FINDING OF THE OPTIMUM TRIGGERING ANGLES FOR THE HARMONIC ELIMINATION IN AC-AC CONVERTERS BY THE HELP OF EVOLUTIONARY ALGORITHMS

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ABSTRACT

The signals which are obtained from AC-AC converters are not purely sinusoidal and they contain unwanted harmonics. In this study, finding optimum triggering angle locates in optimum numbers are purposed by using a Matlab program that is written in the sense of Evolutionary Algorithms(EA) which is an optimization method that is based on the random research technique, in order to suppress undesired harmonics that occur on not purely sinusoidal signal that is optained from AC-AC converter. The optimum triggering angles are the values that make the amplitude of the first(fundamental) harmonic biggest and the amplitudes of the harmonics to be suppressed smallest. By using a wave shape which has half-wave and quarter-wave symmetry, necessary mathematical bases are created and the problem is applied to the EA. The fitness function is defined and the operation of the program is decribed step by step. The harmonic concept is introduced together with its negative effects and the total harmonic distortion is introduced.The results of the problems solved by the prepared program are compared with some of the previous results found by Newton Raphson Method(NRM).The results are also compared with each other for different inputs and presented in tabular and graphical forms by which the success of the procedure is outlined.

1. INTRODUCTION

AC-AC Converter switches the alternative voltage having a constant amplitude and frequency at its input and it produces another alternative voltage at the desired amplitude and frequency at its output. But the harmonics and the associated losses occur in the output voltage obtained by switching. These harmonics cause noise, vibrations, torque oscillations, temperature increase, isolation errors and power losses in nonlinear loads such as alternating current machines. Therefore, it is required to suppress the undesired harmonics to achive good quality outputs. By using the EA, the triggering angles of the switches in AC-AC converters are computed in this work as to maximize the fundamental harmonic and minimize the undesired harmonics. EA are a recently developed systematics population that based on the random research technique which can be used to find global optimum in the solution regions that have complex and a number of local optimums. These algorithms start the solution with a randomly produced population and try to process through a better solutions by applying crossover, mutation and choice operations. The shematic diagram of the EA for the global optimization is shown in Figure 1. But, in the problems with complex and numerous local optimums, at first it may be impossible to reach global optimum by the randomly produced population. Especially, as the dimension of the problems increases, it takes more time to find the global solution[1-2]. In order to avoid these problems, the masked crossover method is developed and the linear scaling of the fitness function is used in this work.

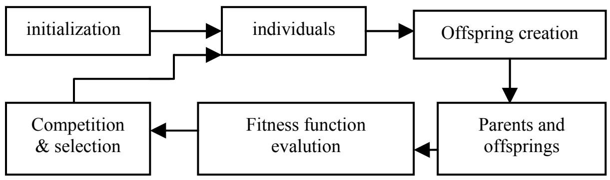

Figure 1. Flow chart of the EA for Global Optimization

The scaling of the fitness is illustrated in Fig.2 and it is defined by

$$SF=\tan(a).(U-U_{ave})+U_{ave}$$

$$\tan(a)=\frac{U_{ave}}{U_{maks}-U_{ave}}$$

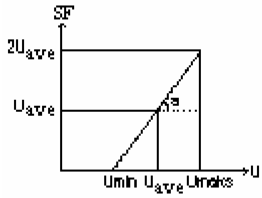

Figure 2. Linear Scaling of Fitness

where SF_{sum} is total of the linear scaled fitness that is mentioned in the generation. Suppose that SF_i is scaled fitness for the variables on the mentioned a raw. According to this, the probability of the choice of the variables in the i-th raw is SF_i / SF_{sum}. The number of copies of the i-th raw is computed as population numbers · SF_i / SF_{sum} [3].

2.CONCEPT OF HARMONIC

The harmonics are defined as the sinusoidal components that has the frequency at the multiples of fundamental frequency, sideways, the fundamental sinusoidal component. When the fundamental frequency is 50 Hz, the component at the frequency 3·50=150 Hz is called the third harmonic. The nonlinear power components which have increased more and more in recent years cause nonsinusoidal variations in power systems. This implies the existance of the harmonics in power systems. Occurance of harmonics are not a desirable state and it is inevitable if the necessary precautions are not taken.

2.1.Total Harmonic Distortion(THD)

Total Harmonic Distortion defined for a periodic voltage or current is a relative representation of all harmonics with respect to the fundamental component. THD on which any wave shape that is for away from its sinus form expresses the harmonic rate as percent on the current or voltage.It is expressed by

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{N} T_n^2}}{T_1}$$

where T_1 is the current or voltage of fundamental component as root mean square(rms), T_n is harmonic voltage or current of n-th harmonic, N is the degree of the highest harmonic[4]. Note that for a pure sinusoid THD is equal to zero.

3.HARMONIC ELIMINATION AND COMPUTATION OF TRIGGERING ANGLES

The following method eliminates the undesired harmonics in the AC-AC converter output and controls the amplitude of the fundamental harmonic. For an AC-AC converter having half wave and quarter wave symmetries, the chopped output wave f(θ) obtained from the original input sinθ is shown in Fig.3 where $\theta=w_0t$, $w_0(t)$ is the fundamental frequency(time).

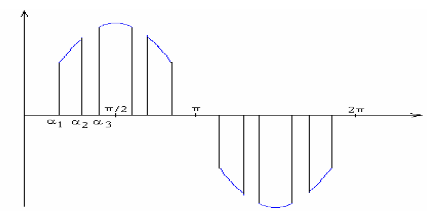

Figure 3. General Form of the Output Voltage

If this signal is expanded to Fourier Series, it is shown to be occurred from sinusoidal terms only with odd numbers because of the symetrical of wave shape. The number of harmonics that can be eliminated is one less than the number of the triggering angle values α_i's[5]. The harmonic components of this signal is counted by Fourier Analysis.

$$f(\theta) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left[(a_n \mathrm{Cos} n\theta) + (b_n \mathrm{Sin} n\theta)\right]$$

$$a_0 = \frac{2}{T}\int_0^T V_0(\theta)d\theta \quad a_n = \frac{2}{T}\int_0^T V_0(\theta)Cosn\theta d\theta \quad b_n = \frac{2}{T}\int_0^T V_0(\theta)Sinn\theta d\theta$$

$$b_n = \frac{4}{\pi}\left[\int_{\alpha_1}^{\alpha_2} Sin\theta \cdot Sinn\theta d\theta + \int_{\alpha_3}^{\alpha_4} Sin\theta \cdot Sinn\theta d\theta + ... \int_{\alpha_4}^{\pi/2} Sin\theta \cdot Sinn\theta d\theta\right]$$

$$b_1 = \frac{2}{\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_{\alpha_1,\alpha_3,\alpha_5.....}^{\alpha_2,\alpha_4,\alpha_6.....} \quad b_3 = \frac{2}{\pi}\left[\frac{\sin 2\theta}{2} - \frac{\sin 4\theta}{4}\right]_{\alpha_1,\alpha_3,\alpha_5.....}^{\alpha_2,\alpha_4,\alpha_6.....}$$

$$b_5 = \frac{2}{\pi}\left[\frac{\sin 4\theta}{4} - \frac{\sin 6\theta}{6}\right]_{\alpha_1,\alpha_3,\alpha_5.....}^{\alpha_2,\alpha_4,\alpha_6.....}$$

$$b_n = \frac{2}{\pi}\left[\frac{\sin(n-1)\theta}{(n-1)} - \frac{\sin(n+1)\theta}{(n+1)}\right]_{\alpha_1,\alpha_3,\alpha_5.....}^{\alpha_2,\alpha_4,\alpha_6.....}$$

$a_n=0$ because of quarter wave symmetry.Wave shape is symmetric around π/2.The aim of the harmonic elimination in AC-AC converters is to find the triggering angles α_1,α_2… as to maximize the fundamental harmonic b_1 and to suppress the undesired harmonics.This is a multi-variable optimization problem with multi-constraints.For the solution of this problem the MATLAB program based on the EA will be used as described in the following section.

4.COMPUTATION OF THE OPTIMUM TRIGGERING ANGLES BY EVOLUTIONARY ALGORITHMS

The prepared MATLAB program uses the fitness funtion=the absolute amplitude of the first harmonic – the summation of the absolute amplitudes of the harmonics to be suppressed + a constant that prevents the fitness function to get negative values. It operates as follows:

-As the input variables choose the number of harmonics to be eliminated, the population number, the maximum generation number, the information wheather the third and multiples of the third harmonics will be eliminated, how many more(extra) triggering angles will be taken than the number of harmonics to be eliminated, the harmonic weights to be suppressed starting from the third harmonic, how many harmonics to be seen(both numerically and graphically) at the end of optimization.

-For initial population, randomly generate different angles between 0^0 and 90^0 as much as(the number of harmonics to be eliminated+the number of extra triggering angles). The harmonics are computed as setting these random angle values which are generated different for every population b_n in general equation. The fitness and fitness average are computed. Then, scaled fitness and associated number of copies are computed.

-According to the computed number of copies, the best angles are converted to binary numbers. Owing to a certain rule(the crossing between 1-10, 2-9, 3-8, 4-7, 5-6 if the population number is 10), the angle values in the initial population are crossed. Mask crossover method is used in this work. According to this method, a random number is generated(between 0 and 90 for this problem). This number is converted into the binary base. The bits of the numbers to be crossovered corresponding to the digits where 1's appear in the binary based converted masked number are interchanged. Crossing operations are applied to the main parts and decimal parts seperately, and then these parts are recombined after the crossing operation.

-If the generation number is smaller than the number of maximum generations, the generation number is increased by one, the new angle values computed after crossing operation are converted from binary to decimal form. The new harmonics and new fitness are computed according to these new angle values.If the angles obtained after crossover operation are greater than 90, random values between 0 and 90 are generated and used instead of these values.(All the numbers between 0 and 90 can be expressed in 7 binary bits;90_2=1011010. If any one of the 0-bits becomes 1, the number will be greater than 90).

-The new fitness of the populations computed by the crossover operations individually compared with the fitness computed previously, the angles of the populations with the highest fitness are choosen. The fitness average of these populations is computed. If this fitness average is smaller or equal to the previous fitness average, (if no success is gained at the end of the crossing operation) mutation operation is started. The angles that are found at last are converted into binary number. A random bit of these binary angles is subjected to mutation and the new angles are obtained the new fitness are computed.If the new fitness are grater than the previous ones, the population angles of each grater fitness are choosen.

-If the generation number is grater than maximum number of generations, the angles of which fitness is the greatest in all of the generation are choosen. According to these best angles,(how many harmonics are wanted to be seen) those are computed and amplitude spectrum is drawn[6]. It is also possible to assign weights to the harmonics to be suppressed in the program.By the proper choice of these weights, each harmonic can be suppressed or can be kept at a certain level as much as desired.

4.1 Effects of Weights Given to the Suppressed Harmonics in Elimination

By giving 1 to all harmonics weights starting 3rd harmonic with 20 population, the triggering angles in which 3rd, 5th, 7th, 9th, 11th harmonics are eliminated in 20 generation are found as following.

1.0021 8.8000 19.9920 31.2598 32.9988 89.8820

Table 1. Values of Harmonics and THD computed without Weighting

1.har.	3.har.	5.har.	7.har.	9.har.	11.har.
0.9704	-0.0611	-0.0670	-0.0380	-0.0209	-0.0068
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
-0.0058	0.0174	0.0373	0.0530		0.1249

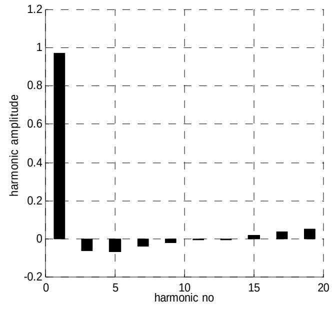

Figure 4. Amplitudes of the Harmonics Computed without Weighting

By giving 1, 0.8, 0.6, 0.3, 0.2 to the harmonics weights starting 3rd harmonic, the triggering angles 3rd, 5th, 7th, 9th, 11th harmonics are eliminated in 20 generation are found as following.

0.7288 2.6563 5.6563 28.4688 29.1882 89.9988

Table 2. Values of Harmonics and THD computed with Weights

1.har.	3.har.	5.har.	7.har.	9.har.	11.har.
0.9959	-0.0088	-0.0063	0.0005	0.0045	0.0017
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
-0.0060	-0.0116	-0.0104	-0.0036		0.0209

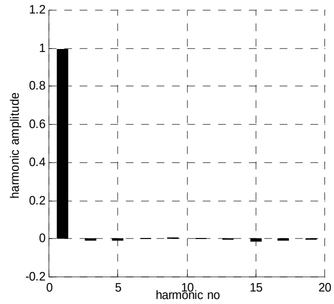

Figure 5. Amplitudes of the Harmonics computed with Weights

Comparison of the above results reveal that the third harmonic is reduced from 0.0611 to 0.0088 and the fifth one is reduced from 0.0670 to 0.0063.Further, the amplitude of the first harmonic is increased from 0.9704 to 0.9959 and the THD is decreased from 0.1249 to 0.0209.Since the harmonic distortion is smaller the losses due to the associated losses will be smaller.

4.2 Harmonic Elimination According to The Number of Triggering Angles

With 30 population, all harmonic weights starting with 3rd harmonic are given 1. Totaly 7 harmonics including the third and multiples of the third harmonics, 8 angles are taken and the triggering angles which are eliminated in 30 generation are found as following:7.1563 16.8563 20.9988 31.9620 32.7188 75.9988 77.9620 89.9929

Table 3. Values of Harmonics and THD Computed with One more Angle

1.har.	3.har.	5.har.	7.har.	9.har.	11.har.
0.9431	-0.0032	-0.0544	-0.0211	0.0164	-0.0264
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
0.0518	-0.0288	0.0410	-0.0162		0.1052

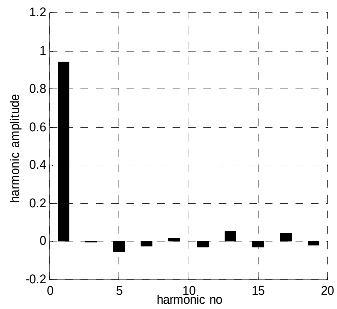

Figure 6. Harmonic Elimination By Taking One More Angle

The values are entered same as before and by taking two more angles (9) than harmonic number that are eliminated, the triggering angles are found as following:1.2988 8.4688 17.4688 19.9688 ***31.9688 31.9688*** 76.4688 77.9688 89.7188. The results are shown in Table 4 and Figure 7.

Table 4. Values of Harmonics and THD Computed with One 2 Angles

1.har.	3.har.	5.har.	7.har.	9.har.	11.har.
-0.9550	-0.0129	0.0447	0.0154	0.0062	0.0224
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
-0.0290	0.0202	-0.0195	0.0177		0.0732

EA have done a successful elimination with different triggering angles as seen in the practice that is done by taking two more triggering angles than harmonic number which is eliminated. Moreover, although the number of triggering angles is increased from 8 to 9, two of solution angles are found same of eachother(31.9688). Hence, the elimination can be equally done with one less angles by disregarding one of the equal angles.This way be number of switchings will be reduced and one extra switching loss will be diminished. Further, the process capasity of the microprocessor for switching will be used efficiently and its speed will not be reduced. Since the EA is capable of doing a successful elimination by considering one more triggering angle than the number of suppressed harmonics, there is no need to increase the number of angles beyond this value and the use of one rather than two extra angle is more advantages due to the less switching lossen.

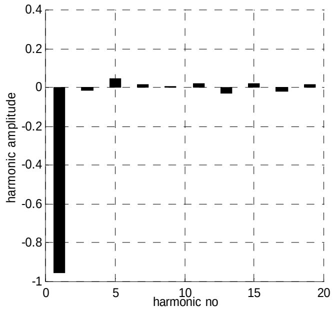

Figure 7. Harmonic Elimination by Taking Two More Angles

4.3 Comparison of EA in Harmonic Elimination and Newton-Raphson Method(NRM)

The results of the Newton-Raphson Method to suppress 3rd, 5th, 7th harmonics with 5 triggering angles are presented in [7] and they are repeated here as follows:23.6306 46.1324 60.8114 82.7109 90

In this reference, the first harmonic is limited to be 0.4 and the last angle is set to 90. The detailed results are given in Table 5 and plotted in Fig.8.

Table 5. Harmonics and THD Computed by Newton-Raphson Method

1.har.	**3.har.**	**5.har.**	**7.har.**	**9.har.**	**11.har.**
-0.4	0	0	0	-0.3420	0.2582
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
-0.0116	-0.0137	-0.0162	0.1003		1.102

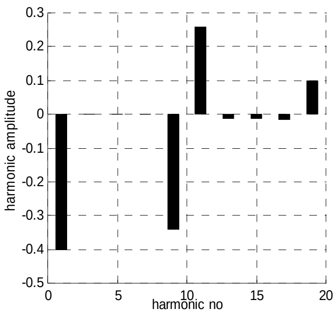

Figure 8. Harmonic Elimination by Newton Raphson Technique

The same problem is solved by the EA with 20 population and 5 triggering angles. The equal weightings are used to eliminate 3 harmonics(together with the third and multiples of the 3rd).With 20 generation the triggering angles are computed

19.7728 38.4856 50.6552 68.8294 80.9303.

Table 6. Values of Harmonics and THD found by EA

1.har.	**3.har.**	**5.har.**	**7.har.**	**9.har.**	**11.har.**
-0.4	0	-0.0004	-0.0004	-0.0015	-0.3330
13.har.	**15.har.**	**17.har.**	**19.har.**		**THD**
0.2693	-0.0087	-0.0097	-0.0097		1.071

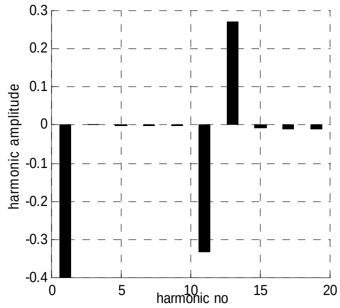

Figure 9. Harmonic Elimination by EA

5. CONCLUSIONS

When complex and high number of local optimums are present in the solution regions, EA based on the random search techniques can be used to find the global optimum. The discussion of the computation of the optimum triggering angles of AC-AC converters by using EA is aimed in this work. A harmonic elimination problem which has been solved previously by using the Newton Raphson Method is solved using EA and it is seen that THD which found by EA is smaller. Apart from this, the initial values must be choosen very conveniently in the NRM; however EA reach the global optimum solution for any initial conditions. An angle is set to 90 in NRM. On the contrary, any of angles are not determined previously in EA. The user can determine the weights with which the choosen harmonics to be suppressed in the prepared program. Although the number of the triggering angles can also be choosen freely, it is shown that the increase of the number of the triggering angles does not supply an important advantage, it causes some disadvantages in contrast. The prepared program for the optimization also give the oppurtunaty to choose wheather to eliminate the third and multiple of the third harmonics. This is important in 3-phase systems of which star point isolated since the third and its multiple harmonics do not appear on the load and do not cause harmonic currents.

REFERENCES

[1]-Yiu-Wing Leung, IEEE and Yuping Wang, An Orthogonal Genetic Algorithm With Quantization for Global Numerical Optimization, IEEE Transactions on Evolutionary Computation, Vol 5,No.1, February 2001

[2]-Cao Y.J., Wu Q.H., Shimmin D.W.,Study Of Initial Population Evolutionary Programming,ECC97 Conferences

[3]-İnce M.C., Fortran Computer Programme for Optimization By Genetic Algorithm, 4th Computer-Communication Symposium, pp.107-110, Bursa, 1996

[4]-Argın M., Kocatepe C., Economic Approach to the Harmonic Filters Project, Eleco 2000, Electric – Elektronic - Computer Engineering Symposium, pp.191-196, Bursa, 2000

[5]-Tatar Y.,Signal Generation For Pulse Width Modulated Inverter to Control Squırrel Cage Induction Motor Based on Digital Signal Processor, Ph.D.Thesis, F.U., Elazığ 1994.

[6]-Gürsu B., Harmonic Elimination With Genetic Algorithms of DC-AC Converters, Masters Thesis, F.U., Elazığ, 2002

[7]-Ayhan F., Harmonic Elimination on Direct AC-AC Converters with one Phase, Masters Thesis, F.U., Elazığ, 2001