HAL open science

Multi-objective Optimization based on Polynomial Chaos Expansions in the Design of Inductive Power Transfer Systems

Yao Pei, Lionel Pichon, Mohamed Bensetti, Yann Le Bihan

To cite this version:

Yao Pei, Lionel Pichon, Mohamed Bensetti, Yann Le Bihan. Multi-objective Optimization based on Polynomial Chaos Expansions in the Design of Inductive Power Transfer Systems. 6th International Workshop on Optimization and Inverse Problems in Electromagnetism, Sep 2021, Szczecin, Poland. hal-03374275

HAL Id: hal-03374275

https://hal.science/hal-03374275v1

Submitted on 12 Oct 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Multi-objective Optimization based on Polynomial Chaos Expansions in the Design of Inductive Power Transfer Systems

Yao PEI, Lionel PICHON, Mohamed BENSETTI and Yann LE BIHAN

Université Paris-Saclay, Centrale Supélec, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, 91192, Gif-sur-Yvette, France;
Sorbonne Université, CNRS, Laboratoire de Génie Electrique et Electronique de Paris, 75252, Paris, France.
E-mail: yao.pei@centralesupelec.fr

Abstract. In this paper, a new methodology combining the Polynomial Chaos Expansions (PCE) and Non-dominated Sorting Genetic Algorithm II (NSGA-II) is proposed to design inductive power transfer (IPT) systems. The relationship between the outputs (mutual inductance and leakage flux density) and structural parameters (coils and ferrite shape, size, thickness) is expressed by a PCE metamodel. Then, this metamodel is set as the objective function and the NSGA-II is used to obtain an optimal design with a trade-off between these outputs. In addition, a sensitivity analysis directly available with this PCE metamodel shows how the structural parameters influence the outputs. This method successfully provides the Pareto front and strongly saves the computation time.

Keywords: inductive power transfer, multi-objective optimization, polynomial chaos expansion.

INTRODUCTION

In order to design a highly-effective inductive power transfer couplers, a large number of design parameters need to be taken into account by using an analytical design approach or numerical simulations. In [1], the majority of the design procedures consider a parametric sweep with 2D finite-element models (FEM) and multi-objective optimization involving the transfer efficiency and the area-related power density without stray field constraints. In [2], a genetic algorithm optimization for three different IPT applications is presented, while details of the optimization process and results are omitted. In [3], a multi-objective real-numbered particle swarm optimization algorithm is employed to generate an optimal design of coils and ferrites. However, the study is limited to a 2-D axisymmetric design environment. In [4], the normalized Gaussian network for the topology representation on the ferrite volume and Non-dominated Sorting Genetic Algorithm II for the transfer efficiency and safety are applied to the design of the coupler in the IPT system, but it only optimizes the shape of ferrite. However, in recent literature, there are quite a few papers considering the multi-objective optimization with a 3D FEM model because it is very time-consuming.

In this paper, we present a new method to perform the multi-objective optimization for an IPT system in order to find an optimal design at a low computational cost. First, the IPT coupler is studied with a 3D FEM model for a wide range of design parameters. Then, a relationship between the outputs (mutual inductance M and leakage magnetic flux density B) and structural design parameters (coils and ferrite shape, size, thickness and so on) is expressed by a polynomial chaos expansion (PCE) metamodel. Secondly, this metamodel is used to evaluate two objective functions: the first objective is to maximize the transfer efficiency through the mutual inductance, the second objective is to minimize the leakage flux density near the electric vehicle to prevent health and safety. Hereafter, NSGA-II is proposed to find the Pareto front between the mutual inductance and the leakage flux density and generate the final optimal design.

DESCRIPTION OF THE METHOD

Let consider the practical IPT configuration studied in GeePs for Vedecom [5] (presented in Figure 1). Normally the input parameters X can be geometric values, material properties, frequency, etc., but here it is considered to be these six independent parameters in Table 1. A PCE metamodel is established to simulate the varying trend of the mutual inductance M (unit: μH) and the leakage magnetic flux density B (unit: μT). In (1), Y is the vector output including both M and B. The polynomial expansion of Y is built from the input samples deduced from 3D FEM modeling computations for the given range of parameters.

(1) $$Y(X) = \sum_{i \in \mathbb{N}^N} \hat{c}_i \Phi_i(X)$$

where $\Phi_i(X)$ are multivariate polynomials basis functions with coefficients $\hat{c}_i$. i is a multi-index that identifies the components of the multivariate polynomials Φ_i [6].

Then according to the PCE metamodels for M and B, NSGA-II [7] is used to find the Pareto front very efficiently, as shown in Figure 2. Since the evaluation of the metamodels requires a very short time, the optimization procedure is very fast.

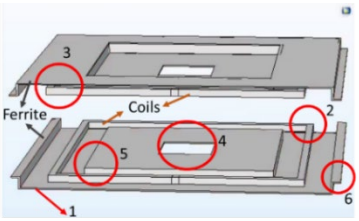

Figure 1: Structural parameters of the IPT system.

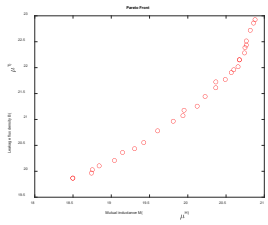

Figure 2: Pareto Front of M and B.

Table 1: Structural parameters ranges.

Number in Figure 1	Structural Parameters	Min (mm)	Max (mm)	Distribution
1	Thickness of ferrite	2	10	Uniform
2	Size of the corner	1	60	
3	Distance between the coil and ferrite	5	15	
4	Size of the inside edge	1	150	
5	Size of the inner boss square	300	400	
6	Width of the border edge	10	30	

A deeper sensitivity analysis with more details will be presented during the workshop.

REFERENCES

[1] R. Bosshard, J. Kolar, J. Muhlethaler, I. Stevanovic, B. Wunsch, and F. Canales, "Modeling and η-α-Pareto optimization of inductive power transfer coils for electric vehicles," IEEE J. Emerg. Sel. Topics Power Electron., vol. 3, no. 1, pp. 50–64, Mar. 2015.

[2] P. Ning, O. Onar, and J. Miller, "Genetic algorithm based coil system optimization for wireless power charging of electric vehicles," in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC), Jun. 2013, pp. 1–5.

[3] J. Han, Y. D. Kim, and N.-H. Myung, "Efficient performance optimisation of wireless power transmission using genetic algorithm," Electron. Lett., vol. 50, no. 6, pp. 462–464, Mar. 2014.

[4] Y.Gong, Y.Otomo and H.Igarashi. Multi-objective topology optimization of magnetic couplers for wireless power transfer. International Journal of Applied Electromagnetics and Mechanics, 64(1-4), 325-333, Dec.2020.

[5] M. Bensetti, M. Debbou, K. KADEM, E. Laboure and Y. Lebihan. Coupleur inductif et système de recharger par induction magnétique pour véhicules électriques et hybrides. FR3094832A1, WO2020208313A1.

[6] S. Marelli, B. Sudret, UQLab user manual – Polynomial chaos expansions, Report # UQLab-V1.3-104, Chair of Risk, Safety and Uncertainty Quantification, ETH Zurich, Switzerland, 2019.

[7] K. Deb, S. Agrawal, A. Pratap, et al, "A fast elitist non-dominated sorting genetic algorithm for multi-objective optimization: NSGA-II," International conference on parallel problem solving from nature, pp. 849-858, 2000.