Transformer Design Based on Diversity-Guided Generalized Extremal Optimization

Leandro dos S. Coelho[1,2], Viviana C. Mariani[2,3], Helon V. H. Ayala[1,4], Mauricio V. F. Luz[5] and Jean V. Leite[5]
[1]Industrial and Systems Engineering Grad. Program, Pontifical Catholic University of Parana, Curitiba, Brazil
[2]Department of Electrical Engineering, Federal University of Parana, Curitiba, Brazil
[3]Mechanical Engineering Graduate Program, Pontifical Catholic University of Parana, Curitiba, Brazil
[4]LACTEC - Institute of Technology for Development, Electrical Systems Division (DVSE), Curitiba, Brazil
[5]GRUCAD-EEL-CTC, Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil
Emails: leandro.coelho@pucpr.br, viviana.mariani@pucpr.br, helonayala@gmail.com, mauricio@grucad.ufsc.br, jean@grucad.ufsc.br

Abstract— **An optimization method, called extremal optimization (EO), inspired by a simplified model of natural selection developed to show the emergence of self-organized criticality in ecosystems was proposed in last years for combinatorial optimization. In this context, it was proposed a generalization of the EO method that makes it easily applicable to a broad class of design optimization problems called generalized extremal optimization (GEO). To enhance and improve the search performance and efficiency of GEO, a novel diversity-guided GEO (DGEO) is proposed in this paper. The results of simulation carried out with a single-phase transformer design optimization have shown the proposed DGEO possesses outstanding performance in convergence speed and solution quality, as compared to standard GEO.**

Index Terms— **Optimization, transformer design optimization, optimization, generalized extremal optimization.**

I. INTRODUCTION

The competitiveness of the market and the pressure for rational use of resources has led manufacturers to seek optimized electromagnetic devices. The large number of variables involved in the design of an electromagnetic device, as well the compromise between performance and efficiency has required the use of optimization techniques in device design [1].

Recent literature reveals the continued interest in application of advanced techniques for transformer design optimization (TDO) [2],[3].

Extremal optimization (EO) proposed in [4],[5] has become in recent years one particular, successful approach to the global optimization applications. The basic idea behind EO is derived from the Bak-Sneppen model [6] of evolution, which shows the emergence of self-organized criticality in ecosystems. In this context, Sousa and Ramos [7],[8] proposed a generalization of the EO method (GEO) to continuous optimization

One of the critical issues is maintaining and computing the diversity in binary string encoding the design variables used in GEO. In this paper, a new GEO approach with diversity-guided mutation (DGEO) is proposed and validated.

To verify the advantages of the proposed DGEO algorithm, a shell core, dry-type, single-phase TDO is tested. Simulation results show the potential of the DPGEO as an efficient search technique for transformer design optimization. Furthermore, A comparison of the DGEO' performance with the classical GEO is also carried out to the TDO.

The rest of this paper is organized as follows. The description of GEO and DGEO approaches is provided in Section II. A description of TDO is given in Section III. Section IV exhibits the simulation settings and results. Section V concludes the paper.

II. FUNDAMENTALS OF THE GEO AND DGEO

In this section, the traditional GEO is first introduced, followed by the DGEO method and its implementation are presented.

A. The traditional GEO

Unlike most optimization techniques, EO, GEO and DGEO approaches focus on removing poor components of solutions instead of favoring the good ones.

In the basic GEO algorithm, each species is represented by a bit in a string, which represents the entire ecosystem of species. The variables are encoded in this string that is similar to a chromosome in the classical genetic algorithm (GA). But different from the GAs, in the GEO there is not a population of strings, but a population of bits represented by one string [8]. The proposed DGEO involves the following steps and procedures:

Step 1: Initialize randomly a binary string of length L that encodes N design variables;

Step 2: Transform the binary string to floating-point representation and calculate the its objective function values;

Step 3: Realize a flip operation for each bit of the string, calculate the objective function values and evaluate comparisons with the best objective function found so far;

Step 4: Rank the bits according to their objective function values;

Step 5: Choose with equal probability a candidate bit i to mutate. Generate a random number *RAN* with uniform distribution in the range [0,1]. If the mutating probability $P_i(k) = k^{-\tau}$, where τ is a positive parameter and the k is a ranking information, of the chosen bit is equal or greater than *RAN* the bit is confirmed to mutate. Otherwise, the process is repeated until a bit is confirmed to mutate.

Step 6: The current configuration of bits is set to be the string resulted from the mutation of bit i in *Step 4*.

Step 7: Repeat *Steps 2-6* until a given stopping criterion related to the number of objective function evaluations is reached.

B. The proposed DGEO

The proposed DGEO algorithm is a simple and modified version of the traditional GEO in which we have induced the concept of guided-diversity mutation in the *Step 5* of traditional GEO, where the absorption coefficient is set to $\tau = 1 - div$, where div is the normalized diversity of the binary string encoding the design variables.

III. TDO PROBLEM

The transformer adopted in this paper is a shell core, dry-type, single-phase transformer with the following setup: the apparent power S=300 VA, the primary tension V_1=110 V, the secondary tension V_2=220 V, and the frequency is equal to 50 Hz. The TDO problem is to minimize the masses and losses in the core and copper while ensuring the operational requirements. The core losses, hysteresis and eddy currents, are calculated with classical approaches. The variables are the core dimensions, turns of windings, and currents densities. A representation of TDO is presented in Fig. 1.

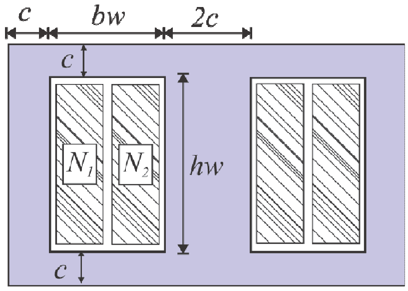

Fig.1. Transversal transformer cutaway. Dimensions of core, primary (N_1) and secondary (N_2) windings. Furthermore, the transformer has a profundity t.

IV. OPTIMIZATION RESULTS

In order to eliminate stochastic discrepancy 30 independent runs were made for the GEO and the proposed DGEO method. The setup used in the GEO and DGEO approaches was a total number of objective function evaluations equal to 500 in each run. In the GEO is adopted $\tau = 0.1$.

A result with Boldface means the best value found in Table I. As it is clear from Table I, the DGEO is able to find the global minimum and mean objective function (f) values that outperform the GEO algorithm. The best result (minimum) using DGEO was $f = 3.7951$.

Table II compares the GEO and DGEO with a classical analytical transformer design. One can observe that although the optimized transformer has a slightly lesser efficiency, the transformer mass is significantly lower for the same power transferred. This characteristic would be useful for embedded applications.

TABLE I
RESULTS IN TERMS OF THE OBJECTIVE FUNCTION IN 30 RUNS

Optimization Method	Objective function f of best solution (after 500 evaluations in 30 runs)			
	Maximum (Worst)	Mean	Minimum (Best)	Standard Deviation
GEO	4.4710	4.1373	3.8416	0.1792
DGEO	4.4187	**4.0842**	**3.7951**	0.1723

TABLE II
COMPARING OPTIMIZED AND ANALYTICAL RESULTS

Parameter	Analytical	GEO	DGEO
c [cm] *	2.5	1.18	1.15
t [cm] *	4.0	3.37	3.59
h_w [cm] *	15	12.55	10.78
b_w [cm] *	2.5	2.46	2.79
N_1	231	549	533
N_2	507	1107	1075
Power [VA]	300	300	300
Core losses [W]	7.2	2.79	2.61
Copper losses [W]	21.7	37.66	39.15
Efficiency	0.91	0.88	0.88
Mass [Kg]	8.1	3.84	3.79

* optimized variables

V. CONCLUSION

In this paper, the proposed DGEO algorithm has been successfully implemented to solve a TDO problem. It has been observed that the DGEO algorithm has the ability to converge to a better quality solution in terms of objective function value and possesses better convergence characteristics than the classical GEO.

Future work is aimed at studying the robustness of the DGEO method to more complex TDO problems.

REFERENCES

[1] A. Khatri, H. Malik and O. P. Rahi, “Optimal design of power transformer using genetic algorithm,” in *International Conference on Communication Systems and Network Technologies (CSNT),* Rajkot, Gujarat, India, pp. 830-833, 2012.

[2] E.I. Amoiralis, M.A. Tsili, and A.G. Kladas, “The state of the art in engineering methods for transformer design and optimization: a survey,” *Journal of Optoelectronics and Advanced Materials*, vol. 10, no. 5, pp. 1149-1158, 2008.

[3] A. Khatri and O.P. Rahi, "Optimal design of transformer: a compressive bibliographical survey,” *International Journal of Scientific Engineering and Technology*, vol. 1, no. 2, pp. 159-167, 2012.

[4] S. Boettcher and A.G. Percus, “Optimization with extremal dynamics,” *Physical Review Letters*, vol. 86, no. 23, pp. 5211-5214, 2001.

[5] S. Boettcher and A.G. Percus, “Extremal optimization: methods derived from co-evolution,” in *Proceedings of the Genetic and Evolutionary Computation Conference* (GECCO), Orlando, FL, USA, pp. 825-832, 1999.

[6] P. Bak and K. Sneppen, “Punctuated equilibrium and critically in a simple model of evolution,” *Physical Review Letters*, vol. 71, no. 24, pp. 4083-4086, 1993.

[7] F.L. de Sousa and F.M. Ramos, “Function optimization using extremal dynamics,” in *Proceedings of the 4th International Conference on Inverse Problems in Engineering*, Rio de Janeiro, RJ, Brazil, 2002.

[8] F.L. de Sousa, V. Vlassov, and F.M. Ramos, “Generalized extremal optimization: an application in heat pipe design,” *Applied Mathematics Modelling*, vol. 28, no. 10, pp. 911-931, 2004.