The Imaginary Pareto Front: a helpful Tool for setting Optimisation Problem for Design of Electromagnetic Devices

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Abstract — This paper suggests that "Setting Optimisation Problem" is an important bottleneck in the practical use of optimization for design of electromagnetic devices. "Setting Optimisation Problem" means in particular finding the "right formulation of the constraints" on the inputs and outputs of the optimization problem. This problematic can certainly become a research topic in which concepts, methodologies and tools should be developed. As an example of this, this paper proposes a concept called the Imaginary Pareto Front (IPF). We will show how it that can be used in order to check very quickly the constraints formulation of an optimization problem, based on a continuous model in which some parameters are discretized. This will be illustrated on the design of a round-rotor synchronous generator.

I. INTRODUCTION: PROBLEM SETTING A NEW CHALLENGE FOR OPTIMISATION

Many scientific literatures exist that tries to define what is design [1]. Some new theories in design demonstrate the importance of distinguishing two fundamental steps:

1° The problem setting (or problem formulation): here the designer must formulate the design problem. For optimization it means defining what are the objectives, what are the constraints on all the inputs and outputs of the model of the device. The work and the main difficulty for the designer in this step is to find a well posed problem, it means a formulation of the problem that accepts at least one solution. We have to pay attention to the fact that this can be really a hard task, especially in industrial context when there are a very great number of input and output parameters. In such a context, the risk is very high for designers to introduce bad constraints, or conflicting constraints, resulting in the fact that the formulated problem simply has no solution, or a too small searching space.

2° The problem solving: here the searching space is defined, so to problematic is now to explore it, what can be done automatically thanks to optimization algorithms that can be deterministic [2] or stochastic [3].

This paper is a contribution to a research topic that could be called "Problem Setting". For this research topic, we will more especially show that a concept, called the Imaginary Pareto Front (IPF), could be very useful. We will define what an IPF is, and we will expose a methodology for obtaining it very quickly (which is a very important property: in problem setting step the designer needs tools that allow him to test and to reformulate quickly the problem). We will show why this IPF provides information to designers related to some questions related to "Optimization Problem Setting": does the formulated problem admit solutions and does the size of the searching space defined by the formulation seem correct?

II. THE CONCEPT OF IMAGINERY PARETO FRONT AS A HELP FOR SETTING THE OPTIMISATION PROBLEM

An Imaginary Pareto Front (IPF) is, first of all, a Pareto Front [4]. A Pareto Front (PF) can be defined for an optimization problem with:

- at least two contradictory objectives f1 and f2 to minimize or to maximize (f1 can be typically the efficiency to maximise and f2 the weight to minimize)
- a Constraint Formulation (CF): a set of constraints (equalities and inequalities constraints) on all the inputs and outputs of the optimization problem
- a Model (M) linking the output to the input parameters.

The Pareto Front (PF) is the set of solutions calculated with the model (M), respecting the Constraint Formulation (CF), and that are best compromise between f1 and f2. For this, we introduce the notation:

PF(max or min f1, max or min f2, CF, M) (1)

What we call an IPF can be defined over models of electromagnetic devices, which we will call, "Continuous Sizing Models" (CSM) and that have the following properties:

- some of the parameters of the model are discrete (typically the number of tooth N1, the number of poles P, …)
- but the underlying model linking all the parameters together is continuous. This is typically the case of analytical and semi-analytical models defined by designer for the first step of the design (like in [5]). Very often those models are analytical or semi-analytical, uses approaches like equivalent circuits or reluctances networks.

A "Continuous Sizing Models" (CSM) allows calculation on "Imaginary Machines" (IM): machines with a number of tooth or poles that are not integer values (for example N1=75.732 or P=4.506). By opposition, "Real Machines" (RM) are the machines that can be built in the real world and that typically have discrete values for parameter like N1 and P.

What we will call the Imaginary Pareto Front (IPF), is the continuous Pareto curve that we can be built over the CSM, by letting the discrete parameters varying continuously with a current set of Constraints Formulation (CF) and at last two contradictory objectives functions f1 and f2. For this, we introduce the notation:

IPF(max or min f1, max or min f2, CF, CSM) (2)

III. THE METHODOLOGY FOR OBTAINING THE IMAGINARY PARETO CURVE

An IPF can be obtained very quickly thanks to the following procedure (described here for obtaining *IPF(max f1,min f2,CF,CSM)* like on fig. 1):

<u>A° Find the possible values of f1</u> ($f1_{min} \leq f1 \leq f1_{max}$): for this solve the two following optimization problem

- minimize f1 with f2 free, with constraints CF over CSM: this allows to obtain $f1_{min}$
- maximize f1 with f2 free with constraints CF over CSM: this allows to obtain $f1_{max}$

<u>B° Find the shape of the IPF:</u> for this solve the n following optimisation problems:

- manimize f2 with $f1=f1_k$ and constraints PF over CSM with $f1_k = f1_{min} + k*(f1_{min}- f1_{max})/n$

This procedure is easy to implement. Each of the previous optimization problems can be solved with a gradient optimization algorithm like SQP (Sequential Quadratic Programming) [2], that has the advantage to be quick and to take into account very efficiently constraints, even if they are in high number. Since the CSM is continuous, the formal right sensitivity can be computed, and thus improve drastically the performance of the SQP algorithm. Fig 1 gives an IPF built with the previous methodology for the example of IV.C. Fig. 2 shows the continuous evolution of the N1 parameter (representing the number of slot of the machine) along the IPF.

IV. USEFULNESS OF THE IMAGINERY PARETO CURVE FOR SETTING THE OPTIMISATION PROBLEM

A. *Properties of theImaginary Pareto Front (IPF)*

First of all we have to insist on two properties of IPF's very important for the designer in Problem Setting phase:

<u>- Property 1°:</u> the IPF is very rapid to obtain: IPF of fig. 1 is obtained is 23 seconds for a CSM model of industrial complexity (see IV.C).

<u>- Property 2°:</u> by definition an IPF is a continuous curve so we can get a good idea of its shape with calculation of some points and extrapolation like in fig. 1.

B. *Practical use of the Imaginary Pareto Front (IPF) for testing the problem formulation*

After having obtained in a short time this IPF, the designer can very quickly have:

- <u>Information about "Is the problem well posed ?":</u> if the IPF can not be build thanks to procedure described in III, it is a serious alert indicated that the problem is bad posed. This seems to indicate that it exist no Imaginary Machines that respects the constraints in CF (in this case no real machines exist also, since we can demonstrate that the set of real machines is a subset of the set of imaginary machines). In this case, the designer should check the constraints in CF and reformulate the problem.

- <u>Information about "Is the search space wide enough ?":</u> An idea of this could be given to the designer if, like on Fig. 1, he puts an initial design on the same plane than the IPF. This initial design can be a previous existing machine [5], or a machine that the designer has defined in order to develop his CSM. He can then measure the margin existing between this initial machine and the front as illustrated on Fig. 1 (see Weight Margin and Short Circuit Margin). As we will show it in the full paper those margins can be increased by changing the constraints formulated in CF. The designer can by this way refine his formulation of constraints in order to define large enough margins in order to give the best chances to find real machines inside those margins.

C. *Application to an industrial Round-Rotor Synchronous Generator*

IPF of fig. 1 and result of fig. 2 have been obtained on the CSM model of an industrial Round-Rotor Synchronous Generator described in [5]. f1 is a short circuit factor (called in [5] Short Circuit Ratio) that has to be increased and f2 is the weight that has to be decreased. The CSM has over 60 input parameters and 120 output parameters. This application with industrial complexity shows the efficiency of the approach.

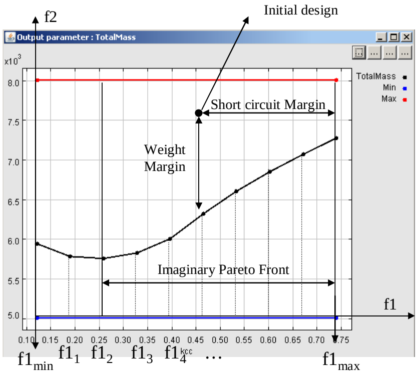
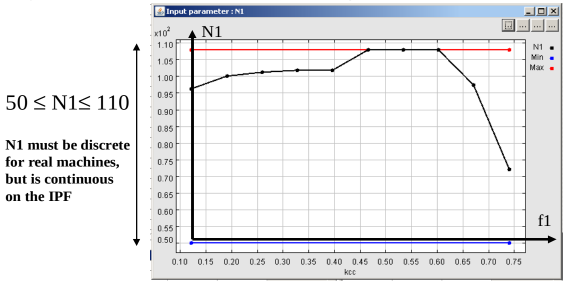


Fig. 1. Imaginary Pareto Front (*IPF(max f1,min f2,CF,CSM)*) of a Round-Rotor Synchronous Generator motor (f1= weight, f2=short circuit factor)



$50 \leq N1 \leq 110$

N1 must be discrete for real machines, but is continuous on the IPF

Fig. 2. Evolution of N1 (number of slots) on the IPF

V. REFERENCES

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