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Quality Enhancement of AC Chopper Using Genetic Algorithm

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Abstract

This paper mainly deals with the design of AC chopper using Genetic Algorithm based harmonic elimination technique. Genetic Algorithm is used to calculate optimum switching angles to eliminate lower order harmonics in the output voltage. Total Harmonic Distortion of output voltage is calculated from the obtained switching angles and also adopted in the proposed fitness function. Comparative analysis is made for the switching angles obtained by the Newton Raphson method and the proposed Genetic Algorithm. The analysis reveals that the proposed technique is on par with conventional method. Additionally, the Genetic Algorithm approach offers less computational burden, guaranteed global optima in most cases and faster convergence. The proposed method is simulated in Matlab/Simulink model and the results shows that the proposed method works with high effectiveness, accuracy and rapidity.

Keywords: *AC chopper, genetic algorithm, pulse width modulation (PWM), selective harmonic elimination (SHE)*

1. Introduction

Performance of electrical system utilities are improved due to the recent advancements in the development of power semiconductor switches. Some of the advantages offered by using such devices are quick response, smaller in size and needs low power for control circuitry. AC voltage controller is the widely used power electronic controller because of its simplicity and the ability of controlling large amount of power economically [1]. AC voltage controllers are increasingly used in several applications such as industrial heating systems, motor soft starters, lighting control, Energy-saving control of induction motor drive, Compensation of an unbalanced supply and excitation system of brushless motor [2-3].

The main drawbacks of the AC voltage controllers using classical techniques for generating the firing angles are increased harmonic content and poor power factor. Hence the PWM based AC chopper was proposed as an alternative solution for the AC voltage controller to reduce the above mentioned drawbacks [4]. In PWM based AC chopper, phase control technique is adopted to produce output voltage with same input frequency. Phase control technique is used only for the naturally commutated switching device which leads to low efficiency and poor performance. For the low output voltage, this type of AC chopper generates considerable amount of harmonic distortion in the load current which can drastically deteriorate the power quality delivered from the power system. At present, the development of fast switching devices and microprocessors permits synthesizing; pulse width modulation (PWM) technique can be used to enhance the performance of this circuit [5]. One of the most popular PWM adopted in AC chopper circuit is “fixed-duration PWM”. THD value obtained from this PWM technique is much better than that of phase control technique [6]. However, to enhance the performance of AC chopper, various strategies were proposed for improving the quality of output voltage.

AC chopper circuit employs forced commutated devices or self-commutating devices. The system performance is further improved using various harmonic elimination techniques in the AC chopper. The common characteristic of the Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) method is that the waveform analysis is performed using Fourier theory [7]. Set of nonlinear transcendental equations are derived from the ouput waveform and the solution is obtained using an iterative procedure, mostly by Newton–Raphson method. This method is derivative based technique and may end in local optima; further, right selection of

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initial values alone will guarantee convergence in the solutions. Another approach uses Walsh functions where solving linear equations instead of solving nonlinear transcendental equations and optimizes the switching angles. Intelligent techniques may be used to solve the complex mathematical problems [8-12].

This paper proposes a minimization technique assisted with a genetic algorithm in order to reduce the computational burden associated with Newton-Raphson method.The dual objectives of genetic algorithm are obtaining optimum switching angles and output voltage with low THD. Various switching angles are identified through the different steps of GA. The proposed algorithm calculates the switching angles even beyond the point where other methods fail to converge. Modulation index may reach unity without resulting in failure of convergence. Based on the switching angles, PWM pulses are generated and applied to the AC chopper fed single phase induction motor. Simulation results of output voltage and current, speed and Torque are presented and analysed in the result and discussion section. A comparative analysis between conventional NR method and GA method is tabulated.

2. AC Chopper Based on SHEPWM

AC chopper driving a capacitor-start induction run motor is shown in the Figure 1. In this circuit, IGBTs are used as semiconductor switches and are marked as S_1 and S_2. Switch (S_1) is used for connecting the source to load and switch (S_2) is employed to free-wheel the load current, when S_1 is switched OFF. Switch (S_1) is turned ON at various switching angles, $\alpha_1, \alpha_2, \ldots \alpha_{k-1}$ and turned OFF at $\beta_1, \beta_2 \ldots \beta_k$ per quarter cycle. In this case, input supply voltage is chopped into segments and output voltage level is decided by the ratio between ON and OFF of the power semiconductor switch. Chopper mode of operation can be realized by using two AC switches, one connected in series and the other in parallel with the load as shown in Figure 1.

The output voltage of the AC chopper with k pulses per half cycle is shown in Figure 2. The switching angles are symmetrical with respect to π/2. The output voltage can be expressed using Fourier series as:

$$V_o = a_o + \sum_1^n A_n \cos(n\omega t) + \sum_1^n B_n \sin(n\omega t) \quad (1)$$

Where n = 1, 2, 3,

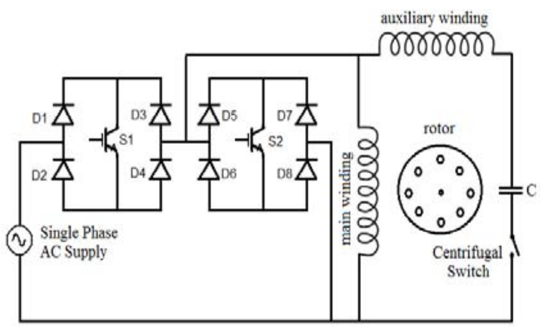


Figure 1. AC Chopper based IM Drive

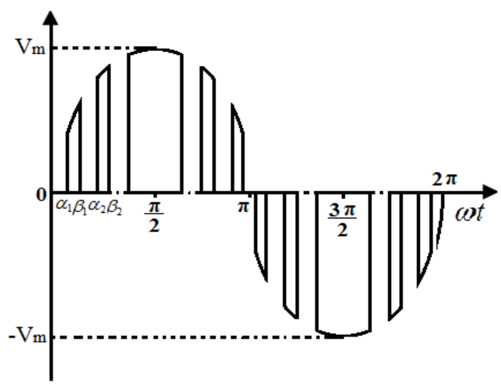


Figure 2. Output Voltage of AC chopper

Due to the symmetry of the wave even harmonics are absent. Further, the coefficients of A_n and a_o are zero. Thus, the above equation reduces to:

The value of Bn is computed as:

$$V_o = \sum_1^n B_n \sin(n\omega t), \text{ where } n = 1,3,5.... \quad (2)$$

$$B_n = \frac{2V_m}{\pi}\left[\frac{\sin(n-1)\omega t}{(n-1)} - \frac{\sin(n+1)\omega t}{(n+1)}\right]_{\alpha_1,\alpha_2..\alpha_k}^{\beta_1,\beta_2...\pi/2}, n \neq 1 \quad (3)$$

Where V_m is the maximum value of the input sine wave. The fundamental component is given by:

$$B_1 = \frac{2V_m}{\pi}\left[\omega t - \frac{\sin(\omega t)}{2}\right]_{\alpha_1,\alpha_2...\alpha_k}^{\beta_1,\beta_2...\pi/2} \quad (4)$$

The objective is to find the switching angles to make $B_1=V_0^*$ and perform selective harmonic elimination where V_0^* is the reference output voltage. This is converted to an optimization problem.

3. Harmonic Elimination using Genetic Algorithm

Genetic Algorithms are stochastic optimization techniques. They are simple, powerful, general purpose and derivative-free stochastic global optimization techniques (search algorithms) inspired by the laws of natural selection and genetics [4]. They follow Darwin's theory of evolution, where fitter individuals are likely to survive in a competing environment. These algorithms are derivative-free in the sense that they do not need functional derivative information to search for a set of solution that minimises (or maximises) a given objective function. This property of GAs reduces the computational burden, search time and also enables them to solve complex objective functions. In this Section, various steps involved in a GA based approach for harmonic elimination in the AC chopper are explained. Various components of GA such as chromosomes, fitness function, reproduction, crossover and mutation as applied to the present work are illustrated in the following section.

The steps for formulating a problem and applying a GA are as follows.

1) Find the number of variables specific to the problem; this number will be the number of genes in a chromosome. In this application the number of variables is the number of controllable switching angles. Each chromosome for this application will have six switching angles, viz. (α_1, β_1, α_2, β_2, α_3 &β_3).

2) Set a population size and initialize the population. Higher population might increase the rate of convergence but it also increases the execution time. The selection of an optimum-sized population requires some experience in GA. The population in this paper has 20 chromosomes, each containing six switching angles. The population is initialized with random angles between 0^o and 90^o taking into consideration the quarter-wave symmetry of the output voltage waveform.

3) The most important parameter in GA is the cost function to evaluate the fitness of each chromosome. The objective of this study is to minimize the specified lower order harmonics. Therefore the cost function has to be related to these harmonics. In this work, third and fifth order harmonics present at the output voltage of the AC chopper has to be minimized or eliminated. Then the cost function (f) can be selected to minimize.

$$f(\alpha,\beta) = f(\alpha_1,\beta_1, \alpha_2,\beta_{2..}\ \alpha_{k-1},\beta_k) = e_r + hc \quad (5)$$

Subject to:

$0 \leq \alpha_1 \leq \beta_1, \alpha_2 \ldots \alpha k_{-1,}\ \beta_k \leq \pi/2$

Where,

$$e_r = \left|V_o^* - \frac{B_1}{\sqrt{2}}\right|$$

$$hc = |B_3| + |B_5| + |B_7| + ...|B_{k-1}|$$

4) For each chromosome an output voltage waveform is created using the switching angles and the required harmonic magnitudes are calculated using Fast Fourier Transform (FFT) techniques.

5) Switching angle set producing the maximum Fitness Value is the best solution of the first iteration.

6) GA is usually set to run for a certain number of iterations (100 in this work) to find switching angle set. After the first iteration, FVs are used to determine the new offspring. These go through crossover and mutation operations and a new population is created which goes through the same cycle starting from FV evaluation. The flow chart for calculation of switching angles is shown in Figure 3.

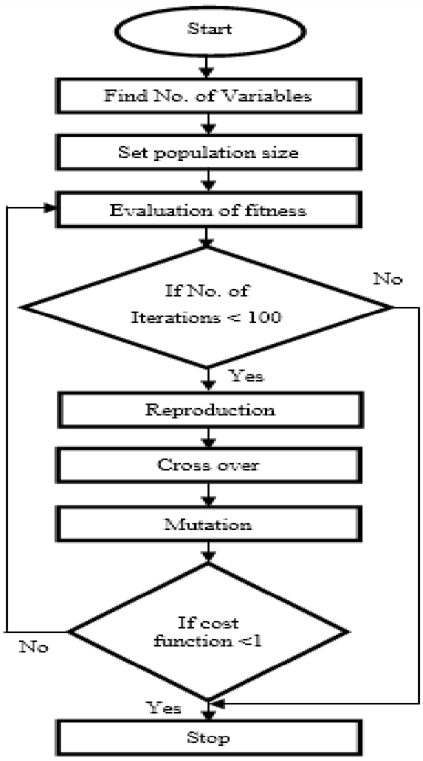


Figure 3. Flow chart for calculation of switching angles

MATLAB coding is developed for the application of GA for voltage harmonic reduction in the AC chopper. The parameters of GA such as crossover and mutation probability, population size and number of generations are usually selected as common values given in the literature, or by means of a trial and error process to achieve the best solution set. It is observed that a value of 20–30 is ideal for population size; a lesser value increases the number of iterations. On the other hand, a large number for population size does not decrease the number of iterations significantly. The number of iterations is first fixed at 100, and increased to 1000 in steps of 100. In most of the operating points, an optimum solution is obtained around 100–400 iterations. Hence, the number of generations is fixed at 500. The probability of crossover is first taken as 0.9 and then changed to 0.8, 0.7, 0.6 and 0.5. It is observed that the best solution for a given termination criterion emerged for 0.8. The probability of mutation is first fixed at 0.1. An increased value yields poor results; as this value is decreased, results get improved until it reaches 0.06. The parameters thus selected for the implementation of GA are given in Table 1. Switching angles calculated by GA for different voltages are plotted in Figure 4.

Table 1. Parameters of GA

S.No.	Parameters	Values
1.	Population size	30
2.	Coding	Binary
3.	Number of generations	500
4.	Selection scheme	Combination of Roulette wheel selection with elitism
5.	Crossover operator	Multipoint crossover
6.	Crossover probability	0.8
7.	Mutation probability	0.06
8.	Termination criterion	500 iterations

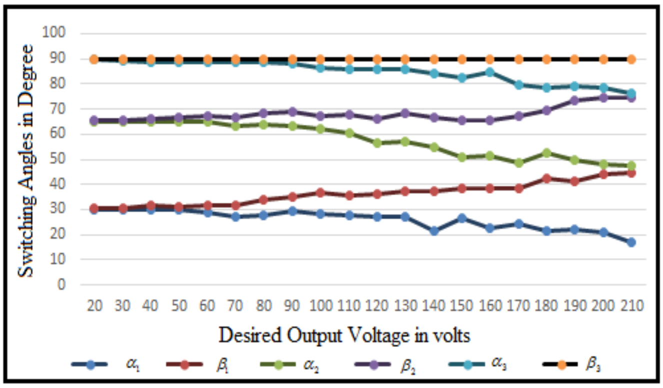


Figure 4. Switching Angles for Desired Output Voltages

4. Simulation Results and Discussion

Simulation of AC chopper fed induction motor were performed using MATLAB/Simulink software and is shown in Figure 5. In the simulation study, all the switches are considered to be ideal. The frequency of output voltage is 50 Hz. In this paper, fundamental frequency switching scheme is used. In this method, the switching angles can be obtained to eliminate some selected harmonics and in turn minimization of total harmonics distortion.

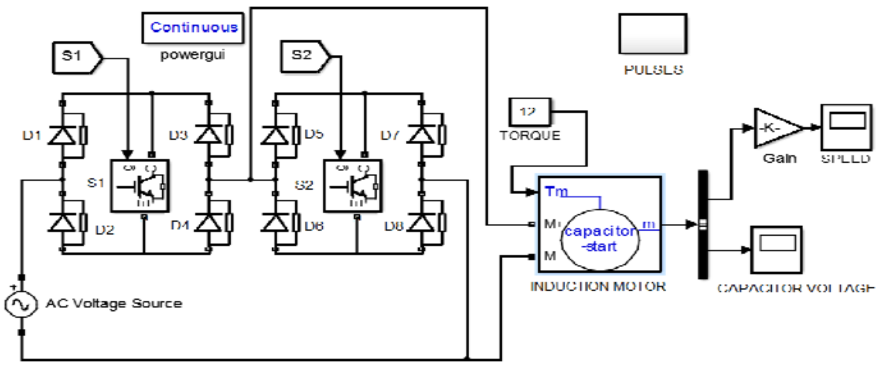
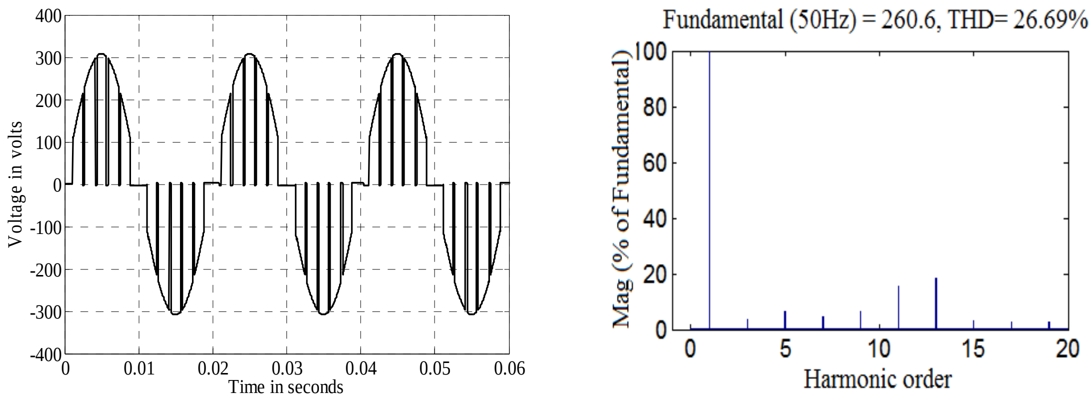


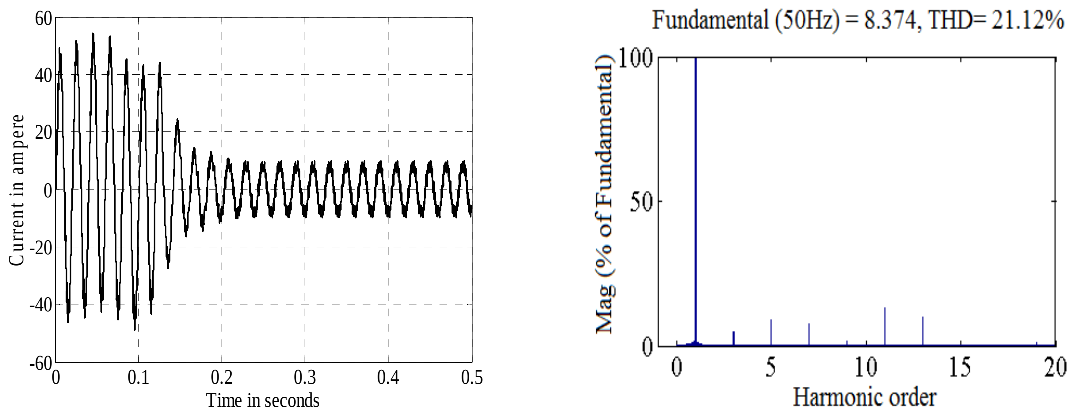
Figure 5. Simulation Diagram of AC Chopper fed Induction Motor

Simulation is carried out using the switching angle shown in Figure 4. The spectrum of the output voltage and current is taken to determine the Total Harmonic Distortion (THD) of AC chopper fed induction motor drive. The simulation results of output voltage, current and their FFT spectrum are presented in the Figure 6 and Figure 7.



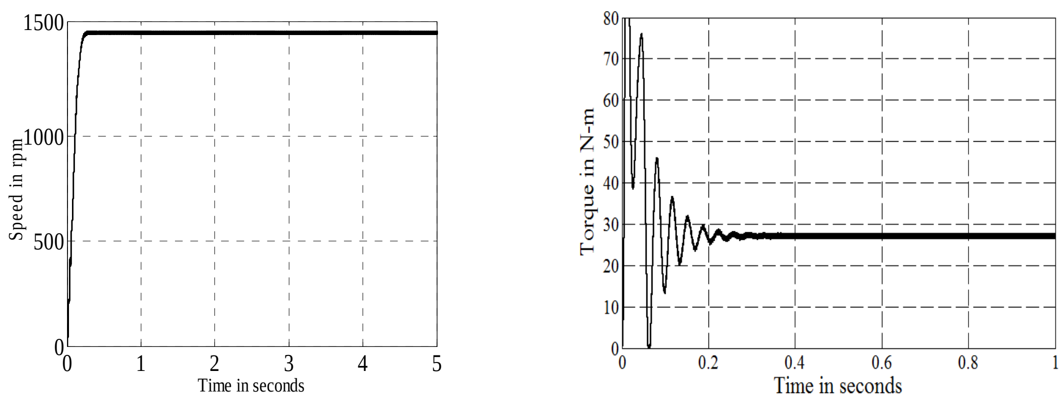
(a) (b)

Figure 6. (a) Output Voltage Waveform; (b) FFT spectrum



(a) (b)

Figure 7. (a) Output Current Waveform; (b) FFT spectrum



(a) (b)

Figure 8. (a) Rotor Speed (b) Electromagnetic Torque

From the Figure 6 and Figure 7, it is observed that the output current waveform is smoother than the output voltage. Current fluctuate up to 0.2 sec and after that they attain a constant value. From the normalized FFT analysis shown in Figure 6(b) and Figure 7(b), it can be seen that the magnitude of lower order harmonics are very low. Rotor Speed curve, electromagnetic toque and capacitor voltage of single phase induction motor is shown in Figure 8 and Figure 9.

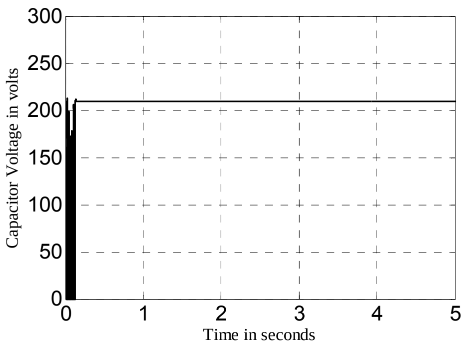


Figure 9. Capacitor Voltage Waveform

The fluctuations in the stator current die out at about 0.2 sec and the currents attain a fairly constant value to reach their full speed of 1430 rpm. Torque has an oscillating characteristic at the starting instant. A nearly constant electromagnetic torque is obtained after a time of 0.3 sec.

5. Comparative Study

In order to indicate the usefulness and effectiveness of the proposed technique, a quality factor has to be chosen. Concerning to voltage and current harmonics amplitudes, the parameters used in the comparative analysis are harmonic factor of n^{th} harmonic (HF_n), total harmonic distortion (THD), distortion factor (DF), WTHD and lowest order harmonics (LOH). Performance parameters for AC chopper obtained from the calculation and simulation is given in Table 2.

Table 2. Performance parameters of AC Chopper

Parameters	Calculated	Simulated
THD (%)	26.2	26.69
V1(Volts)	261.1	260.6
WTHD (%)	2.97	2.92
DF (%)	0.42	0.40
HF3	0.0199	0.0198
HF5	0.0602	0.0595
HF7	0.0713	0.0707
HF9	0.0189	0.0184
HF11	0.191	0.188
HF13	0.1701	0.166
HF15	0.0062	0.0060
HF17	0.0043	0.0041
HF19	0.0277	0.0274
LOH	5th	5th

Table 3 shows the comparison of conventional Newton-Raphson method with proposed GA method. From the Table 3, it can be concluded that the optimization problem works with GA will be efficient, and its performance is superior compared to NR method.

Table 3. Comparison of Conventional Newton-Raphson Method with Proposed GA Method

Harmonic Order	Newton-Raphson Method	Proposed GA Method
HF3	0.15	0.0198
HF5	0.193	0.0595
HF7	0.67	0.0707
HF9	0.71	0.0184
THD (%)	35.81%	26.69%

6. Conclusion

Genetic algorithm based AC chopper is developed in which lower order harmonics are eliminated by proper selection of switching angles. It is observed that the genetic algorithm works efficiently for required output voltage without lower order harmonics. A comparison is also presented between Genetic algorithm and Newton-Raphson iterative Method. Output voltage THD obtained by GA method is 26.69%. It is observed that the GA method is superior to the Newton-Raphson iterative Method on several counts. Although the method is applied to the AC chopper is general in nature and can be easily extended for any number of harmonic elimination.

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