[-1 - 2 \sum_{k=1}^N (-1)^k \cos(n\alpha_k) \right], \quad (2)$$

$$b_n = 0.$$

Equation (2) has N variables (α_1 to α_N) and a set of solutions is obtained by equating $N-1$ harmonics to zero and assigning a specific value of the fundamental amplitude α_1 through the equation (3).

$$\begin{aligned}
 f_1(\alpha) &= \frac{4}{\pi}[-1 - 2\sum_{k=1}^n (-1)^k \cos(\alpha_k)] - M = \varepsilon_1 \\
 f_2(\alpha) &= \frac{4}{5\pi}[-1 - 2\sum_{k=1}^n (-1)^k \cos(5\alpha_k)] = \varepsilon_2 \\
 &\vdots \\
 f_N(\alpha) &= \frac{4}{N\pi}[-1 - 2\sum_{k=1}^n (-1)^k \cos(n\alpha_k)] = \varepsilon_N,
 \end{aligned} \tag{3}$$

where the variables ε_1 to ε_N are normalized amplitudes of the harmonics to be eliminated. The objective function of PWM-SHE technique is to minimize the harmonic content in the inverter line voltage and it is given in equation (4).

$$f(\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_N) = \varepsilon_1^2 + \varepsilon_2^2 + \dots + \varepsilon_N^2. \tag{4}$$

Subject to the constraint equation (5),

$$0 < \alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 \dots \alpha_N < \frac{\pi}{2}, \tag{5}$$

for Quarter-wave symmetric pulse pattern. In the proposed method $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and α_5 solutions are expected with the elimination of 5th, 7th, 11th, 13th and 17th harmonics.

3 Genetic Algorithm Method Aimed at Solving the Proposed PWM Switching Pattern

Genetic Algorithms (GA) are numerical optimization algorithms based on the principle inspired from the genetics and evolution mechanisms observed in natural systems and population of living beings. Binary encoding GA is dealing with binary strings, where the number of bits of each string simulates the genes of an individual chromosome, and the number of individuals constitutes a population. Each parameter set is encoded into a series of a fixed length of string symbols usually from the binary bits, which are then concatenated into a complete string called chromosome. Substrings of specified length are extracted successively from the concatenated string and then decoded and mapped into the value in the corresponding search space. Generally, GA implementation comprises the procedures of initial population generation, fitness evaluation and genetic operations of selection, crossover and mutation.

In this paper, an attempt has been made to determine the most optimal switching pattern to eliminate the lower order line voltage harmonics in the Voltage Source Inverter. The implementation of GA algorithm is given below.

A. Initialization

The initial population (P_1) is generated after satisfying the equation (5) with randomly selected initial individual switching angle. The generated switching angles are distributed uniformly between their minimum and maximum limits by satisfying the equation (5).

B. Fitness of the candidate solutions

The Fitness Value (FV) in this case attempts to minimize the objective function using the given equation (6).

$$FV = \frac{1}{1 + f(\alpha)}, \quad (6)$$

where $f(\alpha)$ can be calculated using the equation (4).

The alpha limit violation can be dealt with the violation coefficient value using equation (7),

$$V_{io_coef} f = \left[1 + (\alpha_{(i-1)} - \alpha_{(i)}) \right] \rho, \quad (7)$$

where ρ is the penalty parameter and $\alpha_{(i)}$ is the i^{th} value of α .

In such cases, the objective function is calculated by multiplying the V_{io_coef} value. After computing the fitness of each individual, the parents then undergo the genetic operation of selection, crossover and mutation; each pair creates a child that has two parents. The process of selecting and mating individuals continues until a new generation is reproduced.

C. Selection

After the evaluation of the initial randomly generated population, the GA begins the creation of the new generation. Chromosomes from the parent population are selected in pairs with a probability proportional to their fitness to replicate and form offspring chromosomes. This selection scheme is known as Roulette wheel selection.

D. Crossover and Mutation

Crossover operator is applied with a certain probability. The parent genotypes are combined to form two new genotypes that inherit solution characteristics from both parents. Crossover although being the primary search operator cannot produce information that does not already exist within the population.

We propose to combine parameter values from two parents into new parameter values for the children. A single point crossover method is used to combine the parents to produce the children.

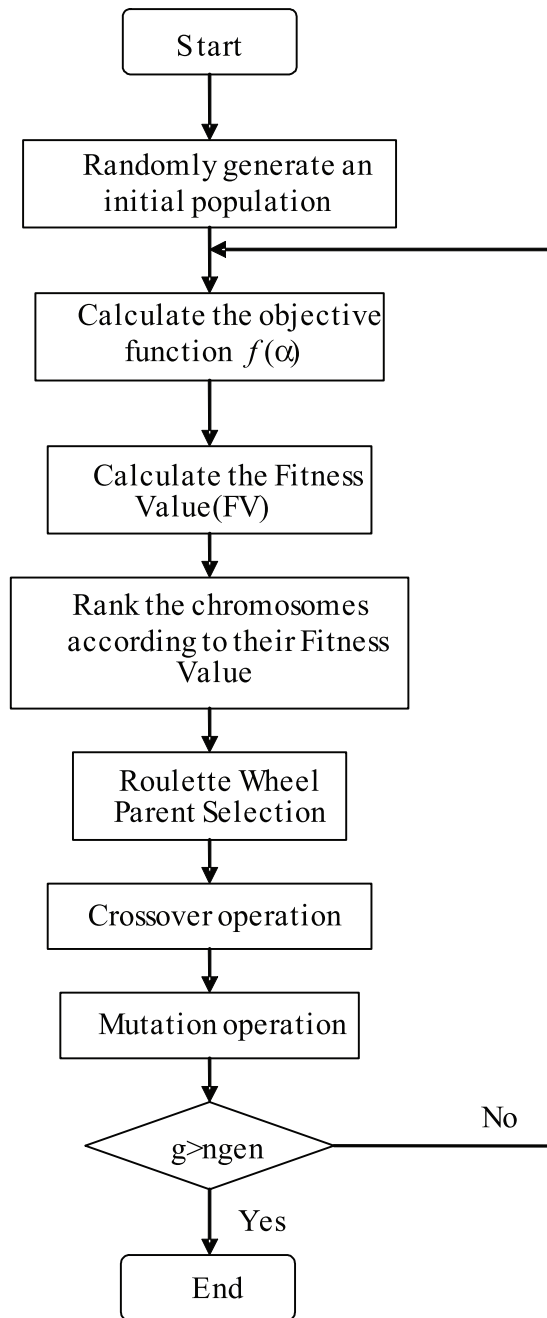


Fig. 2 – Operation of Proposed Genetic Algorithm method.

Mutation operator is also applied with a small probability. Randomly chosen bits of the offspring genotype flip from 0 to 1 and vice versa to give characteristics that do not exist in the parent population. Generally mutation is considered as a secondary operator that gives a non-zero probability to every solution to be considered and evaluated. This operation can help in avoiding the possibility of taking a local minimum for a global minimum. A coin-toss optimum is employed to determine the genes to be mutated, if the random number between 0 and 1 is less than the mutation rate, the gene is mutated in a given region. This random scattering just might find better optima, or even modify a part of a genetic code that will be beneficial in a latter cross. On the other hand, it might produce a weak individual that will never be selected for cross.

E. Elitism

The crossover and mutation for the two chromosomes is repeated until all of the chromosomes of the parent generation are replaced by the newly formed chromosomes. The best chromosome of the parent generation and the best chromosome found in all of the previous generations are copied intact to the next generation, so that the possibility of their destruction through a genetic operator is eliminated.

F. Termination criterion for GA

The above procedure from the section [B-E] is repeated until the maximum iteration count is reached. The main stages and operations of the proposed Genetic Algorithm technique including initialization, selection, crossover and mutation are shown in the flowchart of Fig. 2.

4 Optimization Results

To obtain the best and optimum solution for the given non-linear transcendental equations, the following GA parameters are used.

Population size: 50

Number of generation: 100

Crossover rate: 0.8

Mutation rate: 0.01

After solving the five nonlinear functions of equations (3) simultaneously using Matlab 7.0 optimization toolbox, five angles are obtained. This process is repeated for the various modulation indices from 0.05 to 1.3. Fig. 3 shows the Trajectory of calculated switching angles of proposed PWM-SHE switching pattern using GA.

In Fig. 3, parameters represent five independent angles in (3) used to construct the required PWM-SHE switching pattern as shown in Fig. 4. In the proposed approach, the trajectories of the angles are almost smooth for α_1 and α_2 over the whole range of possible modulation indices. There is an abrupt rise of 25° for α_4 and α_5 in the modulation index 0.7 and fall of about 25° for α_3 . All five angles are smooth after $M=0.8$.

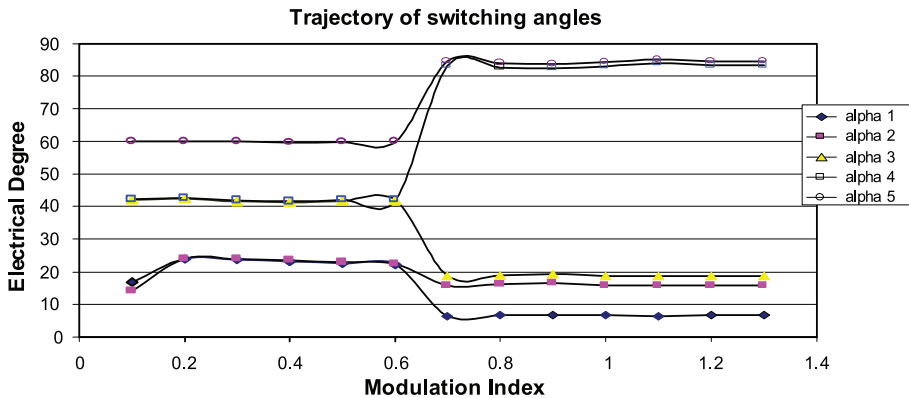


Fig. 3 – Trajectory of calculated switching angles of proposed PWM-SHE switching pattern using GA.

All these characteristics bring unpredictability to traditional algorithms that require precise initial values to guarantee convergence. In the proposed approach GA is widely used because of discrete nature of harmonics to be eliminated.

5 Simulation Results

After obtaining the switching angles through the MATLAB using Genetic Algorithm, the proposed system is developed using PSIM6.1. The circuit uses 230V single phase AC supply sources which is connected to the star-connected primary winding of the 3 phase star/delta transformer. The 6 pulse voltage source rectifier is developed by using six diodes as bridge. This rectifier is connected to Voltage Source Inverter through the Inductor and Capacitor acting as a DC link between the rectifier and the inverter. The load to the proposed converter is a three-phase squirrel cage induction motor. In this proposed method, dual transformer and 12 pulse rectifier are not used to eliminate certain lower order harmonics. High capacity dual transformer connections are avoided so as to eliminate the lower order harmonics by using Genetic Algorithm approach. Simulations were carried out on a Pentium IV 2.4 GHz, 256-MB RAM processor. The Coding is written using Matlab 7.0.

The rating of the proposed AC drive system is

1. Power supply - 400 V (line to line), 50 Hz,
2. DC link Inductance - 1 mH and
3. DC link Capacitance - 470 μ F.

The harmonics are to be observed in the output line to line voltage. With the five switching angles calculated, the whole switching pattern is constructed as shown in the Fig. 4 using quarter wave symmetry method. The output line-to-line voltage waveforms for the modulation index, $M = 0.9$, with Induction Motor Drive is shown in Fig. 5.

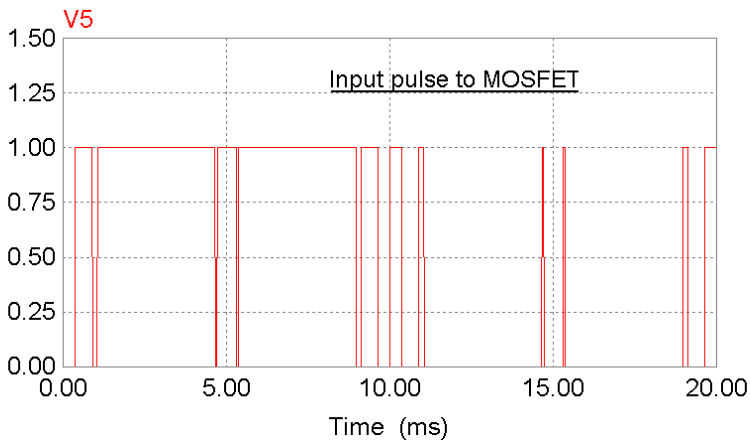


Fig. 4 – PWM-SHE switching pattern for 5th, 7th, 11th, 13th and 17th harmonics elimination.

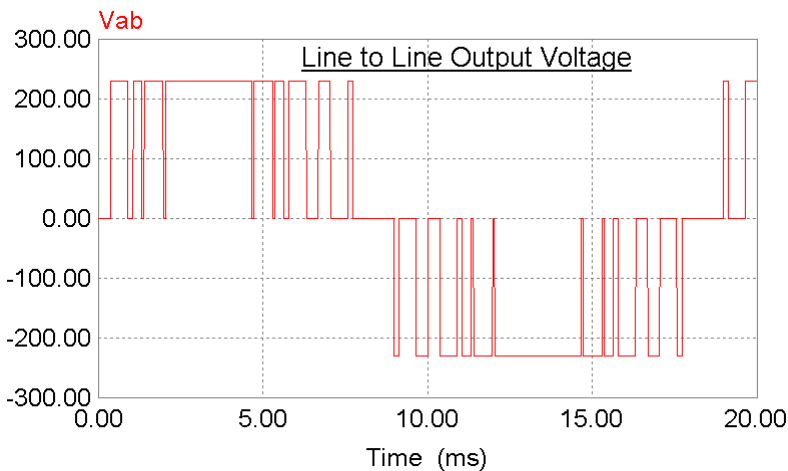


Fig. 5 – Inverter Output Voltage for Induction Motor Drive.

The Harmonic Spectrum of output voltage with Induction Motor Drive is shown in Fig. 6.

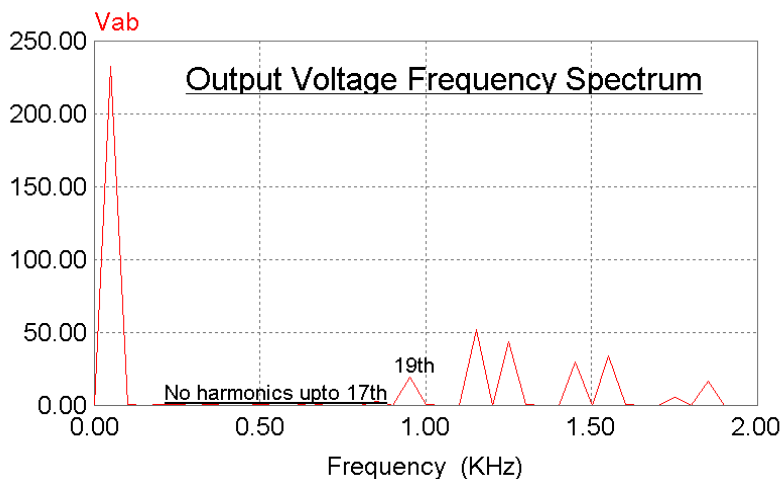


Fig. 6 – Harmonics Spectrum for Inverter Output Voltage for Induction Motor Drive (after eliminating 5th, 7th, 11th, 13th and 17th harmonics using GA) at M = 0.9.

The harmonics spectrum Figs. 5 and 6 show that almost all 5th, 7th, 11th, 13th and 17th harmonics are eliminated for the modulation index value 0.9. These are the characteristic lower - order harmonics to be eliminated for the 6 pulse converter.

6 Conclusion

An efficient technique of calculating switching angles through the Genetic Algorithm method has been illustrated in the paper. A 6 pulse converter is proposed as the power circuit for the 3 phase drive system. PWM-SHE switching is proposed for 3 phase Inverter circuit. The proposed method avoids using 12-pulse rectifier and the traditional complex calculations. Analyzing the Harmonics spectrum shows that 5th, 7th, 11th, 13th and 17th harmonics are eliminated through the proposed method by using Genetic Algorithm. In the proposed method, the dual transformers are not used to eliminate the 5th and 7th order harmonics. High capacity dual transformer connections are avoided for eliminating lower order harmonics by using Genetic Algorithm approach. The designing of similar real-time PWM systems remains to be the subject of further investigations.

The paper emphasized that GA shows great potential in solving not only the required switching angles, but also in the optimization of non-linear converter switching characteristics in general. Matlab 7.0 solutions coupled with PSIM 6.1

implementation results verify the analysis and yield good input/output voltage and current waveforms. The novelty of the paper is the elimination of lower order harmonics of low frequency converter feeding Induction Motor Drive without using dual transformer. The proposed method suppresses up to 17th harmonics in Voltage Source Inverter feeding Induction Motor Drive. This highlights the proposed PWM-SHE method provides a clean power converter environment and meets most accepted standards.

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