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SWITCHING ANGLE OPTIMIZATION BASED GENETIC ALGORITHMS FOR HARMONIC REDUCTION IN THREE-PHASE PWM STRATEGY

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ABSTRACT :- In variable speed drive (VSD), it is desirable to reduce the harmonic effects, which causes current distortion and torque pulsation, besides, the harmonic power losses is an additional power losses that is introduced in the motor due to the presence of harmonic voltages.

However, the problem of the high total harmonic current distortion (THD) still exists specially at low and medium speeds by using sub-optimal pulse width modulation (PWM) strategy. In the past to generate optimized PWM, is done by defining a general PWM in terms of a set of switching angles. Which result in a set of nonlinear equations in terms of the unknown switching angles. These equations are nonlinear as well as transcendental in nature. There is no efficient method that can be applied to solve such equations. The practical method of solving these equations is a trial and error process. Taking all the factors into account, a numerical technique can be applied to solve these set of nonlinear equations, but with some limitations.

To overcome these limitations, Genetic algorithms (GAs) serves to search for optimal switching angles setting. In addition, the (THD) will be reduced, this lead to obtain the optimal PWM waveform and to simplify the practical implementation, and then improving the performance of the system output.

GAs were employed as a search and optimization engine. Normally the tuning of the switching angles is a trail and error problem.

In this paper, GAs provides a much simpler approach to off-line tuning of PWM switching angles than the rather complicated non-genetic optimization algorithms.

Keywords:- Optimization, Genetic algorithm, PWM.

1-INTRODUCTION

PWM inverters have been used for many years not only for controlling the amplitude of the output voltage but also for affecting its harmonic. And several techniques of modulation have been proposed for this purpose. Sinusoidal voltage are obviously desirable in PWM inverter drives also, there are many techniques have been developed employing non-sinusoidal voltage to further reduce the harmonics in the inverter output [1-3]. In the case of six-step inverter, the full load loss is about 20 percent [4]. But, when the motor is controlled by employing PWM techniques, motor loss may be greater or less than that depending on the modulation strategy used.

The sub-optimal PWM technique is presently the most popular and economical method of harmonic minimization and speed control. It is recognized that harmonic elimination and optimized PWM switching strategies can offer significant advantages particularly at low frequency ratios (low PWM pulse numbers), where the total harmonic voltage / current distortion can be minimized, with minimized switching losses. Hence, the sub-optimal PWM switching strategy achieves this requirement using a symmetric regular sampling technique with a non-sinusoidal modulating waveform.

In this paper, a simple but powerful design method based on real-coded GAs to solve the minimization of the THD criterion is presented. GAs provides a much simpler approach to off-line tuning of such parameters (PWM switching angles), than the rather complicated monogenetic optimization algorithms [5,6].

2- THEORETICAL BACKGROUND

It was considered more appropriate to use the well established asymmetric regular sampling process and attempt to determine the form of the modulating wave (which is always non-sinusoidal in sub-optimal strategy) needed to produce the optimized PWM waveform [1]. Also by using asymmetric regular sampling, a linear relationship between the modulation depth and the fundamental of the optimized PWM waveform would emerge these ensuring a simple method based software calculation for obtaining the fundamental voltage

$$V_1 = aM + b \quad \ldots\ldots (1)$$

Where a and b are constants, and M is the modulation depth.

The third harmonic is the largest harmonic component that presents in the output of voltage controlled inverters, which is eliminated with its triple harmonics in the output of three-phase inverters. The modulating function G(t) can therefore be approximated by the approximate equation (2).

$$G(t) = M\left[\sin(w_m t + R\sin(3W_m t))\right] \quad \ldots\ldots (2)$$

Where R is the amplitude ratio (third harmonic / fundamental), and M is the modulation depth (Amplitude of modulating signal (Pm)/ Amplitude of the carrier signal(Pc)).

The more general form of the switching angle a_k can be defined as:-

$$a_k = T_k + (-1)^{k+1}\frac{T_c}{4}G(T_k) \quad \ldots\ldots (3)$$

Where $T_c = 2\pi / Fr$ and $T_k = k(T_c/2) = k\pi / Fr$, for k = {1,2,3,….} and Fr represents the frequency ratio of the sub-optimal PWM strategy. Since the PWM function f(t) is periodic it can be decomposed into a Fourier series [1]. It is clear that the computations of Fourier coefficient (an) for odd n is simplified and can be expressed such that:-

$$a_n = \frac{4}{n\pi}\left[1 + 2\sum_k^N (-1)^k \cos(na_k)\right] \quad \ldots\ldots (4)$$

Where N is the number of switches per quarter cycle.

Substituting equation (2) in to equation (3), the sub-optimal switching angles can now be defined as:-

$$a_k = T_k + (-1)^{k+1}\frac{T_c}{4}M\left[\sin(T_k) + R\sin(3T_k)\right] \quad \ldots\ldots (5)$$

It was found that [1], the ratio equivalently the amplitude of the third harmonic held constant about four over the complete range of fundamental voltage and all frequency ratios, assuming R=1/4.

If we let.

$$x = +(-1)^{k+1}\frac{T_c}{4}M$$

$$\beta = T_k + x\sin(T_k)$$

$$\gamma = \frac{x}{4}\sin(3T_k)$$

For the fundamental component, equation (4) can be simplified to:-

$$A_1 = \frac{4}{\pi}\left[1 + 2\sum_k^N (-1)^k \cos(\beta + \gamma)\right] \quad \ldots\ldots (6)$$

It is possible to further simplify the term cos(β+γ) of equation (6) to the form;

$$V_1 = \frac{4M}{F_R}\left[\sum_{k=1}^{N}\sin^2(\frac{k_\pi}{F_R}) + \sum_{k=1}^{N}\sin(\frac{K_\pi}{F_R})\sin(\frac{3k_\pi}{F_R})\right] + \frac{4}{\pi}\left[1 + 2\sum_{K=1}^{N}(-1)^K\cos(\frac{K_\pi}{F_R})\right] \ldots\ldots (7)$$

Equation (7) now can be written in its simplified linear form mentioned before in equation (1) [3]. From eq. (7) it is clear that N is independent on M. The error ε introduced by simplifying equation (6) and using the approximated equation (7) can be evaluated using the expression [2]:

$$\varepsilon = \left|\frac{A_r - A_a}{A_r}\right| \times 100\%$$

Where A_r and A_a are amplitude of the fundamental component calculated using equations (6 and 7) respectively.

Equation (7) can be used to accurately vary the amplitude of the fundamental in a linear manner with equation (3) replaced by equation (5) in the CAD program, the amplitude of the third harmonic can be determined for each frequency ratio and voltage level with the constraint of minimized the THD

$$THD = \frac{\sqrt{\sum_{n=5}^{\infty} I_n^2}}{I_1} \ldots\ldots (8)$$

With (n) equal to only odd integer values excluding triples. It has also been usual to assume that harmonic current (In) is only determined by the leakage inductance L, thus:-

$$I_n = \frac{A_n}{n w_m L}$$

Equation (8) represents the performance criteria or objective function used in the minimization algorithm.

3- SWITCHING OPTIMIZATION BASED GAs

GAs are exploratory search and optimization procedures that were devised on the principles of natural evolution and population genetics [(7)]. The following are several differences between the functioning of GAs and traditional optimization techniques:

1. GAs searches a space using a "population" of trails, representing possible solutions to the problem. The initial population usually consists of randomly generated individuals.
2. GAs uses an objective function assessment, to guide the search of the problem.
3. GAs use probabilistic transition rules to make decisions, but not deterministic rules. The transition rules of GAs are stochastic many other methods having deterministic

transition rules. A distinction exists, however, between the randomized operators of GAs.

It is desired to find genetically the optimal parameters (three-phase PWM switching angles, as), so that to minimize the THD criterion. Such a case, the number of switching in quarter cycle (N) are considered as the genetic parameters (np) to be optimized by using GAs.

Also, the THD calculation which is mentioned before will be used to construct the fitness function (Ff(t)) calculation:

$$F_f(t) = \frac{100}{1 + THD}$$

4- RESULTS AND DISCUSSIONS

This section will discuss the application of the GAs to further minimize the THD of the three-phase PWM inverter switching angles. In addition a comparison is obtained with the three-phase suboptimal PWM strategy [1-3].

The GAs operators used here has the following specification:

The number of parameters (np) are equal to the number of switching angles (N=7), the number of generations (gen), the population size (pop), probability of crossover (Pc) probability of mutation (Pm) with real coded genetic parameters, and using tournament selection method.

GAs searches for optimal values of as, switching angles, so that to minimize the THD. Therefore different cases are used to obtain the optimal results. The GAs operators of the first case are: (gen=50, pop=600, pc=0.75, pm=0.09). The simulation results of this case are illustrated in Fig.1-2, Fig.1 shows the variation of fitness function for each generation. In addition, Fig.2 illustrates the variation of each switching angle for each generation, to obtain the optimal values. Note that, there is a little variation for the angles a2-a5, and there is no variation with a1 and a6-a7, in this case the value of the THD is decreased to 2.5016.

Further reduction in THD is obtain (THD = 2.0366), if we increase the maximum number of population to (pop =1000) for the second case. The simulation results are illustrated in Figs.3-4, in Fig.2 it is clear that there is big variation in a4, but there is a little variation angles a1 and a6-a7, and there is no variation with a5 and a2-a3, in this case the value of the THD is decreased to 2.0366.

A higher reduction in THD is obtained (THD = 1.9419), in addition if we increase the maximum number of generations to (gen = 100) for the third case. The simulation results are illustrated in Fig.5-6, in Fig.6 it is clear that there is big variation in switching angle with different values, except for a5 and a2 which are still have the same values with no variations as in the second case. This means that the change in values for a5 and a2 do not effect the results.

We get this result by using MATLAB programs language with follow chart description in Appendix.

5- CONCLUSIONS

The aim of the work described in this paper is to improve the performance of the PWM inverter. This improvement is achieved by minimizing the harmonic distortion of the PWM output wave form. The sub-optimal PWM technique is presently the most popular method of harmonic minimization and speed control. In this paper, a simple but powerful method based on real-coded GAs to solve the minimization of the THD criterion is obtained. GAs provides a much simpler approach to off-line tuning of such parameters (PWM switching angles), than the rather complicated monogenetic optimization algorithms. GAs are exploratory search and optimization procedures that were devised on the principles of natural evolution and population genetics.

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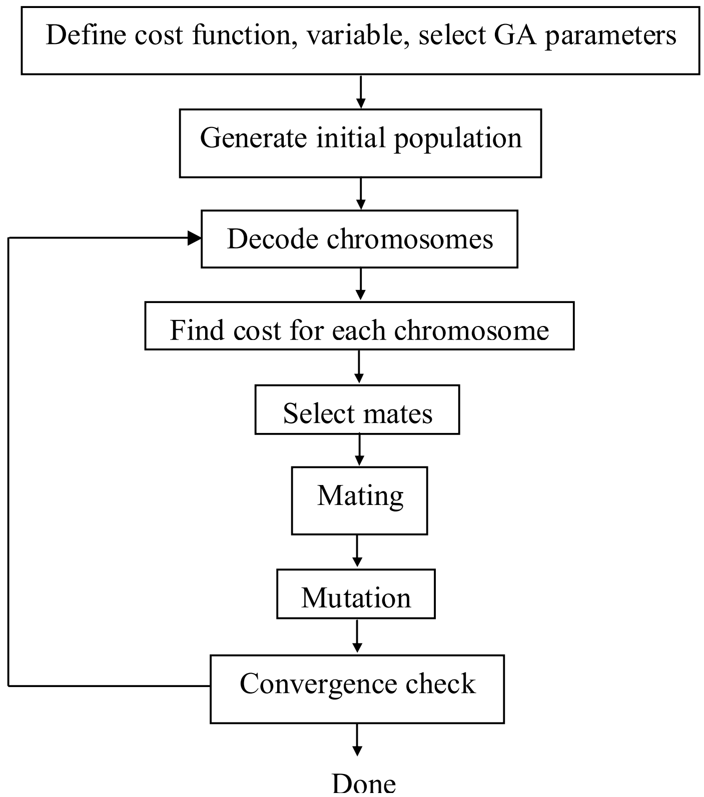
LIST OF ABREVATIONS AND SYMBOLS

Ac	Amplitude of the carrier signal
Am	Amplitude of the modulating signal
VSD	Variable speed drive
Fr	Frequency ratio for suboptimal PWM strategy. Fr=ωc/ωm.
GAs	Genetic Algorithms.
G(t)	Suboptimal modulating function.
In	rms harmonic current
i,k,n	Integers.
M	Modulation depth = Am/Ac.
R	Amplitude ratio,3rd harmonic/fundamental.
Tc	Time period of carrier signal =2 π /Fr.
Tm	Time period of modulating signal.
T_k	Sampling instants =K Tc / 2.
a_k	Switching angles.
w_c	Angular frequency of carrier signal.
w_m	Angular frequency of modulating signal = 2πfm.
gen	Number of generations.
pop	Population size.
PWM	Pulse width Modulation.
Pc	Probability of crossover.
Pm	Probability of mutation.
THD	Total harmonic current distortion.

APPENDIX



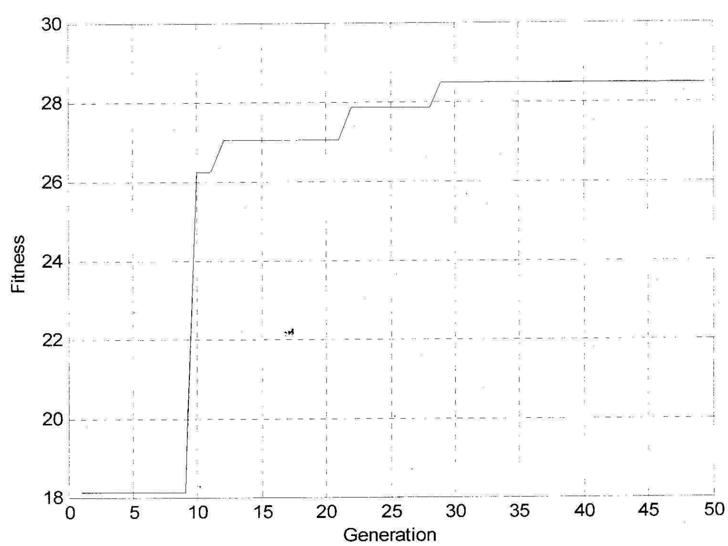


Fig. (1): Fitness variation for each Generation, for case 1.

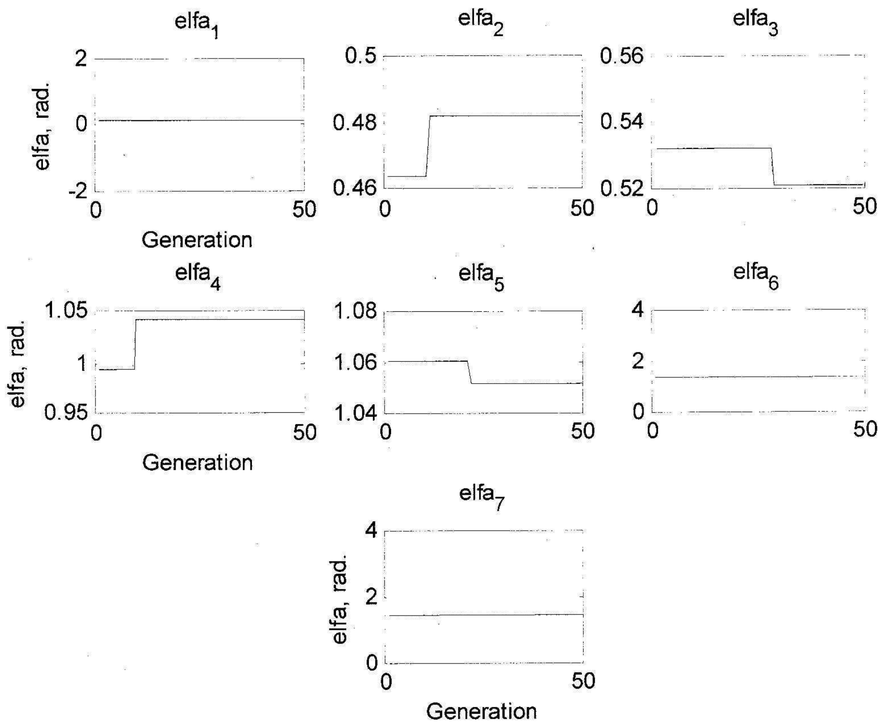


Fig. (2): α 's variation for each Generation, for case 1.

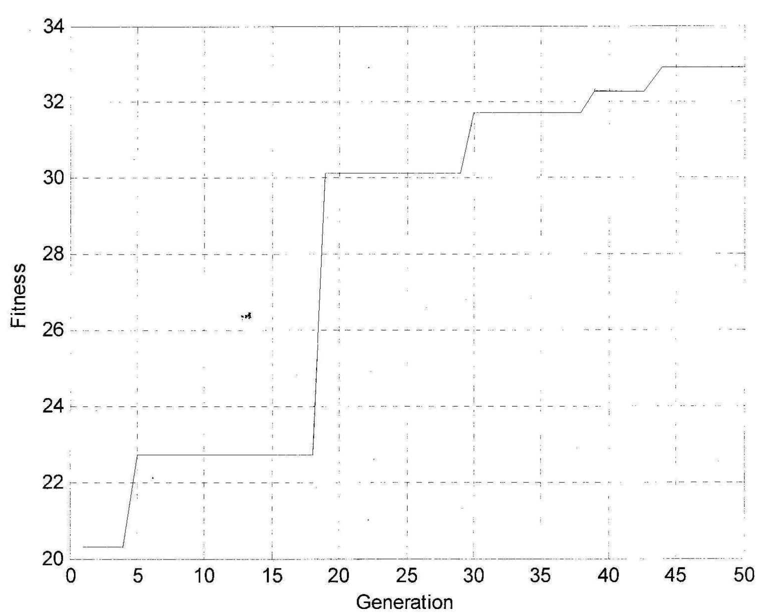


Fig. (3). Fitness variation for each Generation, for case 2.

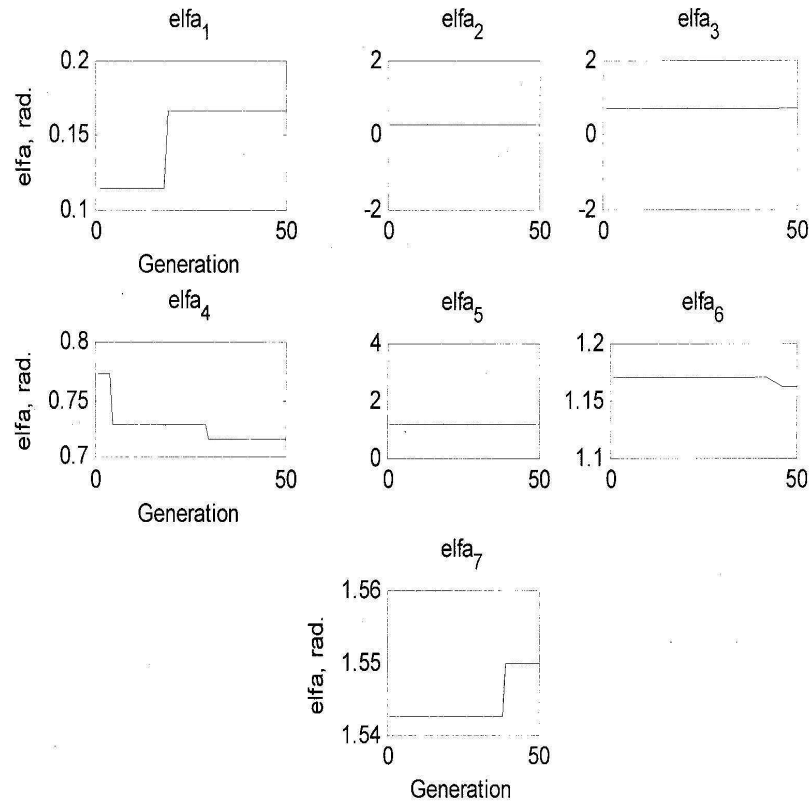


Fig. (4): α 's variation for each Generation, for case 2.

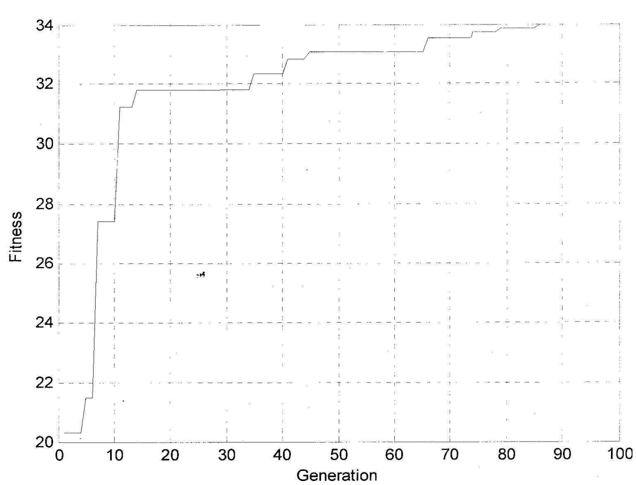


Fig. (5). Fitness variation for each Generation, for case 3.

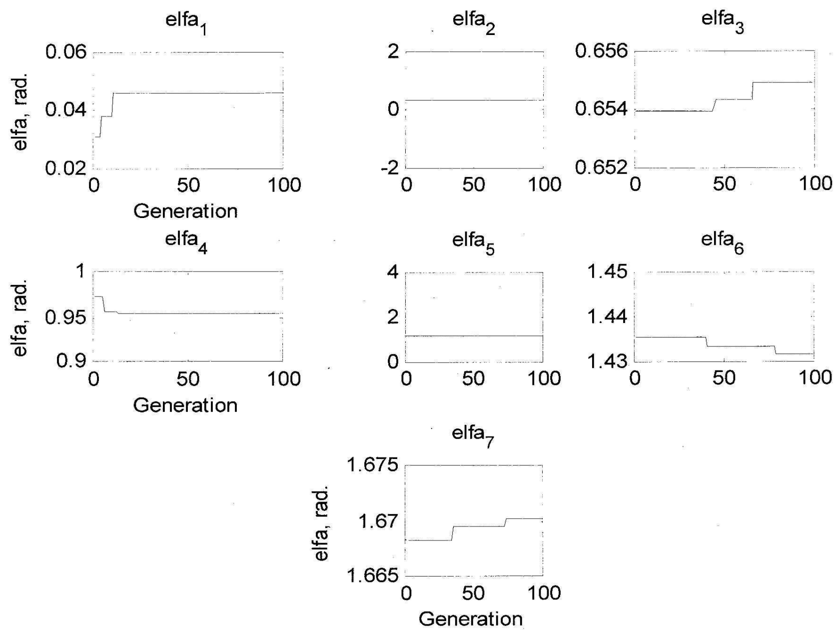


Fig. (6). α 's variation for each Generation, for case 3.

إيجاد أفضل زوايا قطع استنادا إلى الخوارزمية الوراثية لتقليل التوافق بأسلوب تضمين عرض النبضة ثلاثية الأطوار

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الخلاصة

في تصمم مختلف محركات السرعة من المرغوب فيه لتقليل التأثيرات التوافقية والمتسببة من تشوهات التيار ونبضات العزم بجانب خسائر القدرة التوافقية والمتأتية من خسائر القدرة في المحرك نتيجة وجودها في الفولتية التوافقية.

المشكلة في تشوهات التيار التوافقية الكلية وخاصة التي تبقى موجودة في السرعات القليلة والمتوسطة باستخدام PWM الإستراتيجية الشبه مثالية.

في الماضي لتوليد PWM المثالي العام بدلالة مجموعة من قواطع الزوايا , والتي تعطينا مجموعة من المعادلات اللاخطية والمعرفة من خلال قواطع الزوايا وهذه المعادلات اللاخطية توجد طرق لتطبيقها في حل تلك المعادلات اللاخطية الطريقة العملية لحل مثل هكذا معادلات تسامية هي عملية المحاولة والخطأ وبأخذ جميع العوامل في الحسبان، تقنية التحليل العدي يمكن تطبيقها لحل هذه المجموعة من المعادلات اللاخطية ولكن مع بعض التحديدات.

وللتغلب على هذه المحدودبات GAs يؤدي الى البحث عن وضع قواطع الزوايا المثلى. بالإضافة الى ان THD سوف يقل وهذا يكون على شكل PWM المثلى وسهولة تنفيذ عملية وكذلك تحسين اداء خرج النظام .

استخدام GAs لبحث امثل محرك طبيعية لتوليف قواطع الزوايا هي مشكلة عمليات المحاولة وإيجاد الخطأ.

في هذا البحث ان GAs يؤدي لحصول تقريب ابسط لتوليف قواطع الزوايا أفضل من الطرق التي لا تستخدم GAs .

الكلمات الدالة: أفضل, الخوارزمية الوراثية, تضمين عرض النبضة.