



More Electricity in the Air: Toward Optimized Electrical Networks Embedded in More-Electrical Aircraft.

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More Electricity in the Air

*Toward Optimized Electrical Networks
Embedded in More-Electrical Aircraft*

XAVIER ROBOAM, BRUNO SARENI,
and ANDRÉ DE ANDRADE

Along with the main trends and future challenges of electrical networks embedded in more-electrical aircraft, this article also focuses on optimization efforts in the field of industrial electronics and energy conversion. Optimization can be achieved by the means of expertise or from classical analysis methods, especially those based on simulations. However, novel approaches based on optimization algorithms, so-called integrated design by optimization, are becoming increasingly mature and will become particularly powerful if subsequent efforts are made in terms of modeling for design. In the first part, the current context and new standards of the more-electrical aircraft are summarized. The second part deals with the new trends and challenges

of more electrical aircraft, with an emphasis on reversible and hybrid high-voltage dc networks including new storage devices. However, this discussion will mainly focus on systems optimization. Methodological orientations toward integrated optimal design are discussed with representative examples, such as for an environmental conditioning system (ECS).

Current Context and Standards

The air traffic market is estimated to grow at 5% per year until 2020, in the context of strong competition between Europe and the United States, while new providers of commercial aircraft will appear in North America and Asia. The aerospace industry will have to face both economical and environmental issues. For example, civil aviation emitted some 2% of man-made CO₂ emissions into the atmosphere in 2008 [1]. It is often claimed that 1 kg saved on each flight could save roughly 1,700 t of fuel and 5,400 t of CO₂ per year for all air traffic. Furthermore, a decrease in mass would also be profitable in terms of cost: each kilogram of systems costs approximately US\$1,000.

Furthermore, mass saving would be profitable: a gain of 1 kg on the systems increases the price by approximately US\$1,000.

Thus, the aircraft manufacturing industry is placing greater emphasis on the use of technologies that can influence both the overall costs (design, operation, and maintenance) and fuel consumption. In addition to the aerodynamic structure and the engine optimization, equipment systems will also play a major role, especially in reducing operation costs with minimum maintenance and maximum availability.

More Electrical Systems and Power Needs

In this context, the rationalization of power sources has led engineers to an electrical aircraft design in which conventional devices are replaced by electrical systems [2]. This trend is depicted in Figure 1, which displays the

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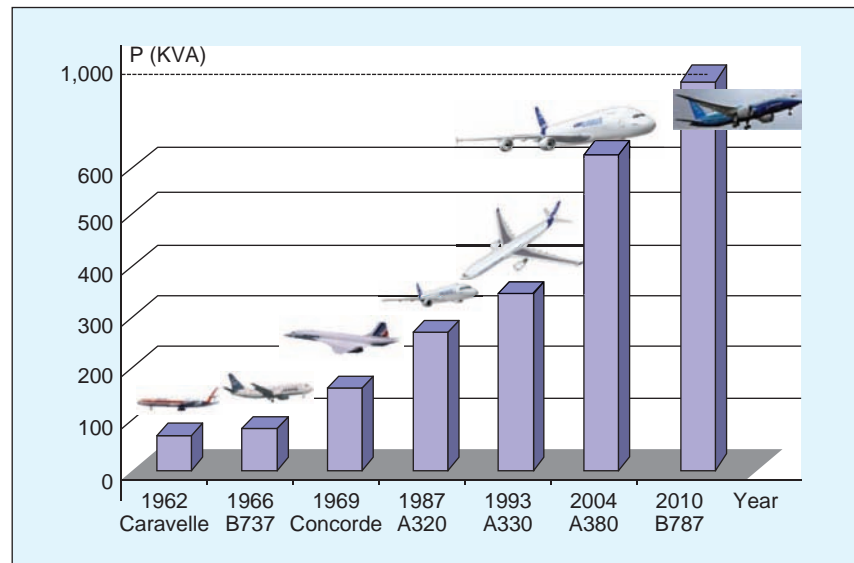


FIGURE 1 – Evolution of electrical power needs.

evolution of electrical power needs. So far, a conventional aircraft has four different integrated energy vectors (see Figure 2):

- pneumatic power for air conditioning, the wing ice protection system (WIPS) and engine start-up
- electric power for commercial loads and avionic systems
- hydraulic power for pumps and flight control actuators
- mechanical power to drive hydraulic or fuel pumps directly from the engine gearbox.

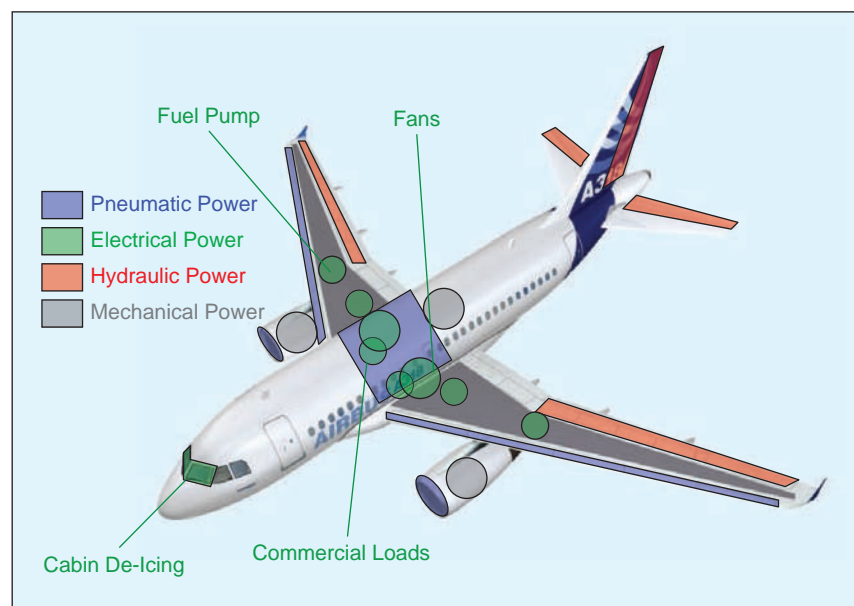


FIGURE 2 – Current architecture with four different energy vectors.

SiC is particularly attractive in terms of thermal conduction and technological maturity, while GaN would be the future low-cost device.

From Fixed to Variable Frequency Generation

The first generation of electrical networks was equipped with fixed-frequency (115/200 VAC 400 Hz) integrated drive generators as on the A320, A330, and A340. In order to simplify the constant-speed mechanical gearbox, the variable-frequency generators are preferred, as on the A380 and on the next A350, for which the voltage standard is doubled (230/400 VAC) with respect to the increase in electrical power needs. Certain prospective solutions for power generation have also been studied. For example, in the framework of the European Commission's Power Optimised Aircraft project [3], [4], Thales AES has proposed a permanent magnet generator directly as part of the engine [5]. The main challenges were thermal constraints (300 °C), safety (in case of stator short circuits), and high peripheral speeds.

Due to the introduction of variable frequency generation, several power loads supplied at fixed frequency, such as induction motor driven pumps, have been replaced with power electronically-fed loads compatible with variable frequency standards (360–800 Hz). For example, it was the case for flight control actuation systems in which electro-hydrostatic actuators (EHAs) were embedded on the A380 for hydraulic network backup. Inside this system, the inverter fed a high-power density permanent magnet synchronous machine (PMSM) driving a volumetric pump-jack association.

Another typical example of power electronics-based aircraft systems is linked to voltage conversion for avionics (28 V) systems [6].

These changes are typical of the current trends toward embedded power electronics, which represent

new challenges in terms of integration (mass decrease) and safety [5], [7]. A power/mass ratio greater than 4 kW/kg is currently considered to be available for applications such as dc/ac converters for drive supply. However, the power density strongly depends on various factors (power rating, environmental constraints, isolated converter or not, etc.). System integration in aircraft with filtering equipment (due to electromagnetic interference and network quality) and a cooling system may actually reduce this density up to 2 kW/kg. Furthermore, some power electronic devices have to face harsh environmental constraints in terms of temperature (–55 °C to ~200 °C), low pressure, humidity, vibrations, and radiation. A wide spectrum of applications is also concerned, but with a reduced number of delivered devices. Because the power device range is almost compatible (voltage, power, etc.), electrical and hybrid vehicles could drive aerospace technologies in the near future, even if environmental and safety constraints are slightly different.

Bleedless Architecture

With the B787 [9], Boeing has caused a major upset in the aeronautical world by speeding up the transition toward a more-electrical aircraft. A bleed-air-based ECS is currently embedded in conventional aircraft in which pneumatic power for air conditioning and de-icing is drawn from high-pressure hot air directly extracted from aircraft engines. Contrarily, in order to decouple engine operation with the air conditioning system, an electrical bleedless system has been proposed for air conditioning as well as for de-icing (WIPS). At the same time, certain loads classically powered by hydraulic networks were replaced by electrical

power loads (braking, pumps). The engine start-up, which was carried out so far with the bleed pneumatic network, is now electrically powered thanks to torque-controlled variable-frequency stator generators (VFSGs): the pulse width modulated voltage source inverter (VSI) dedicated to the ECS is also used on the ground to power the VFSG in motor mode to start the engine [8].

For a given size aircraft, the “bleed-less effect” should multiply by 4 the electrical embedded power by removing mechanical and pneumatic networks and partly suppressing hydraulic loads (4 × 250 kVA generators are embedded in the B787).

Why Is a More-Electrical Aircraft Better?

Beyond mass or fuel consumption reduction, the advantages of the more-electrical aircraft are found in power/energy rationalization and subsequent gains in terms of power management. The aircraft's operation costs include both the direct operating costs (fuel consumption, etc.) and the indirect costs linked to maintenance and availability. For example, 75% of late flights are due to system faults. An electrical device will not offer improved reliability but would increase availability thanks to the opportunity to isolate a subsystem in case of failure [31]. On the contrary, a hydraulic leakage in a device leads to the isolation of the entire circuit, which provokes a “No Go” fault. The failure of a hydraulic circuit is equivalent to an electrical bus bar failure, whose probability is 100 times less. It may even become possible to anticipate faults in the near future through the health-monitoring capacity. Anticipating failures of an electrical network would be possible through the behavioral modeling of systems coupled with fault-detection algorithms [10], [21]. For example, thanks to reflectometry devices, it is possible to detect and localize cabling fault within 1 m of accuracy. Fault-tolerant power electronic structures could also increase the availability of electrical systems [11].

Gains are also expected on the ground. On the one hand, an electrical ground card may replace all ground power services (air starters, aircraft hydraulic system, cabin pressure testing, etc.) by offering a better power rationalization. On the other hand, oversized “green” electrical ground services could be used instead of the auxiliary power unit (APU), which approximately burns 100 kg/h of fuel. Furthermore, using the landing gear system as a motoring system on the ground during the taxi phase, so as to allow airplane engines to idle back during this phase, would allow replacing pushback tugs with the expected triple benefit of reducing ground noise, fuel consumption, and CO₂ emissions [12]. The required power is almost 100 kW, which is compatible with the APUs of more-electrical aircrafts.

Several projects specifically dedicated to the more-electrical aircraft have been developed in the United States and Europe [4], [12], [13]. The European Union (EU)’s More Open Electrical Technologies (MOET EU) project [13] assembled 46 industrial companies and 15 research centers between 2006 and 2009.

New Challenges of More-Electrical Aircraft

More Integrated Power Systems

First of all, more-electrical aircraft will require powerful, compact, and reliable electronic devices in order to facilitate power system integration. New challenges exist in this field, especially with high-temperature devices (GaN, SiC) [14] that will allow high-temperature (~250 °C) operation with subsequent cooling device optimization and power integration. SiC is particularly attractive in terms of thermal conduction and technological maturity, while GaN would be the future low-cost device. Switching and conduction losses are also reduced with respect to classical silicon devices.

Beyond the power electronic device, several possibilities are also being studied for whole-system

Mechatronic integration is another way to reduce system weight as emphasized with the example of the electromechanical actuator for flight control actuation, braking, or landing-gear systems.

integration such as driver integration, powerful connection and passive devices (capacitances, inductances, etc.), and new concepts of cooling devices [15].

Specific constraints of embedded power electronics on board are related to the thermal and pressure environment: the latter parameter varies in the range from one to six. Thermal constraint is not so far from the typical temperature range for ground transportation. In contrast, low-pressure operation at high altitudes is specific for an aircraft and may impact power electronic devices in nonpressurized zones as for flight control actuation [17]. Low-pressure effects cumulated with future high-voltage standards may pose new questions in terms of partial discharges and related problems of electrical arcing in power electronic devices, cables, and machines [35].

Several solutions of high-density converters exist as in [33]. For example, a 70-kW “dual-use” inverter for an electrical ECS and the engine start-up application (see “Bleedless Architecture” section) is a first example in terms of power integration (~4 kW/kg). It is presented in [8] with a “duplex structure” (two inverters in parallel), which allows for optimization of filters, thus reducing the mass. It integrates not only power and control components but also an input EMC filter, a preload resistor, and a cold plate for liquid cooling.

In [16], the authors present an interesting example of an integrated power converter; it corresponds to a buck boost converter unit (BBCU) structure, allowing a 300–28 VDC 12-kW power conversion with galvanic insulation. A multicell (eight cells) interleaved Flyback Converter structure has been proposed using intercell

transformers with power MosFet for primary switching stages and SiC diodes for the secondary rectifier. Finally, a density of 4.5 kW/l has been obtained to fulfill the severe requirements of the BBCU structure.

Mechatronic integration is another way to reduce system weight as emphasized with the example of the electromechanical actuator for flight control actuation, braking, or landing-gear systems [17].

New High-Voltage DC Standard and Architecture

With the increasing number of power electronic loads, a more-electrical aircraft with a classical ac network would include a high number of ac–dc rectifier stages (ATRU, PFC active rectifier), which would have to comply with the ac quality standard (ABD100 for Airbus). A system solution for mass reduction would be to prefer a high-voltage dc (HVDC) network with an optimized association consisting of a generator, a rectifier unit (RU), a filter, and a generator control unit. By doubling the voltage (230 V) on new variable frequency generators as on the A350 or the B787, we obtain a new HVDC standard with ±270 VDC that offers subsequent gains in terms of system mass. If no loads are connected on the ac side, the ac standard may be released and replaced by a new HVDC standard. Several studies have recently been carried out, especially in the framework of the MOET EU project [13], emphasizing the interest in such architecture. The HVDC network would facilitate generator–load coupling with possible regenerative load acceptance. This latter issue should be interesting for certain consumers such as flight control actuators, for which the current power electronic topology

Other innovations in terms of architecture could be proposed with a hybridization of power sources with storage devices, as for the ground electric vehicles.

with a nonreversible RU necessitates the use of braking resistors for regenerative transient management. Other potential advantages, as is the case for hybrid HVDC networks, are displayed in the section “Involvement of Innovative Architecture and Energy Management Optimization” and Figure 3.

Such architecture would impose the availability of reliable HVDC converters and protection devices. The capacity of such devices has been recently demonstrated by Zodiac [5], [12].

With these new HVDC standards, particular issues in terms of quality and stability have to be addressed. The power loads supplied with controlled power electronics (PWM inverter for drive structures) especially involve a constant power operation, which could potentially make the device unstable if a convenient filter sizing is not achieved. Several studies have been devoted to this topic [13], [18], [19]. For example, an analysis tool based on the Routh–Hurwitz stability criteria coupled with an analytical modeling of drive structure input admittance has been proposed in [20]. This study emphasizes that special attention has to be paid in order to ensure stable operation of the whole distributed HVDC network. However, numerous theoretical studies, validated by experiments [13], have shown that this issue may be addressed with a convenient sizing of filtering devices.

Involvement of Innovative Architecture and Energy Management Optimization

Increasing electrical power needs have also led engineers toward innovative

architecture in order to save system mass. One solution should consist of merging several functions supplied with a similar power electronic device [8], which is used for different flight phases. A typical case proposed on the B787 bleedless aircraft [9] consists of a function merging of the ECS with the engine start-up supplied from a common dual-use PWM inverter. This functional merging is all the more interesting since ratings of both functions are almost compatible, which allows considering the electrical engine start-up without any overrating (Figure 4).

One step beyond, in terms of power electronic sharing, was proposed in [24]. The authors have suggested putting in parallel base modules consisting of three-phase PWM inverters. For example, four 30-kVA inverters can be interleaved (phase-to-phase) with inductors to obtain a quadruple switching frequency with a 25% equivalent inductor on each leg, which allows obtaining a 120-kVA equivalent inverter capable of feeding an air compressor for ECS.

Other innovations in terms of architecture could be proposed with a hybridization of power sources with

storage devices, as for the ground electric vehicles. The advantage of network hybridization is that power sources may be underrated thanks to the storage source capacity to contribute to peak power loads. Reversible power may also be acceptable for specific operations with hybrid networks. A typical example was proposed in [25], [26], for the particular case of the emergency electrical network. In an extreme case of engine failure, a ram air turbine (RAT) is classically used to power the essential network with flight control actuators, avionic loads, essential lighting, and de-icing. The authors have proposed to hybridize the RAT with super capacitances; an estimated 30% of mass savings was achieved through this hybrid architecture together with an original optimized energy management process in which the storage device associated with a dc–dc converter is in charge of the HVDC bus voltage management. Consequently, the RAT can be power controlled with a maximum power point tracking exactly as in the case of classical wind turbines (Figure 5).

It has been proven that storage devices are capable of handling an important part (40–50%) of peak power consumption mainly due to the operation of flight control actuators.

It should be noted that an HVDC network facilitates coupling between the main source and the storage device. In the event of total engine failure, the transition between normal and

emergency operation has to be safely ensured, even while the RAT becomes powered. This transient operation was previously ensured by the hydraulic network on classical aircraft but will have to be managed by the electrical storage device in the more-electrical aircraft with an electrical RAT. For this purpose, other storage technologies such as lithium ion batteries could be used to supply the energy needs [27].

The replacement of the RAT with fuel cells has been

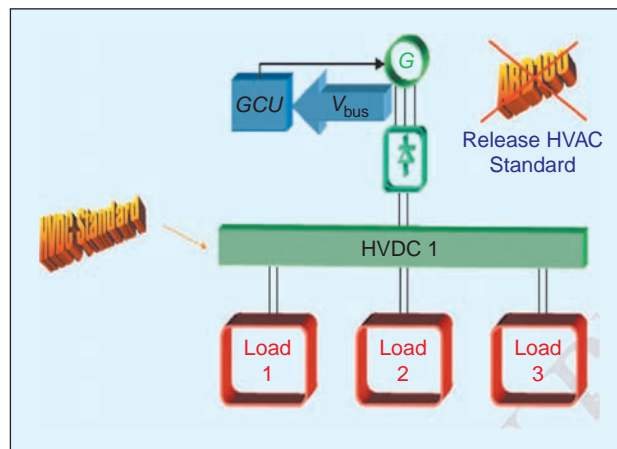


FIGURE 3 – Toward an HVDC network architecture.

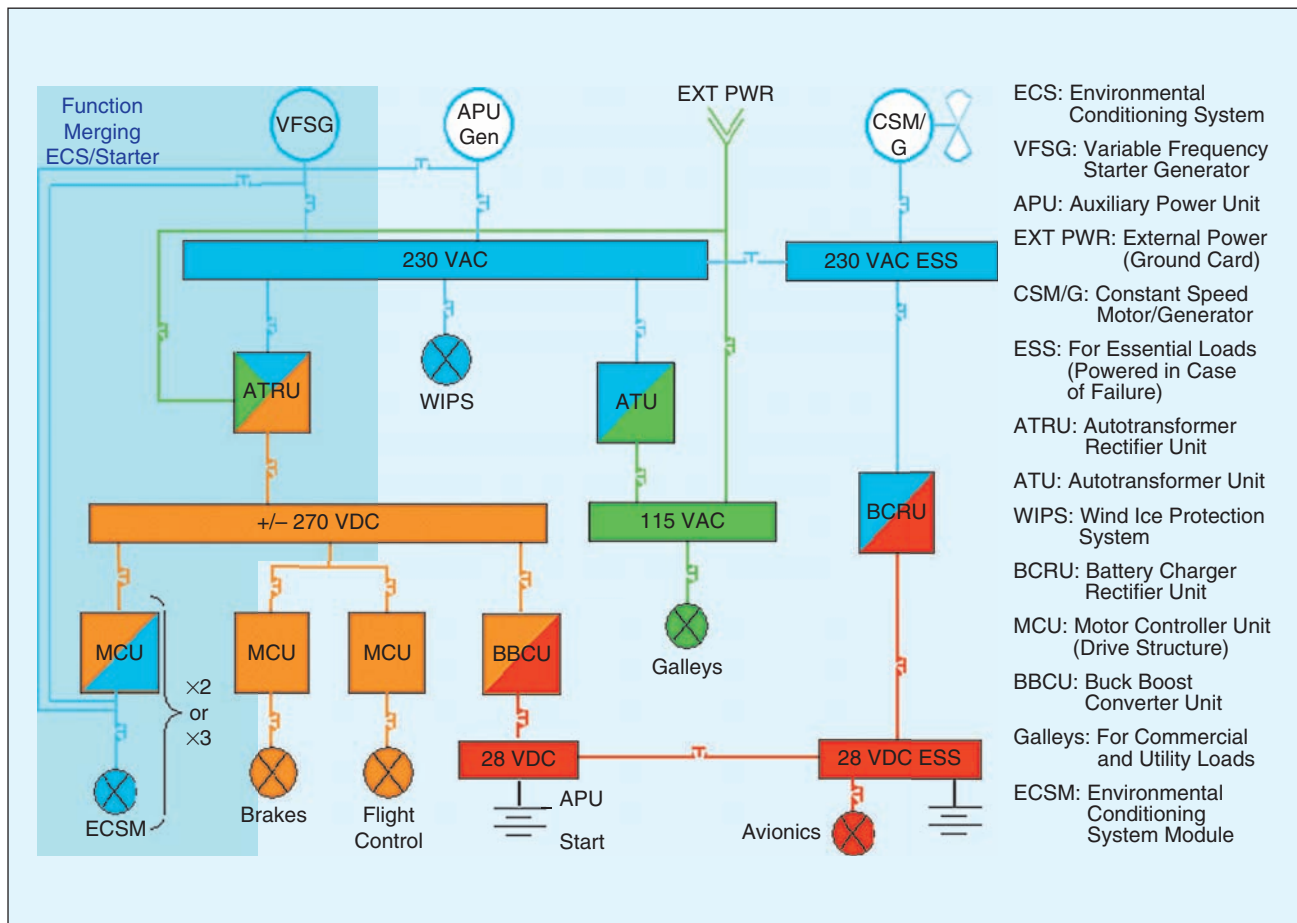


FIGURE 4 – An example of bleedless architecture with the ECS/engine start-up functional merging process.

studied in the CELINA EU project in the context of an emergency network [28]. Replacing the RAT with a fuel cell is technically feasible; a prototype was embedded on the A320 in 2007. Replacing the APU by a fuel cell is another prospect that would also

allow progression toward a greener aircraft during taxiing.

Toward an Integrated Optimal Design

Due to the increased complexity of electrical devices and network

architecture, simulation at a system level has recently been a key issue for system analysis in order to help engineers in the preliminary design steps as well as in the validation and verification process. During the MOET project [13], a work package

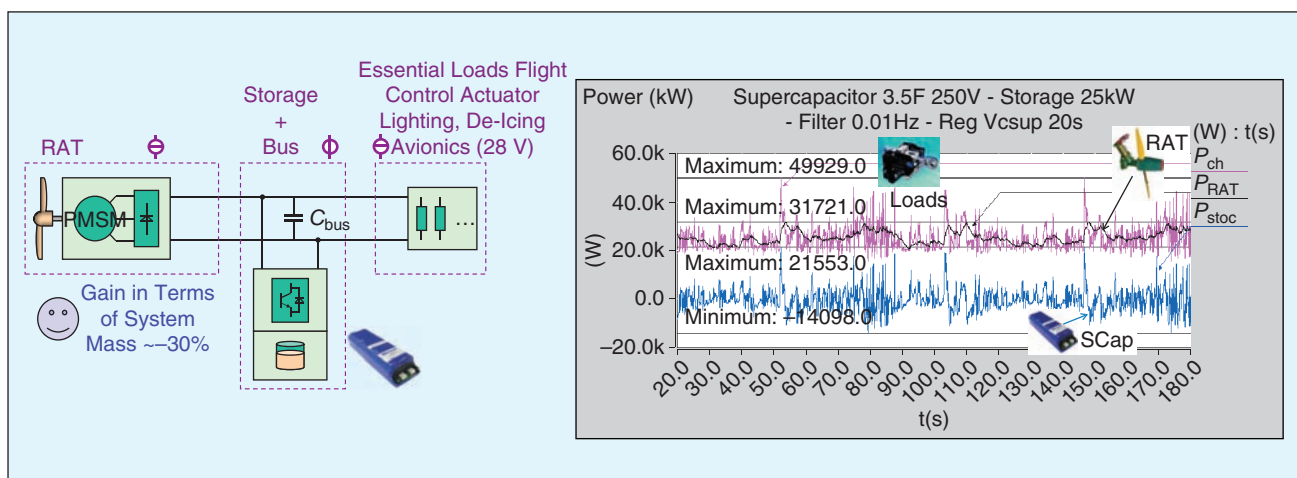


FIGURE 5 – An example of hybridization of the RAT with super capacitors.

“If the 2000s have been the years of network simulation, 2010–2020 could be the decade of integrated optimal design.”

managed by Aeroconseil [22] was fully dedicated to the development of simulation platforms. With model accuracy as the key issue, at least two levels of modeling (functional and behavioral) are required for all equipment. Each device model was first refined with respect to experiments. Second, the same model was integrated at the system level. A virtual prototyping of two rigs (a first for large aircraft and a second for small aircraft) was finally proposed to analyze a broad set of criteria (compliance with quality and stability standards, steady state/transient behavior, etc).

“If the 2000s have been the years of network simulation, 2010–2020 could be the decade of integrated optimal design.” Indeed, optimization has been achieved so far by expert choices through a “test–error” iterative process. Such an approach has proved to be efficient, but designers are never sure of reaching the system optimum, especially when numerous coupling effects are involved. The integrated optimal design approach consists of coupling sizing models with an optimization algorithm that automatically tunes parameters to optimize system criteria (mass, losses, etc.)

while satisfying technological and operational constraints (thermal, compliance with quality/stability standards, etc.). The device weight is certainly the main criterion to be minimized in aircraft systems. However, a tradeoff with losses is classically considered in optimization approaches, as minimization of masses leads to reduction of sizing and subsequently cost of materials, which usually increases system losses and related thermal constraints. Thus, minimizing both criteria at the same time indirectly ensures reliability and increases the lifetime of the systems. Robustness and reliability are not directly focused in the optimization problem. Reliability is usually separately analyzed by means of mean time between failure (MTBF) analysis—providers certify a certain MTBF for their equipment. However, if reliability is not a direct objective of optimization, several supplementary issues are considered as “constraints” in the optimization problem, which can be seen as indirectly related to the reliability issue. For example, the thermal constraints on the power converter as on the electromechanical actuator must be verified, as they are crucial for system sizing and reliability.

Other constraints such as mechanical stress are also verified to indirectly ensure system robustness.

Several optimization studies have recently taken place, for example, in the case of a HVDC power generation system [23]. A complete optimization study of the association between a synchronous generator with controlled excitation, a rectifier unit, and an output filter (mainly capacitive) was done in combination with evolutionary algorithm to solve this complex problem. In order to solve the quality constraint issue and especially to compare the harmonic spectrum (at the HVDC output of the power channel) with the quality standards required by Airbus, an analytical model of the rectifier is used [29] (Figure 6). Finally, very significant improvements were obtained as the generator mass was reduced by 30% with respect to a reference solution (reference defined by the supplier for a classic 230 VAC network) for the same level of losses. The mass of the optimized whole system including the reducer and its output filter was approximately equivalent to the mass of the reference generator alone!

Another analog study was developed in cooperation with Liebherr Aerospace, Inc. in order to minimize mass and losses of an ECS drive including a high power permanent magnet synchronous machine supplied by a PWM VSI connected to an input filter. The approach aimed to take account of the flight mission [see Figure 7(a)] and further explore the integrated optimal design of the whole ECS system, as illustrated in Figure 8.

Figure 7(a) and (b) emphasizes the prime importance of mission profile in the integrated optimal design process. Here, the statistic occurrence in the torque–speed plane of the main operating points is considered to calculate a weighted average of losses along the flight mission. System constraints (electrical, magnetic, mechanical, and thermal) are also evaluated for these variable operations.

Figure 7(c) illustrates the various fields that aim to model the

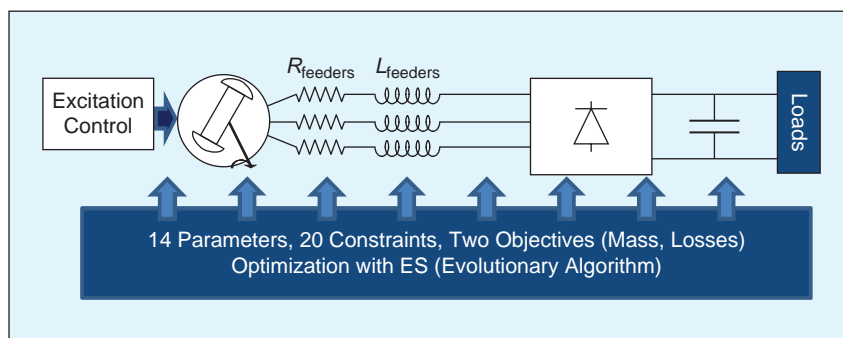


FIGURE 6 – Optimization of an HVDC power channel.

high-speed permanent magnet synchronous motor (HSPMSM) in this integrated optimal design, from geometrical or electrical issues to control aspects, considering all losses and thermal constraints.

The same kind of approach is considered for the “power supply” part, involving the HVDC network as an input, the input filtering device, and the PWM VSI feeding the HSPMSM.

Another analog study was developed in cooperation with Liebherr Aerospace, Inc.

Losses in the inverter (switching and conducting losses), as in the input filter device, are modeled and considered for each operating point of the mission profile. The mass of

main devices (filtering devices, inverter with cooling plate) is also estimated. The input/output harmonic constraints are analyzed by means of a “time–frequency approach” as

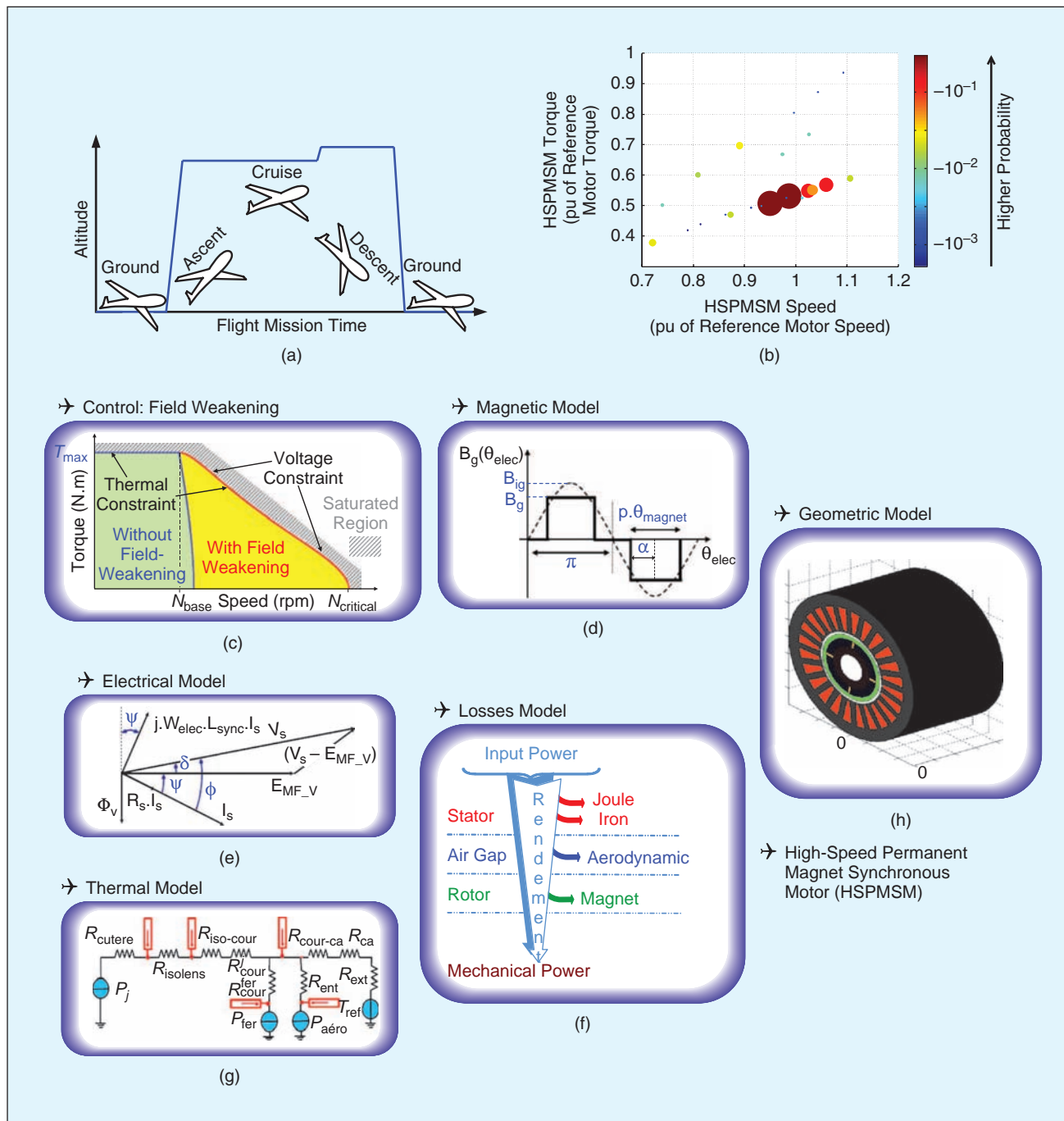


FIGURE 7 – Multifield modeling of the inverter-fed HSPMSM actuation system for the ECS.

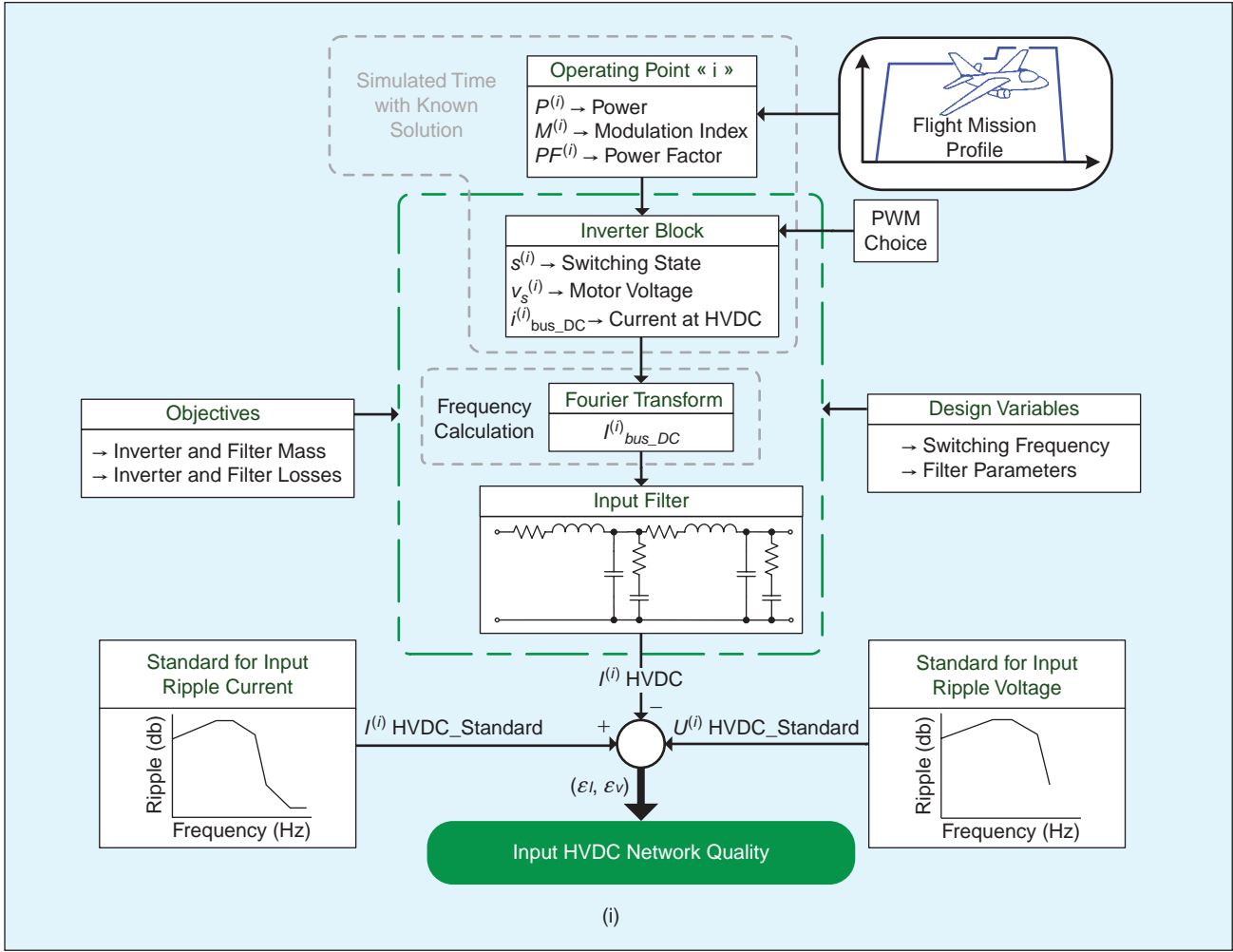


FIGURE 7 – Multifield modeling of the inverter-fed HSPMSM actuation system for the ECS (Continued).

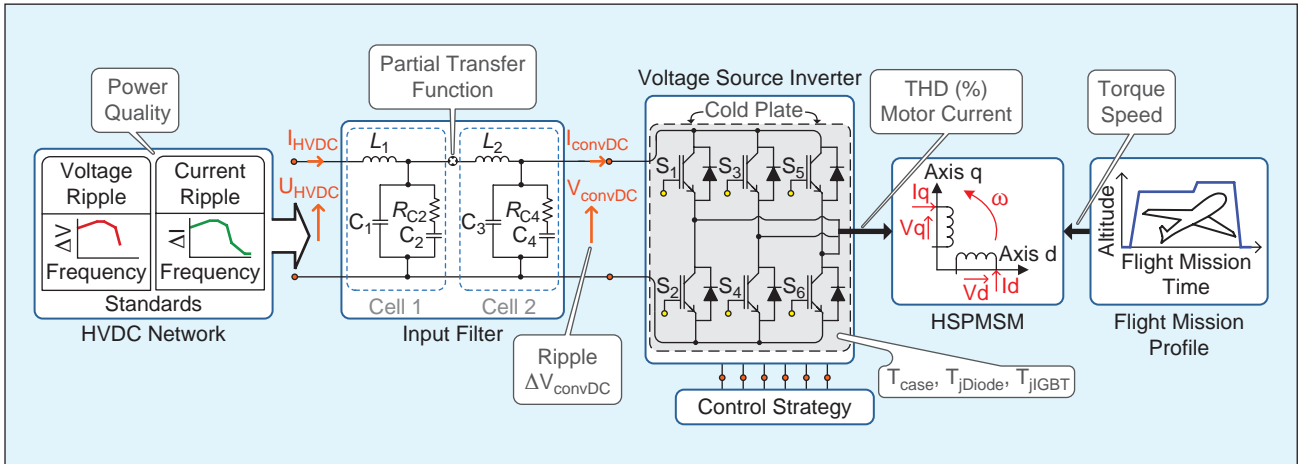


FIGURE 8 – Architecture of the ECS.

illustrated in Figure 7(d): first, a temporal simulation with PWM switching in one electrical period of time is achieved for each operation point (flight mission) and for each actuator

solution. Then, a frequency analysis of input/output currents and voltages allows the analysis of the quality of waveforms. These are compared with the new HVDC quality standards

provided by Airbus in order to analyze the constraints fulfillment. See [34] for more information.

Two approaches have been compared for the component sizing of

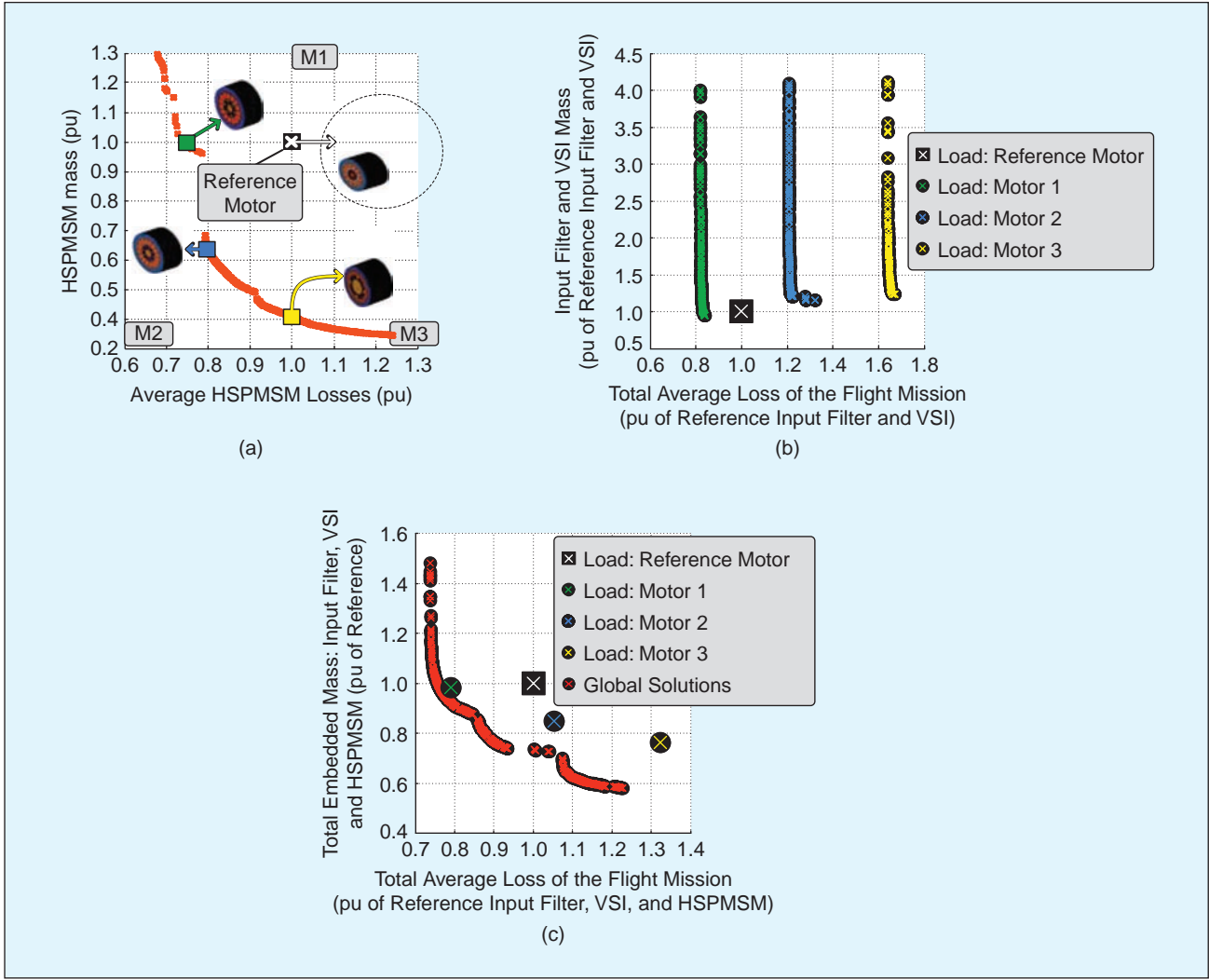


FIGURE 9 – Pareto optimal solutions for the ECS system: (a) Pareto optimal HSPMSM solutions, (b) Pareto optimal input filter and VSI solutions, and (c) Pareto optimal ECS solutions.

the electromechanical conversion chain:

- 1) a local and sequential sizing of each system part: a HSPMSM optimization loop is associated with a second loop involving the VSI and the input filter
- 2) a complete integrated design approach investigating the simultaneous sizing of all coupled components.

Sequential Optimal Sizing

Optimal Sizing of the HSPMSM

The optimal sizing of the HSPMSM is addressed first and can be formulated into an optimization problem using:

- 11 design variables related to the HSPMSM geometric features

(number of pole pairs, number of slot per pole per phase, radius/length ratio, equivalent gap, magnet filling coefficient) electromagnetic variables (yoke induction, current density), and mechanical characteristics (base speed and base torque)

- 12 constraints associated with geometrical variables (minimum and maximum sleeve thickness, minimum and maximum of copper windings per slots), technological limits (maximum rotational speed, magnet demagnetization), and temperature limits in the different motor parts (magnet, insulator, and yoke)
- two objectives to be minimized: the HSPMSM mass and the total

average losses estimated over the flight mission—these losses include iron losses (i.e., hysteresis, eddy current, and excess losses) [32], joule losses, aerodynamic losses, and magnet losses.

Some of the constraints are estimated a priori. Certain other constraints and losses are evaluated during the flight mission, the latter being modeled by representative points in the torque–speed plane. Total losses are estimated by weighting all the losses on each mission point according to their occurrence during the flight. The Pareto optimal plan, represented in Figure 9(a), emphasizes three particular solutions. With respect to the reference solution previously developed by the supplier,

Significant reduction in terms of mass may be obtained by paying a certain price in terms of complexity of the design process (computation time, cost of model development, etc.).

these three solutions are obtained at iso level of mass (for Motor 1), at iso level of losses (for Motor 3), the Motor 2 being a tradeoff solution.

Optimal Sizing of the Input Filter—VSI Set

The optimal sizing of the input filter—VSI set—can be formulated into a second optimization problem using:

- ten design variables related to the VSI (switching frequency, insulated-gate bipolar transistor current rating) and input filter (inductor and capacitor on the HVDC side, capacitor and resistor of the damping branch on the HVDC side, and the same variables on the inverter side)
- 11 constraints associated with the input filter features (limitation of the damping coefficient in each branch of the filter, maximum root mean square current in the capacitors), with VSI semiconductors (temperature limits in each region, i.e., diode and insulated-gate bipolar transistor junctions, package case), and with quality standards on the electrical network (quality of low- and high-frequency currents on the HVDC network side, maximum ripple of the inverter input voltage, and maximum harmonic distortion of the motor current)
- two objectives to be minimized: the mass of the input filter and VSI set and the total losses in this subsystem during the flight mission – these losses include losses in the input filter (i.e., inductor, resistor, and capacitor losses) and VSI losses (i.e., switching and conduction losses).

Considering the three particular solutions delivered by the first optimization loop for HSPMSM, we

plot the corresponding Pareto plan in Figure 9(b) with a reference VSI input filter solution corresponding with the reference motor. The particular steep shape of the resulting Pareto optimal front is mainly due to the inverter thermal constraint, which strongly limits the switching frequency range keeping power supply losses nearly constant. Consequently, we only consider the VSI input filter configuration with minimum mass for each optimal HSPMSM.

ECS Integrated Optimal Sizing

Finally, simultaneous optimization coupling of all ECS components is investigated in a unique optimization loop. Pareto optimal ECS solutions obtained from this approach are illustrated in Figure 9(c) and compared with the three ECS solutions resulting from the sequential optimization approach [combination by mass and average losses additions of HSPMSM and VSI input filter solutions shown in Figure 9(a) and (b)]. As expected, the simultaneous optimization of all the components outperforms the sequential optimization approach. Furthermore, it is interesting to note the tradeoff effect between both optimization loops. Indeed, the less massive machines do not necessarily exhibit the minimal system mass due to all couplings in these complex devices. As a result, a significant mass reduction can be obtained through the sequential, particularly the integrated, optimal design of this system for which a whole mass reduction ratio of –26% can be obtained at iso level of losses.

Both previous examples have put forward the interest of the integrated optimal design by coupling optimization procedure with sizing models for devices. Significant reduction in

terms of mass may be obtained by paying a certain price in terms of complexity of the design process (computation time, cost of model development, etc.).

Conclusion

Recently, more electrical power needs and systems have been embedded in aircraft. The gains in terms of mass are increasing. However, the advantages of the more-electrical aircraft should mainly reside in energy rationalization and management capacity that would allow increasing the availability of the systems. Maintenance costs could also be reduced from the health monitoring capacity. Electrical systems may also contribute to making aircraft greener for particular operations such as the ground phase.

Nevertheless, the electrical systems and components have to be more mature with increased reliability. Their power density should also be increased to save mass. This objective involves numerous areas of progress in terms of power integration at both the component and device level. In particular, the cooling devices must be optimized together with new types of architecture in order to avoid “recreating a new secondary hydraulic network.” Research efforts are particularly active in these areas in U.S. and EU industry and also at the university level. Furthermore, as illustrated in the last section, the whole system has to be more optimized; this may be addressed by means of novel integrated optimal approaches.

Electric and hybrid electric vehicles would give added impetus to the whole adventure of the more-electrical aircraft since standards, devices, and certain constraints are quite similar.

Biographies

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André de Andrade received his M.Sc. degree in electrical engineering from the Institut National Polytechnique of Toulouse (INPT), France, in 2007. Currently, he is a Ph.D. student working on integrated design by optimization of an electrically powered air conditioning system (ECS) with high-speed synchronous actuator. His thesis research is conducted in the Laboratory on Plasma and Conversion of Energy (LAPLACE), Toulouse, in the framework of the PREMEP French project in cooperation with Liebherr Aerospace. He is with the Université de Toulouse, France.

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