Modified grey wolf method for optimization of PM motors

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Abstract. The paper presents an algorithm and computer software for the optimization of electromagnetic devices. The mathematical model of the optimization method was presented. The modification of the classical grey wolf algorithm was developed. The modification consists in decreasing the coefficient responsible for the possibility of migration individuals in the permissible area of solved task. The optimization procedure was elaborated in the Borland Delphi environment. The optimization of the rotor of the line-start permanent magnet synchronous motor has been carried out. It has been pointed out that the grey wolf algorithm is effective method for optimization of electromagnetic devices.

1 Introduction

Nowadays the process of device designing is strongly connected with optimization procedures. The final solution of the optimization process should fulfil imposed requirements regarding functional parameters of designed object. The optimality criteria are usually of economic type or are related to natural environment protection [1]. Very often the optimization task consists in limitation of the energy consumption and improvement of the device efficiency.

At present, an intense development of new optimization algorithms, particularly effective to solution the synthesis problem of designing electromagnetic devices is observed. Currently, the most dynamically probabilistic (non-deterministic) algorithms are expanded [2]. These types of algorithms have a much higher probability of finding a global optimum in comparison to deterministic algorithms. Among them, the algorithms based on an observation of natural environment (nature inspired algorithm) are very intensively developed. For this group of method can include: firefly algorithm, bat algorithm, killer whale algorithm, rain water algorithm and grey wolf algorithm. The simplified classification of the optimization algorithms is presented in Fig. 1.

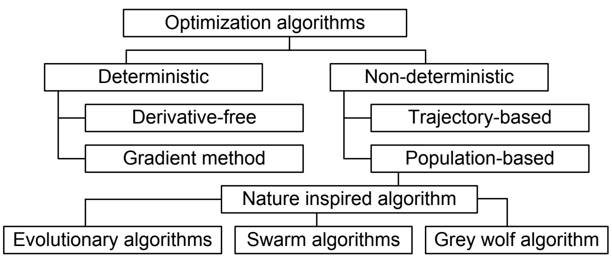

Fig. 1. Classification of optimization algorithms.

The aim of research is to develop effective modification of the grey wolf optimizer (GWO) adapted to electromagnetic devices designing.

2 Organization of the grey wolf pack

The wolf packs have an extensive social rank system (hierarchy), which determines the position of each individual in the group. The pack leader is called α individual [3]. The hierarchy in the wolf pack is similar to linear dependence; the wolf that has directly won with all other wolves in the pack becomes pack leader. Another important wolf in the pack is the β individual. This individual plays role of "alternative" leader. The third level in the hierarchy consists of δ individuals. The ω individuals are on the lowest level of the pack hierarchy.

3 Mathematical model of grey wolf method

The mathematical model of grey wolf method was elaborated on the basis of observations of strategy of hunting wolves. In GWO algorithm similarly as in other optimization methods from nature inspired algorithm, the positions of each individual are calculated in subsequent iterations. The position of the *i*-th wolf in the *k*-th iteration is determined as follows [4]:

$$\mathbf{X}_k^i = \mathbf{X}_{k-1}^p - A_k \left| C_k \mathbf{X}_{k-1}^p - \mathbf{X}_{k-1}^i \right| \quad (1)$$

where $\mathbf{X}_{k-1}^p$ is the position of the prey in previous iteration, A_k and C_k are the coefficients of the algorithm.

At each iteration, the coefficient A_k and C_k are determined according formulas:

$$A_k = 2b_k r_1 ,\ C_k = 2r_2 \quad (2)$$

where r_1 and r_2 is random numbers from range (0, 1), b_k is the factor which determine the ability of wolves to migration in the area of optimization task.

In the classical GWO method, the value of factor is usually chosen from the range [2, 0]. The elaborated modification consists in linear decreasing of the value of

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coefficient b in the subsequent iterations. The value of b in k-th iteration is determined as follows:

$$b_k = b_0 - \frac{b_1 - b_0}{k_{\max} - 1}(k - 1) \quad (3)$$

where b_0, b_1 are the initial and final value of factor b respectively, $k_{\max}$ is the maximum number of iteration.

Changes the value of factors determining the position of an individual in subsequent iteration of optimization process is often used in another non-deterministic optimization methods as for example in PSO algorithm.

The mathematical model of GWO algorithm is based on the three stage of hunting: (a) searching of the prey, (b) encircling prey and (c) attacking of the prey [5]. The vector of position for i-th wolf at k-th iteration can be calculated:

$$\mathbf{X}_k^i = \frac{\mathbf{X}_1 + \mathbf{X}_2 + \mathbf{X}_3}{3} \quad (4)$$

$$\text{where: } \begin{cases} \mathbf{X}_1 = \mathbf{X}_{k-1}^{\alpha} - A_k^{\alpha} D^{\alpha} \\ \mathbf{X}_2 = \mathbf{X}_{k-1}^{\beta} - A_k^{\beta} D^{\beta} \\ \mathbf{X}_3 = \mathbf{X}_{k-1}^{\delta} - A_k^{\delta} D^{\delta} \end{cases} \quad (5)$$

here $D^{\alpha} = \left| C^{\alpha}\mathbf{X}_{k-1}^{\alpha} - \mathbf{X}_{k-1}^{i} \right|$, $D^{\beta} = \left| C^{\beta}\mathbf{X}_{k-1}^{\beta} - \mathbf{X}_{k-1}^{i} \right|$, $D^{\delta} = \left| C^{\delta}\mathbf{X}_{k-1}^{\delta} - \mathbf{X}_{k-1}^{i} \right|$.

4 Optimization of LSPMSM

The optimization procedure using GWO method has been elaborated in Delphi environment as a separate module. The optimization module is connected with mathematical model of line-start permanent magnet motor. The model of motor is based on finite element method [5, 6] and is developed in Ansys Maxwell environment.

The optimization task consists in designing of the excitation system for PM synchronous motor. In this project the stator from commercially produced six-pole induction motor has been used. The rated power of induction motor was equal 6.3 kW. The structure of the considered motor is presented in Fig. 2.

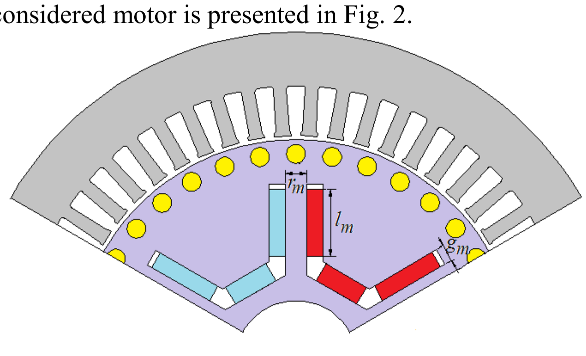

Fig. 2. The structure of LSPMSM.

The motor excitation system is described by three design variables (see Fig. 2): g_m – magnet thickness, l_m – magnet length and r_m – distance between poles. The excitation system was made of NdFeB N33 material with the properties H_c = 836 kA/m and B_r = 1.15 T.

As a criterion of optimality, the compromise function consisting of three components has been adopted [7]. For i-th individual has been defined as follows:

$$f^i(\mathbf{x}) = \left(\frac{\eta^i(\mathbf{x})}{\eta_0}\right)\left(\frac{\cos\varphi^i(\mathbf{x})}{\cos\varphi_0}\right)\left(\frac{T_{80}^i(\mathbf{x})}{T_0}\right)^{0.5} \quad (4)$$

where $\mathbf{x}=[g_m, l_m, r_m]^T$ is the vector of design parameters, $\eta^i(\mathbf{x})$, $\cos^i\varphi(\mathbf{x})$ and $T_{80}^i(\mathbf{x})$ are the efficiency, power factor and electromagnetic torque at speed equal to 0.8 of synchronous speed respectively. Parameters η_0, $\cos\varphi_0$ and T_0 are the average values of these parameters obtained in the initiation procedure of gray wolf pack.

The optimization calculations were performed for following parameters: number of individuals N=30, value of coefficients b_0=2 and b_1=0.1 and maximum value of number iteration $k_{\max}$=20. The result of computer simulation for selected iteration are presented in Table 1

Table 1. The results of optimization process

k	g_m [mm]	l_m [mm]	r_m [mm]	η(x) [%]	cosφ [-]	T_{80}(x) [N]	f(x) [kg]
1	7.78	3.80	9.10	88.36	0.585	167.0	1.541
2	7.77	4.84	10.27	91.77	0.901	94.5	1.613
5	6.89	4.91	10.71	91.45	0.861	110.3	1.740
8	5.07	6.50	11.94	91.87	0.951	119.0	2.021
20	5.07	6.50	11.94	91.87	0.951	119.0	2.021

5 Conclusions

The non-deterministic method of unconditional optimization and its application to optimization PM motor is presented. The mathematical model of algorithm was developed on the basis of behavior and hunting techniques of wolf. The developed algorithm is very effective and avoids "stuck" in local extremes. The robustness of the GWO method can be a result from the algorithm of determination of position of the each individual in successive iteration in comparison to other non-deterministic methods as particle swarm optimization.

References

1. A. Stuikys, J. Sykulski, *IEEE Transactions on Industry Applications*, **53**, 3, 1985 - 1993 (2017).
2. E. I. Amoiralis, M. A. Tsili, D. G. Paparigas, A. G. Kladas, *IEEE Transactions on Industry Applications*, 50, 1, 383 – 394 (2014).
3. S. Mirjalili, S. M. Mirjalili, A. Lewis, *Advances in Electrical Engineering,* **69,** 46 – 61 (2014).
4. J. Song, F. Dong, J. Zhao, H. Wang, Z. He, L. Wang, *IEEE Transactions on Industrial Electronics*, 60, 2, 1001 – 1011 (2019).
5. P. Idziak, K. Kowalski, L. Nowak, Ł. Knypiński, *International Journal of Applied Electromagnetics and Mechanics,* **51**, s1, S81-S87 (2016).
6. K. Kowalski, L. Nowak, Ł. Knypiński, P. Idziak, *Archives of Electrical Engineering,* **66**, 3 (2017).
7. K. Bednarek, *Przegląd Elektrotechniczny*, **84**, 12, 138-141 (2008).