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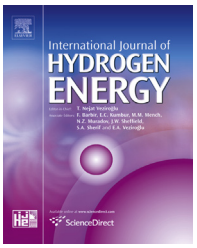

An inverse problem methodology for design and optimization of an interior permanent magnetic BLDC motor

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ABSTRACT

In the theory of inverse problem, the parameters identification by optimization is considered as one of its main applications. This paper presents an optimal design of a slotted permanent magnet Brushless DC (BLDC) motor with surface mounted magnets. The inverse problem method is applied by using a thriving solver afforded by the nonlinear optimization toolbox of Matlab 'Fmincon', this function is based on Active-Set and Sequential Quadratic Programming approaches with calculation of the Hessian from Quasi-Newton algorithm. The optimal magnetic field density considered as the main objective is obtained by picking several parameters and analyzing their effects. The proposed approach is highlighted by using the obtained parameters in the design of the motor. The Finite element method is applied on the motor for numerical analysis by using FEMM magnetic coupled with Matlab code. Effectiveness and robustness of the proposed approach are verified by a comparison between the initial and optimized design.

Introduction

The rotating electrical machines and particularly the induction machines are widely used in many industrial fields. Indeed, since they are very simple to construct, their use and their maintenance have contributed to the success of this type of machines with immense achievement. Nevertheless, the problem of the optimal use of available energy and the rising cost of metals lead us to propose alternatives of induction machines. One possible solution is, by the use of Brushless Direct Current (BLDC) type of machine. Indeed, the latter has three major advantages over induction machines. First, its performance is superior to induction machines. This is particularly marked for relatively low power machines. Second, the BLDC machines can vary their speed easily [1], which is not the case of induction machine. Finally, this type of machine benefits from the development of the rare-earth permanent magnets and nano-composite materials for energy-efficient electric motors and the progress in the field of modern electronics [2–4]. This development, in both technical and economic, provides excellent performance at a reasonable cost and ensures a bright future for BLDC motors.

BLDC motors are suitable for applications that require high speed and high accuracy, they are swiftly gaining attractiveness. They have been largely used in industrial applications including, automotive, aerospace, medical apparatus, automated industrial equipment and instrumentation, electric

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vehicles and railway applications [5]. In addition, the BLDC machines don't presuppose brush maintenance and have seen recent interest due to a continued reduction in power electronics and controller costs [6].

The design problem and optimization of electrical machines in general have a very important role in electrical power production and conversion as well as in the development of modern industries. Most of the scientific research in the field of electrical machine design seeking to maximize improvement in their performances by using mathematical and engineering methods [7].

A review of the electrical machine design approaches was proposed in Ref. [8]. Several design algorithms are studied including direct and stochastic search algorithms for both single and multi-objective design optimization cases followed by a comparison between response surface and differential evolution algorithms on a permanent-magnet-synchronous-motor (PMSM). The obtained results show the superiority of the differential evolution algorithm especially when more design candidates are considered. In addition, a robust design methodology has been developed to a surface-mounted permanent magnet synchronous motor followed by an analytical-based particle swarm optimization (PSO) method [9]. The first method is for increasing the robustness of the torque ripple peak and the second method is for reducing optimization process time. Results are verified according to the experiments.

BLDC motor has interested several researchers due to the several advantage of this type of motor. Chin et al., in their work have presented a compact brushless permanent magnet motor design for transient applications such as emergency breakers, protective devices in explosive environments and emergency exit opening etc. The design procedures for both internal and external rotor are presented and well described in their paper, the results of their work have been verified and tested by building a prototype motor. However, the significant results of the proposed design are found that the most critical criterion in this case is to avoid magnet demagnetization [10]. Nazri Bin Othman in his paper [11] has well-considered a BLDC motor design strategy by selecting numerous parameters and analyzing their outcome on the overall performance, in which involves software and hardware methods. Overall performances are optimized and verified by using a standard software and experimental prototype. In the field of flights duties, when high performance actuation are mandatory, Laxminarayana et al. [12] have presented a methodology for rotor design of BLDC for short duty high performance actuator. However, they have investigated and developed an optimum sized rotor. Nevertheless, it's found that the most critical parameters for achieving high accelerations of motor is in the choice of rotor shape and dimensions. From the designed model and obtained results, a prototype has been built and the tested parameters meet the input specifications. They conclude that the BDLC motor is one of the desired solutions from a compactness and design effort perspective.

A new design based on some significant factors as the length, thickness of magnet and the angle between the interior permanent magnets of a spoke-type BLDC motor. By using a ferrite Fe-PM magnet instead Neodymium Nd-Pm has been presented by Man-Seo et al. [13], in their work, the authors conclude that by changing the angle between the permanent magnets, the usage of PM can be maximized. They also conclude that the cogging torque and torque ripple may be reduced although a rotor surface structure alteration.

Methods of artificial intelligence have been used for optimal design of electrical machines especially BLDC motor. However, an optimal multi-objective design method using improved bees algorithm [IBA] of a slot-less permanent magnet brushless direct current motor has been presented by Alireza et al. [14]. The obtained results show that the developed approach has better performance and the convergence speed has been enhanced. Rahideh et al. have been presented a method for the optimal design of a slotless permanent magnet brushless DC (BLDC) motor with surface mounted magnets using a genetic algorithm with constrained objective function. However, the objective of the proposed function covers the power losses, material cost and volume of the motor besides the mechanical and electrical requirements. The results obtained show the effectiveness of the proposed technique [15]. Hadef et al. in their work [16] describes the optimal design of a permanent magnet synchronous motor on the basis of a systematic inverse problem. The proposed function has improved in the torque by optimum choice of the thickness and arc of magnet pole. The simulation results obtained by using finite element and compared to analytical design indicate the usefulness of the proposed strategy.

This work is motivated by the ever increasing use of brushless permanent magnet motors in industrial applications [17]. It is focused on choice and determination of important parameters of the machine dimensions by using inverse problem methodology to increase flux density in the air gap with several variables and constraints. Timely, the design problem has been solved by combining the optimization algorithm with analytical models of simple design. The methodology is effective, but the solutions provided cannot meet perfectly the specifications because of overly restrictive simplifying assumptions of the used models.

Our objective is to propose more accurate approach by taking advantage of the advanced technology in computer performance and the easy use of numerical techniques such as finite element method. The proposed new methodology design of a BLDC motor combines optimization algorithm and analytical model. The solution is validated by finite element method. Finally, the developed methodology makes it possible to solve design problems more reasonably and it is ideal to propose solutions that satisfy imposed conditions.

The paper is organized as follows. Section "Motor equivalent magnetic circuit and geometry analysis" presents the equivalent magnetic circuit and the geometry analysis of the BLDC motor. Section "Sequential Quadratic Programming" describes the programming Sequential Quadratic Programming (SQP) approach. Section "Optimization and design procedure" provides and explains the optimization and design procedure. Section "Optimization results and discussion" dedicated to results and comparison of obtained characteristics and compared to those obtained analytically. Finally, Section "Conclusion" concludes the paper.

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