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A METHODOLOGY FOR SOLVING “ILL POSED” OPTIMIZATION PROBLEM. APPLICATION TO AN ELECTRICAL POWER CHANNEL OF AN AIRCRAFT

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Abstract. Setting and formulating system design problems into mathematical optimization problems is not always straightforward especially when constraints associated with the system components are not clearly defined or well known. In this paper, the authors propose a methodology based on the Pareto front analysis in order to help designers to solve this kind of problems. This approach is directly applied to the optimization of an aircraft electrical system.

Keywords: Auto-Transformer-Rectifier-Unit, System Design, Multiobjective Optimization, Pareto Analysis

I. INTRODUCTION

The design of electric aircraft systems today has grown in complexities because of the increase of heterogeneous elements coupled through different physical fields (i.e. electrics, hydraulics, mechanics and thermodynamics). On the other hand, in the more electric aircraft trend, many hydraulic devices are replaced with equivalent electric systems [1]-[3]. This leads to major changes of the electric network architecture and significant modifications of the onboard energy management strategy. In this context of strong evolution, the new constraints which should be respected by the electrical elements are not clearly identified. This increases the difficulty of formulating the system and component sizing into a standard optimization problem which can be solved by optimization algorithms [4]. In this paper, we study the design of an Auto-Transformer-Rectifier Unit (ATRU) system [5] in order to illustrate this kind of design problems. In particular, we distinguish two classes of problems:

–“well-posed” problems: such problems even complex (i.e. containing lots of equations, variables and constraints) should be solvable by an optimization algorithm implemented on a computer.

–“ill-posed” problems: such problems cannot be directly solved by a computer and an optimization algorithm. This is due to the fact that data are incomplete, ambiguous, and unreliable to formulate completely and definitely the optimization problem (e.g. some constraints or limits on components are unknown). In this case, the designer has to do *a priori* choices and to manage the risks associated with these choices. In this paper, a methodology based on the Pareto analysis [6] is proposed in order to help the designer to manage the difficulty relative to such “ill-posed” problems. This methodology is applied for two different test cases: when the constraint limit of a component in the system is unknown and then when a set of constraints, defining a standard with respect to the component, is not well defined. This approach is applied to the optimal sizing of a power channel for an electrical aircraft system.

II. INTEGRATED OPTIMAL DESIGN OF A POWER CHANNEL

We focus on the ATRU optimization for an aircraft electrical power distribution network. The objective is to minimize the ATRU mass while fulfilling its integration into the power channel.

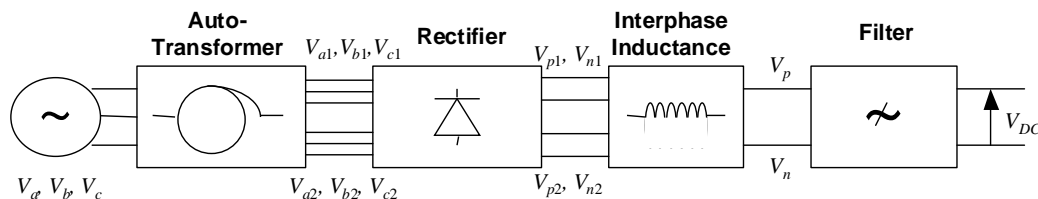


Figure 1. The ATRU based mixed network structure

A “well-posed” problem “Minimize the ATRU mass while fulfilling the DC voltage and the AC input current harmonic standards” has been solved in [5]. In the present paper, two “ill-posed” problems are presented and solved with a Pareto analysis approach.

II.1 Solving the problem when a constraint on a component is unknown

Problem: In system optimization, a constraint on a component can be unknown. The designer can then define an approximate value of this constraint, but there is a risk to do this. If the constraint value is not well-chosen, the result given by the optimization can be “sub-optimal”. In our application, the ATRU has to be sized so that the circuit breaker integrated on the DC bus interrupts the short circuit currents. The level of assigned short-circuit current is a constraint. If this value is unknown and chosen too low by the designer, the ATRU will be “oversized”. On the other hand, if the value is too high, the circuit breaker will be “oversized”.

Approach: In order to help to designer to set a relevant value of the ATRU short circuit current while minimizing the power channel mass, we propose to convert the monoobjective optimization problem into a multiobjective one. In the ATRU case, this consists in finding the best tradeoffs between the unknown constraint value (i.e. the short circuit current) and the ATRU mass. This can be performed using a multiobjective optimization algorithm (e.g. NSGA-II [6]). Fig. 2 illustrates the optimal Pareto front associated with our example. The Pareto analysis of the best compromises helps the designer to set the suitable value for the ATRU short circuit current. It can be seen from Fig. 2 that a reasonable value for the unknown short circuit current is roughly 1800 A. Below this value, the weight of the ATRU increases very quickly. Over this value, there is no interest to increase the value of the short circuit current, because there is no real impact on ATRU weight.

II.2 Solving the problem when a standard is not well defined

Problem: Components of a system are generally designed and provided by different suppliers to the system integrator. The components have to fulfill standards generally defined by the integrator. It should be noted that in the case of the more electric aircraft, standards are not completely defined because of the lack of exploitation feedback for the moment. If the standards are too restrictive, the system objectives (e.g. mass, efficiency) might be sub-optimal. On the other hand, if the standards are not enough constrained, the network quality (e.g. reliability and lifetime) might be affected.

Approach: As in the previous case in II.1, a multiobjective formulation can be used in order to transform the “ill-posed” problem into a “well-posed” problem that can be solved using multiobjective optimization methods. Finding the best tradeoffs between the primary objective and the deviation to the most critical standards can help the designer to redefine the standards with respect to the system optimization.

As example, we investigate the ATRU mass minimization in compliance with a standard related to the quality of the input AC current. It is required that the harmonics of the input current respect the following standard:

$$\text{ThIe}_i \leq \text{ThIe}_{\max_i} \quad (i=2..37)$$

$$\text{ThIe}_i = I_i / I_{e1} \quad (I_i, I_{e1}: \text{rms values of } i\text{th harmonic and fundamental value of the AC current})$$

ThIe_{\max_i} : standard value that limits the ThIe_i value.

It will be shown in the final paper that only the standard value of the 5th harmonic (ThIe_{\max_5}) is actually influent on the ATRU mass optimization. Thus, if this value is not well-known, the Pareto-optimal front corresponding to the ThIe_{\max_5} minimization and the ATRU mass minimization shall be determined (see Fig. 3). According to this figure, a reasonable value for ThIe_{\max_5} is around 0.023. Below this value, the ATRU mass increases very quickly. Over this value, there is no interest to increase the value of ThIe_{\max_5} because the ATRU mass reduction is not significant.

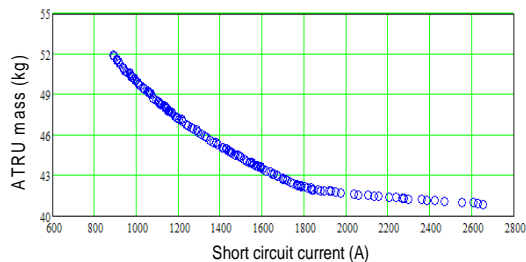


Figure 2. Pareto-optimal front (ATRU mass and short circuit current minimization)

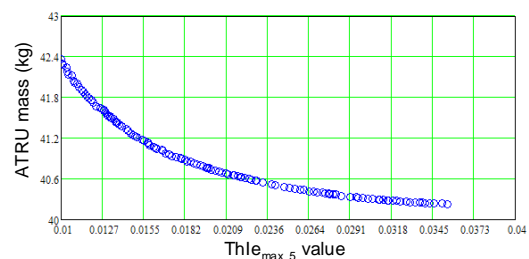


Figure 3. Pareto-optimal front (ATRU mass and ThIe_{\max_5} minimization)

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