

X. Wang. 2005. Clonal Selection Algorithm in power filter optimization. In: Jarno Martikainen (editor). Proceedings of the 2005 IEEE Mid-Summer Workshop on Soft Computing in Industrial Applications (SMCia 2005). Espoo, Finland. 28-30 June 2005, pages 122-127.

© 2005 IEEE

Reprinted with permission.

This material is posted here with permission of the IEEE. Such permission of the IEEE does not in any way imply IEEE endorsement of any of Helsinki University of Technology's products or services. Internal or personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution must be obtained from the IEEE by writing to pubs-permissions@ieee.org.

By choosing to view this document, you agree to all provisions of the copyright laws protecting it.

Clonal Selection Algorithm in Power Filter Optimization

X. Wang

Institute of Intelligent Power Electronics
Helsinki University of Technology
Otakaari 5 A, FIN-02150 Espoo, Finland
Phone: +358 9 451 4965, Fax: +358 9 451 2432, E-mail: xiaolei@cc.hut.fi

Abstract – Inspired by natural immune mechanisms, Artificial Immune Optimization (AIO) methods have been successfully applied to deal with numerous challenging optimization problems with superior performances over classical optimization techniques. Clonal Selection Algorithm (CSA) is one of the most widely employed immune-based approaches for handling those optimization tasks. In this paper, the proposed CSA is used to search for the optimal parameters (values of inductor and capacitor) of a passive filter in the diode full-bridge rectifier. Simulation results demonstrate that the CSA-based approach can acquire the optimal LC parameters with certain given criteria for power filter design.

Keywords: Artificial immune system, optimization, clonal selection algorithm, passive filter, harmonic distortion.

I. INTRODUCTION

Natural immune systems are complex and enormous self-defense systems with the distinguished capabilities of learning, memory, and adaptation [1]. Artificial Immune System (AIS), based on the natural immune systems, can be considered as an emerging kind of biologically inspired computational intelligence methods, which have attracted considerable research interest from different communities over the past decade [2]-[5]. As an important partner of the AIS, the Clonal Selection Algorithm (CSA) methods have been successfully applied to handle challenging optimization problems with superior performances over classical approaches [6] [7]. Modern science and engineering are rich in the problems of optimization. In this paper, we demonstrate the efficiency of the CSA in the optimization design of a power filter in a full-bridge diode rectifier.

II. CLONAL SELECTION ALGORITHM

The AIS is a new kind of computational intelligence methodologies inspired by the natural immune system to solve real-world problems [8]. The CSA is based on the Clonal Selection Principle (CSP), which explains how an immune response is mounted, when a non-self antigenic

pattern is recognized by the B cells [9]. It is an evolutionary process in the natural immune systems, during which only the antibodies that can recognize intruding antigens are selected to proliferate by cloning [10]. More precisely, the fundamental of the CSA is the theory that the cells (antibodies) capable of recognizing non-self cells (antigens) can proliferate. The main ideas of the proposed CSA borrowed from the CSP are [11]:

- maintenance of memory cells functionally disconnected from the repertoire;
- selection and cloning of most stimulated antibodies;
- suppression of non-simulated cells;
- affinity maturation and re-selection of clones with higher affinity;
- mutation rate proportional to cell affinity.

The block diagram of our CSA-based optimization algorithm is shown in Fig. 1, in which the corresponding steps are explained as follows.

1. Initialize the antibody pool (P_{init}) including the subset of memory cells (M).
2. Evaluate the fitness of all the individuals in population P . The fitness here refers to the affinity measure.
3. Select the best candidates (P_r) from population P_{init} according to their fitness (affinity with the antigen).
4. Clone these best antibodies into a temporary pool (C).
5. Generate a mutated antibody pool (C_1). The mutation rate of each individual is inversely proportional to its fitness.
6. Evaluate all the chromosomes in C_1 .
7. Eliminate the antibodies those are similar to ones in C , and update C_1 .

8. Re-select the individuals with better fitness from C_1 to compose the memory set M . Other improved individuals of C_1 can replace some members in P_{init} to maintain the antibody diversity.

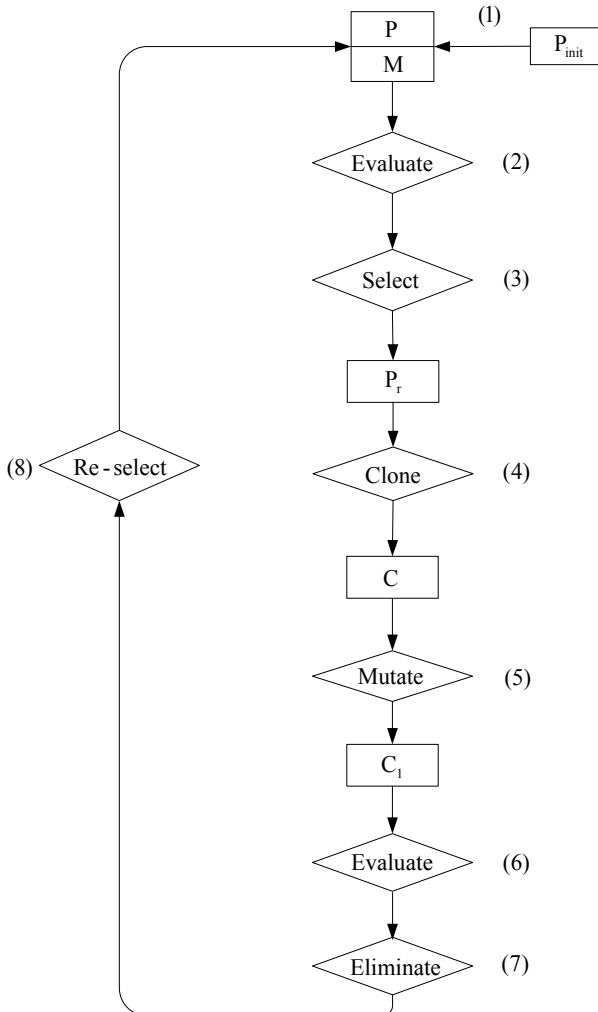


Fig. 1. Block diagram of the clonal selection algorithm.

We should point out that the clone size in Step (4) is generally defined as either a monotonic function of the affinity measure or a constant value [11]. In our algorithm, it is set to be a constant. Obviously, the process of the CSA is very similar to that of the Genetic Algorithm (GA). However, compared with the GA, the convergence speed of the CSA is usually slower. To overcome this drawback, we employ a new mutation operator in Step (5), through which the mutated values of individuals are inversely proportional to their fitness by means of selecting different mutation variations. That is to say, the better fitness the individual has, the less it changes. Another factor affecting convergence speed is the similarity of candidates due to the system expansion manner. The idea of suppression is therefore borrowed from immune network theory to eliminate the new generated antibodies, which are similar to those already in the candidate pool (Step 7). Based

on our rules, the antibody pool tends to more diverse, and the CSA can, thus, avoid being trapped into local minima.

III. SINGLE-PHASE DIODE RECTIFIERS

In modern power electronics, it is advantageous to utilize inexpensive rectifiers with diodes to convert input AC into output DC in an uncontrolled manner. These rectifiers are widely applied in the majority of power electronics applications, such as switching DC power supplies and AC/DC motor drives [12]. A large capacitor as a filter at the DC side is used to charge a value close to the peak of the AC input voltage. However, the deployment of this electrolytic storage capacitor results in a poor Power Factor (PF) as well as highly distorted current of AC side from the utility. Generally, a power filter (active or passive) targets at shaping the input waveforms. It has been proved that by using the active filters, we can improve the PF to be very close to unity with small harmonic currents. However, this approach increases the control complexity and circuit costs as well. Alternatively, passive filters are more attractive choices, due to their simple configuration, reliability, and easy implementation, especially in case of a specific load power [13]. Hence, they have become an effective method for the tasks of PF correction and harmonic current reduction. Figure 2 illustrates a typical LC passive filter circuit topology for full-bridge rectifiers. Conductor L_s and capacitor C_s can be used in conjunction with the diode rectifier bridge to improve the current waveforms. Actually, a large inductor has a negative impact on the associated post regulator control strategy caused by the increased DC source voltage regulation. Thus, we have to select as small inductors as possible in our passive filter design [14]. The analysis of the single-phase diode full-bridge rectifier system is based on the following two assumptions.

- Capacitor C_o is sufficiently large so that the output voltage is ripple free constant DC voltage.
- AC voltage and diodes D_1 , D_2 , D_3 , and D_4 are ideal components.

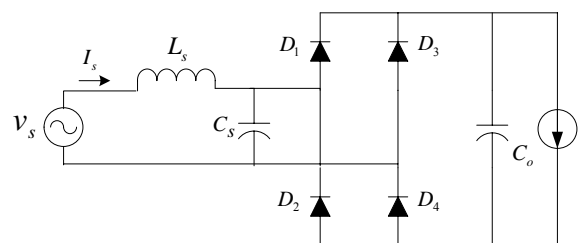


Fig. 2. A typical LC passive filter circuit topology for full-bridge rectifiers.

It is well known that the performance of the passive filter is determined not only by its circuit topology but also the values of the inductor and capacitor involved. Numerous passive filter design methods have been introduced to

optimize these LC parameters in order to obtain the best input current waveform. For example, two recent versions are advocated by Moo and Chen. Moo developed a computer program to create the contour maps of the PF, Total Harmonic Distortion (THD), and DC voltage in dimensioning the LC passive filter [13]. The optimal operation point can be selected under practical considerations as well as the required specifications. However, drawing such contour maps is always time-consuming, and different loads require different maps to be drawn. Instead of the traditional gradient descent methods, some modern optimization approaches have emerged during recent years. For example, Chen introduced the GA to design the passive filter [15]. As discussed above, compared with the GA, our CSA can achieve both local and global search. In the next section, we will investigate a new CSA-based scheme to optimize the LC parameters of the diode full-bridge rectifier (shown in Fig. 2) with the following three criteria:

1. small inductor for LC input filter;
2. large PF;
3. low THD.

It should be emphasized that the CSA is flexible in dealing with different optimization performance criteria.

IV. SIMULATIONS

Four kinds of software, i.e., MATLAB, SIMULINK, SimPowerSystems, and Piece-wise Linear Electrical Circuit Simulation (PLECS), are utilized in our computer simulations.

A. Simulation parameters

Since both L_s and C_s of the passive filter are supposed to be optimized by the CSA, every antibody, in form of float numbers, includes two sub-segments that represent the values of L_s and C_s , respectively. Their search ranges should be initially chosen in our CSA. Based on certain prior knowledge, we set $L_s \in [0, 200\text{mH}]$ and $C_s \in [0, 20\mu\text{F}]$ [13]. The fitness (affinity) function has to be defined beforehand as well. According to the principle of the passive filter and other practical appreciations, two issues are considered here.

1. Maximal PF.
2. As small L_s as possible.

Apparently, a better fitness would lead to a larger PF and a smaller inductor. The object of employing the passive filter in the AC/DC rectifier is to obtain the maximal PF as well as minimal THD. As aforementioned, the higher the internal source L_s , the greater the voltage distortion. A small inductor is always desired, although this is not the major optimization goal. In other words, a smaller value of L_s is preferred, if it can achieve a slightly lower but

acceptable PF. Thus, the fitness of antibodies is written as the weighted combination of L_s and PF [15]:

$$fitness = PF - k \log_{10} L_s . \quad (1)$$

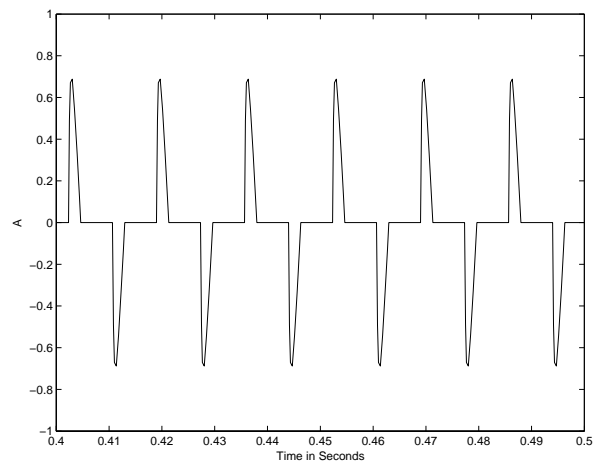
The user-defined coefficient k provides the degree of freedom to adjust the impact of L_s on the fitness and PF of the AC side. The memory set M in the CSA acts as a pool to accommodate all the antibodies (possible L_s and C_s) with the high affinity. In summary, all the parameters of our simulations are given in Table 1. It should be emphasized that to accelerate the convergence of the CSA, the mutated value of antibodies is inversely proportional to the individual's affinity.

Table 1. Parameters of the system.

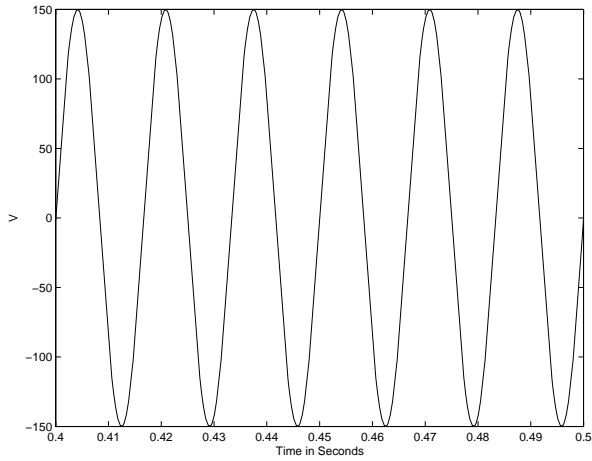
Parameter	Value
Population size	20
Clone size	4
Weight k	0.001
C_s (μF) range	0 ~ 20
L_s (mH) range	0 ~ 200

B. Simulation results

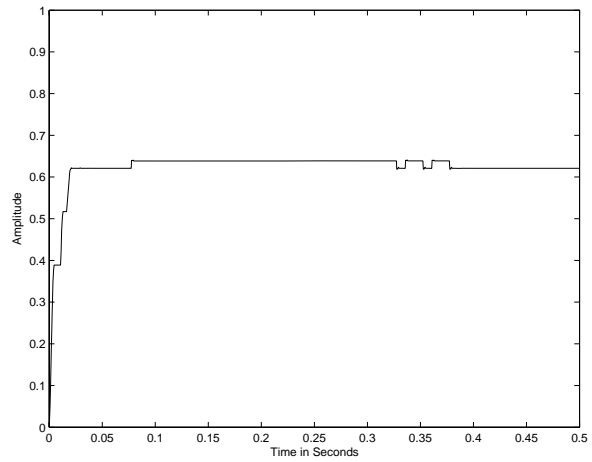
For the diode full-bridge rectifier in Fig. 2 without the LC passive filter, the simulated input current I_s , source voltage v_s , PF, and THD are illustrated in Fig. 3 (a), (b), (c), and (d), respectively. Without the passive LC filter, the PF of the AC mains is 0.62, and the input current THD is 115% for the load current $I_o = 0.4\text{A}$ with output capacitor $C_o = 220\mu\text{F}$. The desired PF is set to be 0.98.



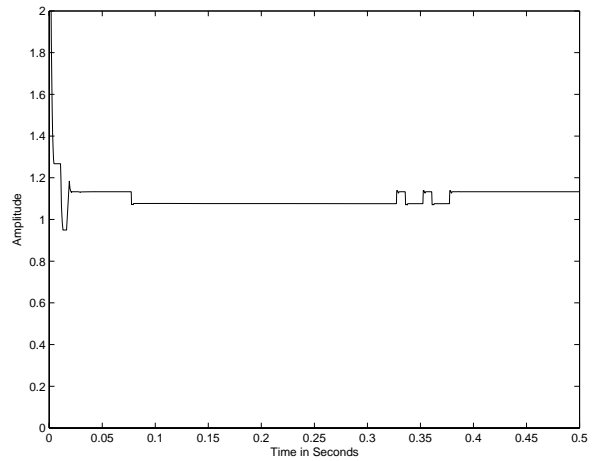
(a)



(b)



(c)

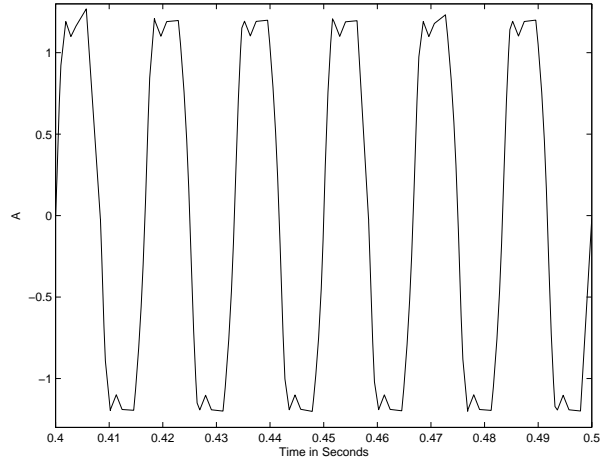


(d)

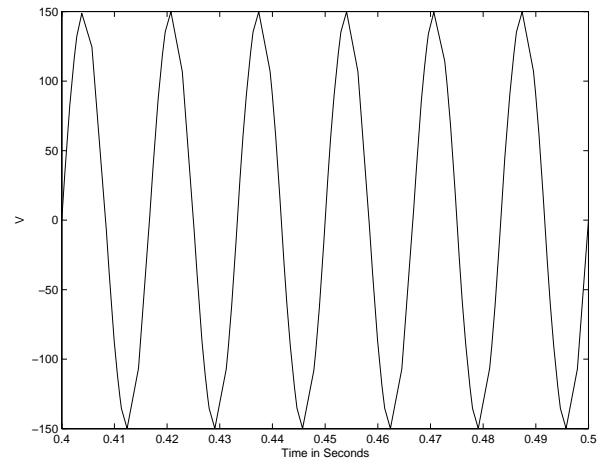
Fig. 3. Waveforms of I_s , v_s , PF, and THD in Fig. 1 without LC passive filter: (a) I_s , (b) v_s , (c) PF, and (d) THD.

In our LC passive filter optimization, the load current is set to be $I_o = 0.8$ A, and the desired PF is 0.98. The waveforms of I_s , v_s , PF, and THD for this case are illustrated in Fig. 4 (a), (b), (c), and (d), respectively, which are given in Table 2. The new L_s and C_s are 146 mH and 5.6 μ F, respectively. It is clearly visible that the CSA

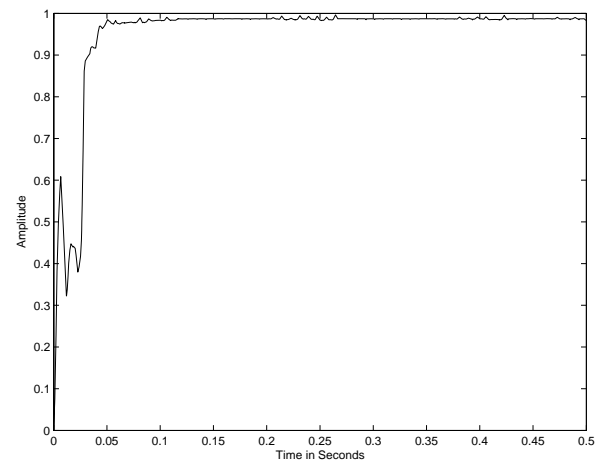
can optimize both L_s and C_s to achieve the desired PF = 0.98. Meanwhile, the THD has also been reduced to 16.9%. We should emphasize all the optimization results are obtained only under ideal conditions, i.e., the four diodes are assumed ideal, and values of inductor and capacitor are 100% accurate.



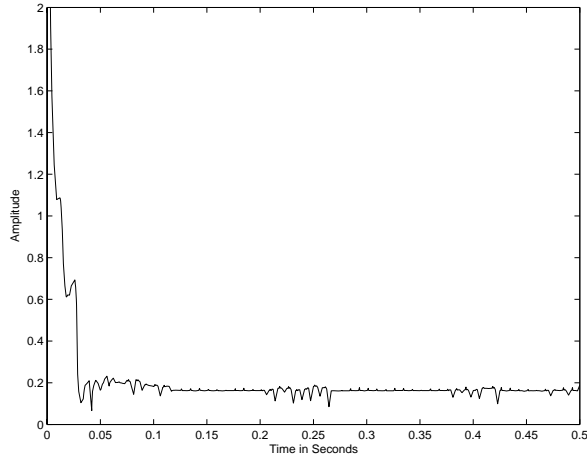
(a)



(b)



(c)



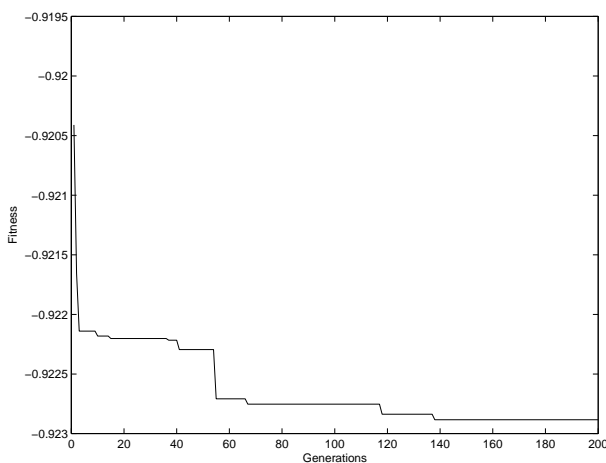
(d)

Fig. 4. Waveforms of I_s , v_s , PF, and THD of Case III
(a) I_s , (b) v_s , (c) PF, and (d) THD.

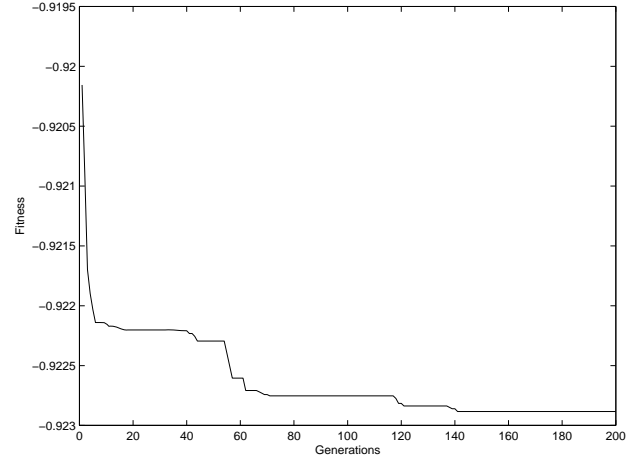
Table 2. C_o , L_s , C_s , PF, and THD.

Parameter	I_o (A)	C_o (μ F)	L_s (mH)	C_s (μ F)	PF	THD (%)
Value	0.8	220	146	5.6	0.98	16.9

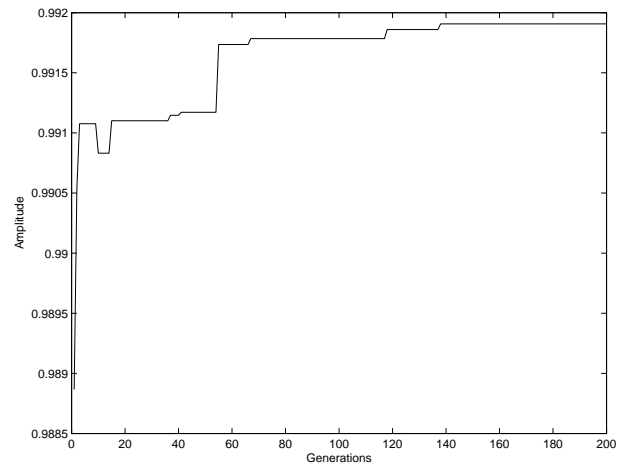
To further demonstrate the optimization characteristics of our CSA, the evolutionary behaviors of the best and average fitness in each generation as well as the PF are shown in Fig. 5(a), (b), and (c), respectively. In this example, after 200 generations, the PF has been improved to 0.9918, and THD reduced to 12.7%. In addition, Fig. 5 (a), (b) and (c) illustrate that the convergence procedures of the best and average fitness are similar, which implies the CSA is capable of simultaneously searching for the multi-optimal configuration of the LC passive filter.



(a)



(b)



(c)

Fig. 5. Evolutionary behaviors of CSA in LC passive filter optimization:
(a) best fitness, (b) average fitness, (c) PF.

One essential advantage of the proposed CSA over the GA is that CSA also takes into account the affinities among the antibodies. The CSA therefore can provide a group of different antibodies with the best affinity. Table 3 illustrates such a pool accommodating various candidates with low self-affinity. All of the LC combinations in Table 3 can improve the PF too be PF=0.94 ($I_o=0.4A$). The diversity of these candidates can offer more flexible choices, which have great potentials in engineering.

Table 3. LC parameters with PF=0.94.

L_s (mH)	C_s (μ F)	THD (%)
172.47	1.96	33.2
174.50	1.92	33.4
178.79	1.76	32.8
188.96	3.35	30.8
189.16	3.59	29.8
191.95	3.71	29.0
192.74	2.86	34.1
193.65	3.39	29.9
197.11	1.87	35.0
197.93	1.96	35.0
199.13	3.30	31.6

V. CONCLUSIONS

In this paper, a new optimization approach inspired by the CSA is employed to design a LC passive filter. Simulations demonstrate the proposed CSA-based power filter design approach can acquire the optimal LC parameters with certain given criteria, such as the desired PF and THD. As we know, the GA tends to bias the whole population of individuals toward the best candidate solution [6]. However, it has been demonstrated that the CSA can avoid being trapped into local minima as well as provide more choices due to its diverse candidate pool. Therefore, we conclude that the CSA is an effective and flexible optimization method for handling various engineering problems.

ACKNOWLEDGMENTS

This research work was funded by the Academy of Finland under Grant 201353. The author is grateful to Docent Xiao-Zhi Gao, Prof. Seppo J. Ovaska, and M.Sc. Konstantin Kostov for their warm-hearted help.

REFERENCES

- [1] L. N. de Castro, F. J. von Zuben, and G. A. de Deus Jr., "The construction of a Boolean competitive neural network using ideas from immunology," *Neurocomputing*, vol. 50, pp. 51-85, January 2003.
- [2] A. Acan, "Clonal selection algorithm with operator multiplicity," in *Proceedings of the Congress on Evolutionary Computation*, Portland, OR, June 2004, pp. 1909-1915.
- [3] J. Yoo and P. Hajela, "Immune network simulations in multicriterion design," *Structural Optimization*, vol. 18, no. 2-3, pp. 85-94, 1999.
- [4] S.-J. Huang, "Application of immune-based optimization method for fault-section estimation in a distribution system," *IEEE Transactions on Power Delivery*, vol. 17, no. 3, pp. 779-784, July 2002.
- [5] N. Tang and V. R. Vemuri, "An artificial immune system approach to document clustering," in *Proceedings of the 20th Annual ACM Symposium on Applied Computing*, Santa Fe, NM, March 2005, pp. 918-922.
- [6] L. N. de Castro and F. J. von Zuben, "Learning and optimization using the clonal selection principle," *IEEE Transactions on Evolutionary Computation*, vol. 6, no. 3, pp. 239-251, June 2002.
- [7] X. Wang, X. Z. Gao, and S. J. Ovaska, "Artificial immune optimization methods and applications – a survey," in *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics*, The Hague, The Netherlands, October 2004, pp. 3415-3420.
- [8] D. Dasgupta, "Information processing mechanisms of the immune system," in *New Ideas in Optimization*, D. W. Corne, M. Dorigo, and F. Glover (Ed.), Berkshire, UK: McGraw-Hill, 1999.
- [9] G. L. Ada and G. J. V. Nossal, "The clonal selection theory," *Scientific American*, vol. 257, no. 2, pp. 50-57, 1987.
- [10] L. N. de Castro and J. Timmis, *Artificial Immune Systems: A New Computational Intelligence Approach*. London, UK: Springer-Verlag, 2002.
- [11] L. N. de Castro and F. J. von Zuben, "Artificial immune systems: Part I—Basic theory and applications," Technical Report RT-DCA 01/99, FEEC/UNICAMP, Brazil, 1999.
- [12] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications, and Design*. New York, NY: John Wiley & Sons, 1995.
- [13] C. S. Moo, H. L. Cheng, and S. J. Guo, "Designing passive LC filters with contour maps," in *Proceedings of the International Conference on Power Electronics and Drive Systems*, Singapore, May 1997, pp. 834-838.
- [14] A. R. Prasad, P. D. Ziogas, and S. Manlas, "A novel passive waveshaping method for single-phase diode rectifiers," *IEEE Transactions on Industrial Electronics*, vol. 37, no. 6, pp. 521-530, December 1990.
- [15] Y.-M. Chen, "Passive filter design using genetic algorithms," *IEEE Transactions on Industrial Electronics*, vol. 50, no. 1, pp. 202-207, February 2003.