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Imaginary machine design: proposal of concepts, principles and a methodology as a new paradigm for preliminary design by optimization of engineering system

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Abstract This paper outlines the importance of the early steps of the design of engineering systems (the so called preliminary or sketch phase design). If those steps should be probably addressed by an optimization approach, we suggest an approach much more focused on the feasibility of the formulated optimization problem (the so called “Problem Setting Phase”), than on the research of the optimal solutions (the so called “Problem Solving Phase”), that we propose to address later in the design process. That is why, this paper proposes an approach called “imaginary Machine Design” (IMD). The fundamental principle of IMD is a reformulation of the design problem, initially formulated as a discrete optimization problem in a real design space, toward a continuous and differentiable optimization problem in a design space of “Imaginary Machines”. Besides the synthesis of the concepts, principle and methodology of the approach, we show the efficiency of this approach for the preliminary design of electromagnetic devices thanks to an overview of studies and results obtained for static converters, rotating machines and positive energy buildings.

Keywords: Preliminary or sketch design, optimization, static converters, rotating machines

List of acronyms - IM: Imaginary Machines, RM: Real machines, PD: Preliminary Design, FOO: First Order Optimization, ZOO: Zero Order Optimization, RDDP: Real Discrete Design Problem, IMD: Imaginary Machine Design, ICDP: Imaginary Continuous Design Problem, IPF: Imaginary Pareto Front

THE IMPORTANCE OF PRELIMINARY DESIGN AND THE NECESSITY OF A NEW APPROACH OF OPTIMIZATION FOR THIS CRITICAL DESIGN PHASE

It is now well understood, that the early steps of a design process (or PD for Preliminary Design) represent only a fraction in the total cost of an engineering project (about 5% to 10%). However, the choices made during these first steps will impose the greatest part of the final costs (up to 80%) [1]. Thus addressing PD is a fundamental issue. We will show that it could be addressed efficiently by optimization thanks to an important change of view. Indeed, the actual dominant state of the art of optimization in engineering is, what we propose to call a Zero Order Optimisation (ZOO) Approach: The ZOO principle is to associate a simulation model seen, as a blackbox, providing outputs as functions of inputs, to an optimization algorithm that is, very often, a stochastic algorithm (typically a genetic algorithm like NSGAI). If efficient in the advanced design steps, this approach is probably not adapted for PD (can be slow, limited to a restricted number of parameters and constraints - no more than 10 to 20, ...).

IMAGINARY MACHINES AND IMAGINARY MACHINE DESIGN (IMD) AS A NEW APPROACH FOR PRELIMINARY DESIGN OF ELECTRICAL DEVICES

The paper argues the need to introduce First Order Optimisation (FOO) as a new complementary approach much more adapted to PD. FOO means the use of optimization with deterministic algorithms like SQP [1] (Sequential Programming) and models differentiable with gradients computation in order to make preliminary optimization in the continuous searching space. This continuous searching space contains what we call Imaginary Machines (IM). IM can be defined relatively to Real Machines (RM). On the contrary to RM that have discrete parameters and topologies and that can be built in the real world, IM cannot be built. However IM can be perfectly designed and/or optimized. An important property is :

RM are a subset of IM. Thus, if the set of feasible IM solutions is empty, it implies that the set of feasible RM machines is also empty. This allows understanding that IM can be used to prove that the proposed formulation of the optimization problem is definitely not feasible, and must then be renegotiated or relaxed. Besides other examples and applications, the paper will show how the introduction of the concept of IM is particularly adapted for PD with very interesting properties for this design steps like speed, the capacity to manage hundreds to thousands of constraints and parameters, ... From a scientific point of view, we will also argue that this deployment of FOO for PD, defining what we call Imaginary Machine Design, is a novelty:

- Firstly, by proposing a “new way of thinking“ for PD, that consists to focus more on finding the right formulation of the design specifications formulated as an optimisation problem with objectives and constraints (“Problem Setting”) than finding directly the final solutions (what must be the goal of latter “Solving problem” design phases in which ZOO approach will be entirely pertinent).
- Secondly, by proposing a scientific challenge that is to develop methods and strategies to reformulate a Real Discrete Design Problem (RDDP) (in which many parameters are discrete with several combinations of technologies, topological alternatives), in an Imaginary Continuous Design Problem (ICDP). This corresponds to a mathematical immersion from RDDP to ICDP.

APPLICATION OF IMAGINARY MACHINE DESIGN(IMD) TO PRELIMINARY DESIGN OF ELECTRICAL DEVICES

The paper will present an overview of studies in which IMD has been used successfully for PD from static converters, to rotating machines [3] and systems like Energy Positive buildings [2] by introducing among others, the concept of Imaginary Pareto Front (IPF). Besides the results, we will define and present the different mathematical projection from RDDP to ICDP we have identified for Electrical Machines (“Projection by Extension” applied to static converters or rotating machines for parameters like inductance or number of wires for inductance, “Projection by Immersion” applied to static converters for discrete parameters like the number of legs of the converter [4]).

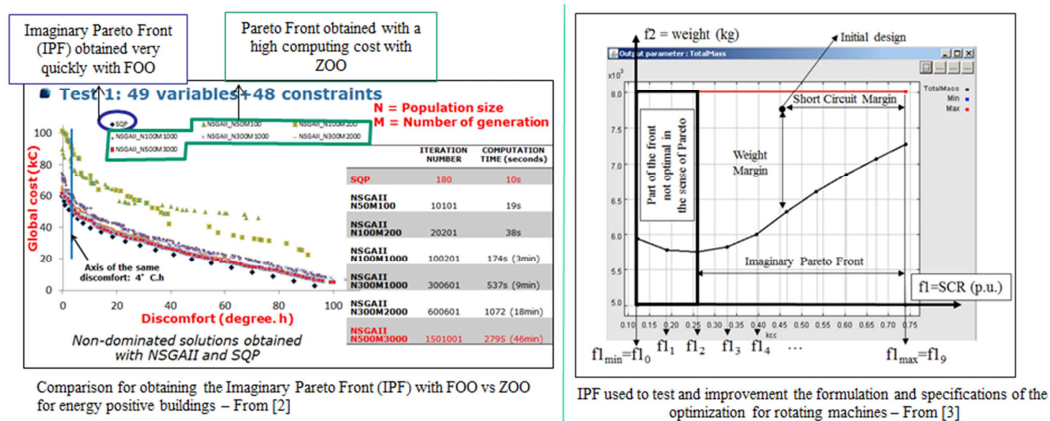


Figure 1: Studies and results in which IMD has been used successfully for PD of Electrical Machines

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