APPLICATION OF GENETIC ALGORITHM IN DESIGN OPTIMIZATION OF A PERMANENT MAGNET SYNCHRONOUS MOTOR

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Abstract: Permanent magnet synchronous motors have been preferred in industrial applications since 1985 because of their high torque/volume ratios and in particular to highly efficient. Although the main factor determining the efficiency of permanent magnet synchronous motors is absence of rotor windings, effective choice of design parameters and design model of permanent magnet synchronous motor affect the efficiency. This study proposes design optimization of concentrated-winding surface-mounted permanent magnet synchronous motor for high efficiency. Preliminary analytical design and then heuristic design optimization by using genetic algorithm have been studied. The obtained results were compared with finite element analysis results. It was finally observed that the results were satisfactory.

Keywords: design optimization, genetic algorithm, permanent magnet synchronous motor

Permanent Magnet Senkron Bir Motorun Tasarımının Optimizasyonunda Genetik Algoritma Uygulaması

Özet: Kalıcı mıknatıslı senkron motorlar, yüksek moment/hacim oranları ve özellikle yüksek verimlerinden dolayı, 1985 yılından itibaren endüstriyel uyuglmarda tercih edilmektedir. Kalıcı mıknatıslı senkron motorların verimini belirleyen temel faktör rotor sargılarının olmaması olsa da, tasarım parametrelerinin ve kalıcı mıknatıslı senkron motor tasarım modelinin etkin seçimi de verimi etkilemektedir. Bu çalışma konsantre-sargılı yüzey-mıknatıslı bir kalıcı mıknatıslı senkron motorun tasarım optimizasyonunu amaçlamaktadır. Ön analitik tasarımı ve daha sonra genetik algoritma kullanılarak sezgisel tasarım optimizasyonu çalışılmıştır. Elde edilen sonuçlar sonlu eleman analizi sonuçları ile karşılaştırılmıştır. Neticede sonuçların kabul edilebilir olduğu görülmüştür.

Anahtar Kelimeler: tasarım optimizasyonu, genetik algoritma, kalıcı mıknatıslı senkron motor

1. INTRODUCTION

Electric motors are one of the largest consumers of electrical energy; they are about two thirds of produced electrical energy in developed countries [1]. Therefore, the productions of highly efficient motors and design optimization of them are very important to ensure energy saving. Permanent magnet synchronous motors have high efficiency values because they do not have rotor windings; the loss of excitation windings is prevented thus [2].

Nowadays the production and use of permanent magnet synchronous motors have been increased in industrial applications because of decreasing prices of rare-earth magnets. This situation is an important development in terms of energy efficiency. Due to the placement of permanent magnets in the rotor, different design architectures arise in permanent magnet synchronous motors. One of them preferred for low speed applications is surface mounted because of ease of production. In addition to placement of permanent magnets, by paying attention to pole number/slot number ratio concentrated windings have been often chosen because of their lowest losses [3].

Different heuristic methods have been used for design optimization of electric motors. The most widely used and powerful method is genetic algorithm [4-6]. Design optimization studies of permanent magnet synchronous motors have been focused on different purposes such as reduction of cogging torque, torque ripple, and motor weight and also enhancement of torque density. Input design parameters have been selected by experience and preliminary analytical design owing to objective function of the design optimization.

In this paper, design optimization of a concentrated winding surface mounted permanent magnet synchronous motor was proposed. The efficiency results were compared with finite element analysis results. The main benefit of our work is to provide the simple motor design approach by choosing of geometrical input design parameters and genetic algorithm. The obtained results are finally acceptable.

2. GENETIC ALGORITHM

Genetic algorithm based on struggle between individuals of population is an intuitive method. Every individual in the population is a solution of the optimization problem. Therefore the most robust individuals carrying the best values of the fitness function in the population transfer features to a new generation [7]. This progress narrows the solution space and thus allows to genetic algorithm convergence speed.

Genetic algorithm is often chosen for optimization problems because they do not require initial solution, they provide fast and accurate solutions for multi-parameter problems, and they can be run without need for experimental data. But there are some considerations especially for objective function nevertheless. It must be careful whether the objective function is dealt with the problem, that is to say, how well the objective function reflects the optimization problem. Because the used method and equations in achieving the objective function directly affects the accuracy of the solution. This situation is even more important especially for multi-equations motor design problems.

If we look at the structure of genetic algorithm there are three robust and useful operators of genetic algorithm: Reproduction, crossover, and mutation. There are unique functions of each operator in genetic algorithm. Reproduction operator uses the objective function selection criteria. By means of reproduction operator, individuals with highest fitness value send to the pool of matching and so their properties transfer to the future generations by use of other operators. The second operator is crossover. Genes of the selected parent from pool of matching is swapped. In this process the selection of parent and crossover point is randomness. During the operation sensitivity of genetic algorithm may be reduced by dragging a local solution. Mutation operator changes randomly the string's bit from a "1" to a "0" or vice versa and so it prevents the falling of genetic algorithm in a trap.

3. DERIVATION OF THE OBJECTIVE FUNCTION OF THE DESIGN OPTIMIZATION

In this study, concentrated winding surface mounted permanent magnet synchronous motor design optimization with 16-poles and 18-slots was investigated. According to output power (7.5kW), rated speed (195rpm), and supply voltage (380V), other electrical and magnetic values were obtained by genetic algorithm. The geometry of the motor was given in Figure 1. Depending on the motor model, ten number of independent design variables were determined. These variables are the outer rotor diameter D_{rc}, magnet thickness l_m, air gap length δ, slot wedge height h_{sw}, stator tooth width b_{ts}, outer stator diameter D_o, stator slot height h_{ss}, ratio of the slot opening over the slot width k_{open}, the half pole angle a., and stack length L_{stk}. Copper and iron losses of the motor were calculated through the obtained input design parameters. Eventually, the efficiency was acquired as objective function.

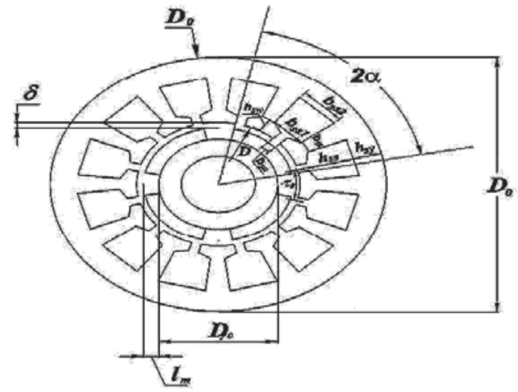

Figure 1. **Two-dimensional geometry of the motor**

$$P_{out} = T \times \omega_{mech} \tag{1}$$

$$P_{cu} = 3R_{cu} \times I_{eff}^2 \tag{2}$$

$$P_{iron} = P_h + P_e = k_h \hat{B}^{\beta_{st}} \omega_e + k_e \hat{B}^2 \omega_e^2 \tag{3}$$

$$\eta = \frac{P_{out}}{P_{out} + P_{cu} + P_{iron}} \tag{4}$$

where, ω_e is electrical angular velocity, ω_{mech} is mechanical angular velocity, k_h is hysteresis loss coefficient, k_e is eddy current loss coefficient, P_{out} is output power, P_{cu} is copper loss, P_{iron} is iron loss, and η is efficiency of the permanent magnet motor.

4. IMPLEMENTATION OF PERMANENT MAGNET SYNCHRONOUS MOTOR DESIGN OPTIMIZATION

Preliminary analytical design of the permanent magnet synchronous motor was achieved by means of an analytical computer program and simulations were done by finite element analysis program [10]. A geometric model was produced and thus the efficiency and error between analytical and finite element analysis results was calculated as 91.23%, 88.92%, and 2.61% respectively. This study proposes to use of genetic algorithm as optimization algorithm and so the population number, iteration number, crossover ratio, and mutation ratio was chosen 25, 50, 0.8, and 0.1 respectively. Each gene was chosen for ten-bits. Afterwards, optimization algorithm was run five times and subsequently design parameter and efficiency values of the motor were obtained and also tested by finite element analysis program. To make a good assessment of the studies, the whole values of the design parameters and efficiency results are in Table 1 and the meshed model of the motor were shown and Figures 2.

Table 1. The pre-analytical and optimization results

		Pre-Analytical Design	Heuristic Design
Input Design Parameters of the Permanent Magnet Synchronous Motor	**D_{rc} (mm)**	197.1	224.41
	l_m (mm)	4.7	5.36
	δ (mm)	1.25	0.95
	h_{sw} (mm)	3.31	1.83
	b_{ts} (mm)	18.2	19.4
	D_o (mm)	311.96	377.54
	h_{ss} (mm)	37.44	41.54
	k_{open}	0.85	0.96376
	α (°)	64.36	61.89
	L_{stk} (mm)	180	185.95
	Iteration Number	–	50
	Optimization Time (sec)	–	5.06
	η (%)	91.23	94.93
	Finite Element Analysis η (%)	88.92	94.13
	Error (%)	2.61	0.85

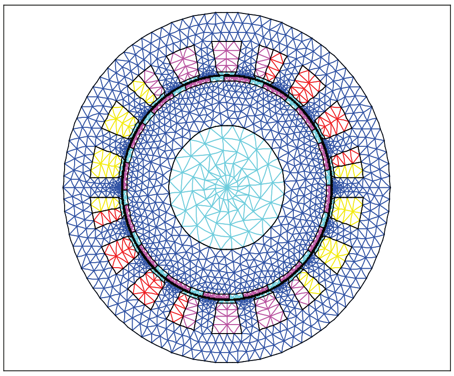

Figure 2. **2D meshed cross section of the motor**

The efficiency results and error were obtained by means of the genetic algorithm and finite element analysis as 94.93%, 94.13%, and 0.85% respectively. Moreover the obtained optimal efficiency results by genetic algorithm were shown in Figure 3. Genetic algorithm obtained the better optimal result in fifth iteration number. Finite element analysis verified the optimal efficiency result with 0.85 percent. Finally, permanent magnet synchronous motor with high efficiency has been achieved.

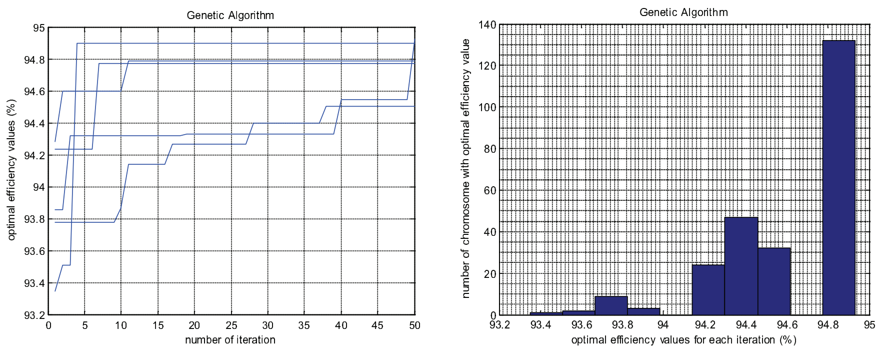

Figure 3. Graphics of optimal efficiency results by the genetic algorithm for all runs

5. CONCLUSION

Design optimization of surface mounted concentrated winding permanent magnet synchronous motor was investigated by using genetic algorithm. Independent design parameters were determined to provide a simple design optimization. According to the obtained efficiency results, the attempted approach for the design optimization of permanent magnet synchronous motor is satisfactory. This study presents effective geometrical design parameters and practical approach for high efficiency determination of permanent magnet synchronous motor in industrial fields.

Acknowledgements

This study is supported by the Scientific Research Projects of Selçuk University.

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