THE HYBRID ALGORITHMS IN CONSTRAINED OPTIMIZATION OF THE PM MOTORS

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Abstract

In this paper, the different hybrid optimization algorithms have been applied to the constrained optimization of the line-start permanent magnet synchronous motor. The optimal results for the hybrid Cuckoo Search and hybrid Grey Wolf Optimization have been compared. In the primary objective function, the parameters describing motor parameters in the steady-state have been included. Moreover, the non-linear constraint function has been taken into account. The optimization procedures have been elaborated in the Delphi and Matlab environments. The mathematical model of the line-start permanent magnet motor has been developed in Maxwell environment.

1 Introduction

The metaheuristic optimization algorithms (MOA) provide good efficiency with robustness in searching for the global extreme point [1]. Many authors employ MOA to solve constrained and unconstrained optimization task [2]. The number of metaheuristic algorithms is still increasing. The researchers develop new and more effective optimization algorithms, able to provide global extreme with smaller numbers of iterations. The following algorithms have been developed in recent years: (a) sparrow search algorithm [3], (b) spotted hyena optimizer, and (c) Harris hawks optimization [4].

In order to improve the quality and reliability of the optimization procedure, the authors more and more often develop hybrid algorithms. A hybrid optimization algorithm combines two, three or even more different optimization algorithms. The hybrid algorithm can connect two heuristic algorithms [5]. Also, the hybrid algorithm can join two different approaches, such as a heuristic algorithm and a deterministic method [6].

The aim of the paper is application different hybrid algorithms to optimise rotor structure from line-start permanent magnet motor. Next, the performance of this algorithms has been compared in the extended version of the paper.

2 Different optimization approach

2.1 Hybrid Cuckoo Search algorithm

The hybrid cuckoo search algorithm (HCS) combines the heuristic cuckoo search (CS) algorithm with deterministic Hooke-Jeeves (HJ) method. In the single iteration of HCS algorithm are simultaneously executed calculations for both approach (CS and HJ). In the first stage of HCS algorithm, new positions of all individuals are determined by the use CS algorithm. Next, two cuckoos in actual population are selected randomly. For both cuckoos the value of objective functions and positions in permissible area are determined. Using the HJ method, the best displacement for the cuckoo with worst objective function in the direction of the better adapted function is computed.

2.2 Hybrid Grey Wolf Optimizer

The hybrid grey wolf optimizer (HGWO) algorithm [7] utilize the advantages of key features obtained from the two metaheuristic approaches. The optimal solution based on the leader-follower strategy of GWO algorithm and switching of exploration-exploitation phases through sine-cosine functions of SCA algorithm have been selected for the preparation of hybrid algorithm. The considered features of two individual algorithms helps in obtaining optimal solutions without sticking at local optima over the search space. The probability of fetching optimal solutions can be further enhanced through dimension learning-based hunting (DLH) strategy for the finally obtained solution at the end of each iteration.

3 The optimization problem formulation

In order to rate the performance and reliability of the developed hybrid optimization procedures, the optimization of the rotor from the PM motor with self-starting ability has been performed. The structure of the rotor with pointed design variables is presented in Fig. 1.

The aim of the optimization problem is to search the dimensions of the structural parameters describing construction of the rotor. The stator structure with winding and selected rotor structure parameters such as: air gap length, stack length, O_2 (see Fig. 1) and squirrel-cage have been adopted as a constant. The rotor has been described by three design variables: $s_1=r$ – the distance between poles, $s_2=l$ – total length of permanent magnet for one pole, and $s_3=O_1$ – the parameter describing position of the magnets. The design variables create the vector $\mathbf{s}=[r, l, O_1]^T$.

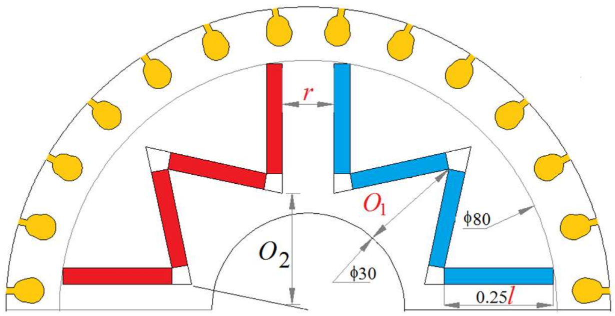

Fig. 1: The structure of the LSPMSM

Permanent magnets available in commercial catalogues have typical geometrical dimensions (length, thickness and height). Thus, in the set of design vector are discrete (l) and continuous (r and O_1) variables.

In the primary objective function, the functional parameters in the steady-state have been into taken consideration. For the i-th individual the primary objective function has form:

$$f^i(\mathbf{s})=\alpha(I(\mathbf{s})/I_0)^{-1}+\beta(\eta(\mathbf{s})/\eta_0), \tag{1}$$

where $I(\mathbf{s})$ and $\eta(\mathbf{s})$ are the line-current and efficiency in the steady state operation, I_0 and η_0 are the average values of line-current and efficiency calculated from five start-up of optimization process.

During optimization process, the $f(\mathbf{s})$ function is maximized, while constraint concerning the proper synchronization has been taken into account.

In the developed algorithm, the constraint has been taken into account using penalty function approach. The penalty term is calculated:

$$P_k(\mathbf{s})=a^k(1-T_{80}(\mathbf{s})/T_f), \tag{2}$$

Here k is the external penalty iteration, a is the penalty coefficient, T_f is the permissible value of electromagnetic torque for the velocity equal $0.8n_s$, n_s is synchronous velocity.

If $T_{80}(\mathbf{s})\geq T_f$ the modified objective function i-th individual has form:

$$h^i(\mathbf{s})=f^i(\mathbf{s}), \tag{3}$$

otherwise:

$$h^i(\mathbf{s})=f^i(\mathbf{s})-P_k(\mathbf{s}) \text{ for } T_{80}(\mathbf{s})<T_f. \tag{4}$$

4 Results and conclusion

The optimization calculations were made for following parameters: (a) number of individual equal 32, (b) maximum number of iterations 35, (c) weighting coefficient of primary objective function α=0.4 and β=0.6, (d) a=1.1. The 4 iteration of hybrid algorithms was executed in single penalty iteration (k). The permissible values of the electromagnetic torque T_f=10 Nm have been enforced. Each optimization procedure was run three times for different initial population of cuckoo or wolfs. The average values of I_0 =8.21A and η_0=88.1% were assumed. The comparison of the optimal solution for both hybrid algorithms are presented in Table 1.

Alg.	r	l	O_1	I	η	T_{80}
HCS	2.37	38.0	18.42	7.09	90.2	10.03
HGWO	2.57	40.0	19.79	6.99	90.2	10.2

Table 1: The optimal results for hybrid algorithms.

During optimization process both hybrid algorithms found optimal solution with similar values of efficiency, the value of T_{80} satisfied imposed non-linear constraint.

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