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Multi-level integrated optimal design for power systems of more electric aircraft

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Abstract

This paper proposes a multi-level optimal design method for a complex actuation system of more electric aircraft. The multi-level structure consists in sharing the optimization process in several levels, here 2, a "system level" which involves main coupling variables and a "component level" with one optimization loop for each device. The interest of this method is to separate the optimal design of each component, making easier the convergence of loops. This method is applied to a relatively complex power conversion system including a high speed permanent magnet synchronous machine (HSPMSM) supplied by a pulse width modulation (PWM) voltage source inverter (VSI) associated with a DC-link filter. Its interest is shown through a comparison with classical design approaches employed in previous works.

Keywords: Optimal design; Multi-level optimization; ATC (analytical target cascading); Power integration

1. Introduction

Thanks to the significant advances in aircraft electric technologies, integration of electrical energy has significantly increased in the last century [3,4,10,16]. Fig. 1 shows the trend in the power demand in commercial aircrafts. The main advantage of more electrical architectures is related to energy management as electric generators are controlled to match exactly the demand of consumers, reducing thereby losses contrarily for example to pneumatic systems powered by bleed-air at the operating pressure of the engine, irrespective of the needs of the systems [9]. Additional advantages of electrical systems are due to the opportunity for an easier power management through shared sources [4]. Moreover, the potential of improvements in the power density (power to mass ratio) of electrical systems is seen as high [9] while hydraulic and pneumatic systems are stabilized being more mature. Table 1 resumes the benefits of electrical systems compared to hydraulic, mechanical and pneumatic systems [4]. However, a separate design process of all the different electrical systems would not lead to an important gain compared to conventional systems [1] (e.g. fuel burn, integrated mass and drag impact).

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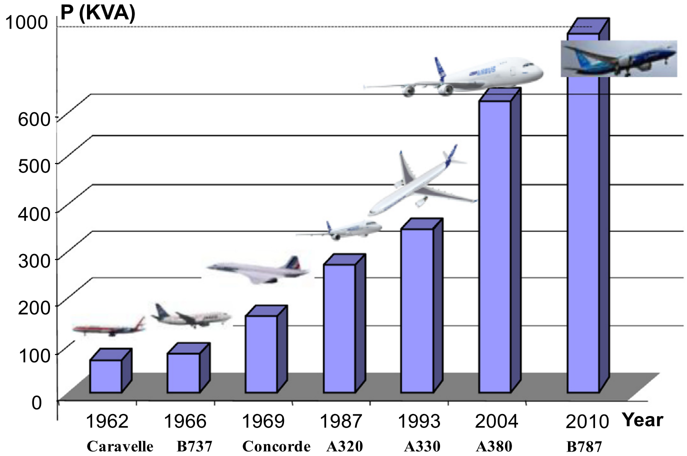

Fig. 1. Trend in commercial aircraft power demand.

Table 1
Comparison of aircraft secondary power distribution systems [4].

System	Complexity	Maintenance	Technological maturity
Electrical	Complex	Simple	System—Mature New technologies—Immature
Hydraulic	Simple	Complex and hazardous	Mature
Mechanical	Very complex	Frequent and slow	Very mature
Pneumatic	Simple	Complex	Very mature

In order to maximize the gain of electrical systems, all couplings must be considered in the design process, which means that coordination between different partners is essential to have a global optimal design instead of a set of local optimal designs which cannot ensure the optimality of the overall system. However, in this range of application, the complexity of the global design problem (number of decision variables, number of constraints, limits of optimization algorithms, separated expertise, "confidentiality problems") is far to be overcome by using simple design techniques involving an overall optimization ("all in one loop"). In this context, the interest of a multidisciplinary design optimization (MDO) has been proved [8,12]; it allows facing the needs of high-complex design problems by dividing the global system into subsystems that may correspond to different design teams which cooperate between them [12]. Several hierarchical formulations and coordination strategies are proposed in the literature: Cramer's [8] and Sobieski's [21] formulations, collaborative optimization [6,7], Wismer and Chattergy's coordination [25], Nelson's sequentially decomposed programming (SDP) [17] and target cascading [13,15,21] where local and global convergence are proved in [21].

In this paper, an integrated design problem of a complex multidisciplinary aircraft system is proposed. This system is composed of a HSPMSM (high speed permanent magnet synchronous machine) supplied by a pulse width modulation (PWM) voltage source inverter (VSI) associated with a DC-link filter. A multilevel formulation of the problem is proposed and results are compared to global and sequential formulations developed in [18]. Three parts are proposed:

– In the first part, we detail the analytical models of the different components of an electrical drive system for aircraft application (input filter, inverter and machine);
– In the second part, a "sequential" approach is applied to the aircraft system and compared to the global optimization approach;
– The last part deals with a multi-level optimization method applied to the aircraft system.

2. System model

This example refers to the integrated design of an electrical power system including a HSPMSM supplied by a VSI associated with an input filter (Fig. 1). The actuation mission is ensured by the HSPMSM motor which must operate