Multi-objective Optimization dedicated to the design of MEA Equipment

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Abstract

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Les convertisseurs statiques : percées dans les applications

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Abstract

The main purpose of this paper is to introduce a new methodology of constrained optimization answering to the challenges of the new electrical networks powering the future aircrafts. The new concept of the “more electrical aircraft” (MEA) is looking forward to replace the hydraulic and pneumatic systems by electrical ones. Inclusion of new electrical networks is a solution to reduce dramatically the total aircraft weight and therefore fuel consumption, though it requires an advanced work to decrease mass, volume and cost of electrical systems, while maintaining a high reliability. In this context, this work presents a new detailed methodology of optimization respecting the thermal and EMC issues, while reducing the volume, weight and cost objectives. This method of pre-design is also really efficient to determine in a minimum of time and with an ease of convergence, the best topology and technologies to operate for a specified avionics function.

1. Introduction

In the MEA context, new electrical architectures have appeared, like an HVDC network 540-28V [1][2]. The design of lighter, integrated and more efficient converters, while respecting restrictive constraints, becomes a complex challenge. The main current problems concern the heat transfer, EMC management, the volume and weight integration and the recurrent cost. Nowadays, no tools are really able to design directly “the optimal” system according to a specification. Only the experience of a qualified designer can solve this kind of problem. However it takes more time and lets sometimes an uncertainty about the optimum of the results. For a few years, the research has improved the computational design and proposed several methods to optimize some parts of the electrical systems [3][4][5]. This paper has the ambition to present a new methodology, more global than the previous methods found in the bibliography. It proposes a beginning of a solution regarding a global and multi-objective optimization, while ensuring a fast computing time and an ease of convergence. The first part introduces the pattern design of the different models and explains how they interact each other.

2. Methodology

a. Component Models

In the real world, all properties of a component are fully defined when its shape, dimensions and materials are specified, as shown in figure 1. For instance, a capacitor can have a round or rectangular shape, be electrolytic, ceramic or filmed, with variable dimensions according to its internal characteristics. From these properties, it is quite easy to deduce the main outputs needed to a pre-sizing, which are the weight and volume, the cost or the electrical and thermal model. In order to get these outputs, a computation tool composed of analytical equations, physical and empirical databases is needed. The method of calculation is explained in [6]. Figure 1: Component Philosophy for the moulding from the geometry-shape-material b. Composite and System Models

As it had been said, the objective is to optimize the whole electrical system. Usually, specifications in aeronautics are given for systems and not for components (DO-160[7]...). In order to accomplish this task, the electrical, magnetic and thermal
models of all the components must be combined. These models are included in an optimization loop and the optimal solution is obtained. A simple example of a composite system is the case of a LC filter, which is an assembly of the components “inductor” and “capacitor”, as shown in the table 1 and 2. This example will be detailed in the final paper. Figure 2: Complexity levels for the component Capacitor c. Modeling Complexity All models should have different levels of modeling, sorted by increasing accuracy. Harmonization of the levels is desirable between the different components. Obviously, the least accurate models must be simpler and faster to compute and used in a first phase to allow a broad but rapid exploration. On the contrary a higher level of accuracy implies a longer time of calculation and/or a restriction of the field of investigation. If a level of precision is not available for some items, a substitution rule should be defined. Four complexity levels are identified and will be detailed in the final paper. An example will also be done with the case of the capacitor models for instance, represented in the figure 2. Moreover, the level modelling makes possible to choose between different technologies depending on the complexity level. The technology choice will depend on the optimal operational point (frequency, temperature, voltage, current etc.) Level L C 0 1 C Lelec ESR ESR Table 1: Electrical models for the components Inductor and Capacitor Level Filter LC 0 1 C Lelec ESR C Lelec ESR Tble 1: Electrical models for the composite Filter LC 3. Main Constraints a. EMC Differential mode The purpose is to take into account the requirements of the network stability (HVDC directive requirements). The input impedance must ensure not to absorb too much current for a given voltage ripple. This is the reason why the parasitic components must be detailed in the electrical model in order to bias the filtering. An evolution of the complexity of the circuit is planned as a function of the accuracy level. This part will be detailed in the final paper as a function of the avionics directives. Common Mode This model takes into account the calculation of the main parasitic elements influencing the common mode perturbations of the system, especially the parasitic capacitance due to the isolation of the switching cell with the cooling system, as shown in the figure 3. This part will be detailed in the final paper as a function of the avionics directives and extended to multi-level topologies. Figure 3: Common Mode Model b. Thermal Considerations The calculation of the hot spot or the global temperature of a component can be made by different ways of complexity in order to get the thermal circuit. The main goal of this simulation is to compare different types of cooling technologies like the natural or forced convection with air or water. The cooling model can be extended to the use of a loop heat pipe, which is one of the new trends to cool embedded systems. The example of the forced air convection with an axial fan and heat sink with fins will be detailed in the final paper. 4. Main Objectives to minimize In the MEA context, three main objectives to minimize have appeared: the embedded weight, the recurrent cost, and the volume to integrate. a. Weight The weight is easily deduced from the inputs of the geometry and the associated materials characteristics. This part will be detailed in the final paper; and results of a sizing of a multi-level topology will be explained in the final example. b. Cost Consideration Thanks to information and databases, several cost models for each component have been built with the basis of [6]. This part will be detailed in the final paper. An example of the GaN semiconductor will be given, shown in the figure 4. Figure 4: GaN model Price with projection for the future c. Volume Consideration The final aim is to calculate a direct 3D integration in order to optimize the volume of the power converter, shown in the figure 5. This part will be detailed in the final paper; and results of the sizing of a multi-level topology will be explained in the final example. Figure 5: 3D integration of a power converter 5. Objective of this methodology a. Topology Optimization A recurrent problem to design a defined electrical system is the choice of the best topology according to a specification. The previous methodology allows to simulate sequentially different topologies in order to get the best choice. Another feature of this method is the setting of the multicellular and multi-levels topologies in order to define the best combination between the number of serial and parallel branches for the high and low voltages, with different calibers and types of semiconductors. This part will be detailed in the final paper and results will be explained in the final example, comparing different simple topologies (figure 6). Figure 6: Generic topology of a bidirectional multilevel buck-boost converter b. Technology Optimization The same method can be used to determine the best technology of a component with a defined topology thanks to a sequential algorithm: for instance the choice of the best magnetic material for a planar transformer, shown in the figure 7. An example will be detailed in the final paper. Figure 7: Improvement of the weight-cost-volume thanks to a new technology simulation 6. Application on a defined topology An example gathering all the previous parts in a global example optimizing a defined multi-level topology will be presented (figure 8). Figure 8: Topology to defined for an example of the previous part. 7. Conclusion A detailed methodology is presented in this paper in order to build a complete and global optimization of any power converter in an aeronautical context, shown in figure 9. This simulation allows to find the best multi-objective solution as a function of the weight, the volume and the cost, while considering the thermal and EMC issues. This tool allows to compare different topologies or technologies according to a specification, and resolve complex problems in a short time to support the work of the designer. References 1 X. 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Roboam, “Integrated optimal design for power systems of more electrical aircraft”, MEA2012, 2012 S Forest F., Brunello J., Bourdon J., Meynard T., “Modèles analytiques simplifiés des composants de puissance passifs et actifs pour la conception optimale de convertisseurs”, SGE 2014 6 Airbus Directives (ABD) and Procedures, ABD0100- Equipment-Design General Requirement for Suppliers, Issue C, 1998 COMPUTATION Internal variables Analytical equations Physical and/or Empirical Database GEOMETRICAL INPUTS Dimension-Shape-Material Thermal Losses Temperatures Hot Spots MATERIAL SPECIFICATIONS SPECIFICATIONS FROM SYSTEM LEVEL EMC Electrical Values Magnetic Values Parasitics Elements Weight Cost Volume
Thermal Nodal circuits Electrical Nodal circuits Magnetical Nodal Circuits Global Weight/ Volume Global Cost For each component STEP 1 External Solver Assembly of each nodal circuits component in a global nodal circuit Nodal Circuits of each component Thermal – Electrical - magnetical Aeronautical constraints Fixed Topology For all the components STEP 2 Figure 9: Sum up of the global methodology

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