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Influence of the energy management on the sizing of Electrical Energy Storage Systems in an aircraft

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HIGHLIGHTS

- Association of battery and supercapacitor system as energy and power sources in an aircraft.
- Sizing method for Electrical Energy Storage Systems (battery and supercapacitor) to minimize the global weight.
- Influence of an energy management based on a frequency approach on the storage system sizing.
- Assessment of the sizing by simulation at a critical temperature and adaptation of the energy management.

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ABSTRACT

In an aircraft, Electrical Energy Storage Systems (EESS) are used as support to other sources in few mission phases in order to ensure the energy availability. They are also used as electrical smoothing devices in order to guarantee the required levels of reliability, stability and quality for an embedded electrical network. This paper deals with the association of two EESS: supercapacitors and secondary battery, which exhibit complementary properties. In this paper, a sizing method for both EESS is developed by taking into account their hybridization and their characteristics (such as capacity or depth-of-discharge) so as to minimize the global storage system weight. Moreover, an energy management based on a frequency approach is implemented to dispatch the power between all the sources. The influence of this management on the sizing is studied. Indeed the cut-off frequency of the low-pass filter is used as a setting parameter of the sizing algorithm. Finally, the sizing validity is assessed and discussed according to temperature constraints. Although battery performances are reduced at low temperature, the sizing determined with the algorithm at 20 °C is still valid on all the temperature range thanks to an adaptation of the energy management parameter.

1. Introduction

The electrical network embedded in an aircraft is composed of several electrical sources and some of them are storage components [1]. Aircrafts make use of Energy Storage Systems (ESS) to provide all or some of the energetic requirements, according to the hybridization rate and to the mission profile. In some cases, the Electrical Energy Storage Systems (EESS) provide the whole required energy when the other sources are unavailable. Indeed, they are helpful as support to engine start at the mission beginning or as electrical emergency back-up. Moreover, the reliability, stability and quality issues of embedded network can be solved by the connection of EESS to the network. In this case, they are used to fulfill the power peaks and smooth the power supplied by the main sources.

Batteries, supercapacitors, flywheels and so on [2] can be electrical storage equipment for hybrid vehicles [3,4] or for miscellaneous hybrid applications [5,6]. In the considered aircraft application, the embedded EESS are supercapacitors and secondary batteries. Secondary battery means the electrochemical cell is rechargeable, contrary to primary battery which is not rechargeable. The complementarity of these sources is demonstrated in a first part. Then, a method is presented to size EESS by taking into account their hybridization and the energy management which is developed for this application. In literature [7–9], sizing tools for supercapacitor or secondary battery systems are suggested, where

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only one source is sized at a time from its energetic requirements, and where only one cell is pre-chosen for the sizing. The tool described in this paper leads to size both EESS in parallel by choosing the suitable cell among a library. The third part deals with the study of the influence of few parameters, such as Depth-of-Discharge (DoD) and cut-off frequency, on sizing results. Finally, a validation of the sizing is suggested and the sizing validity is discussed according to the temperature.

2. The Electrical Energy Storage Systems

In our application (aircraft), two EESS are embedded: supercapacitor and Lithium-ion polymer battery systems. They were chosen because of their specific energy and power and also their technical complementary [10,11], as shown below.

In literature [3,12], Electrical Energy Storage Systems are compared through their energetic characteristics (energy and power) via Ragone plots [13]. It is also interesting to list other characteristics, which have a great impact on the use of such devices. A suggestion to compare easily different EESS is to group some characteristics together in a spider web diagram. This plot needs beforehand to define a scale for each characteristic. A five-level scale, where the fifth level indicates the best performance, is suggested in Table 1. The comparison is carried out on six criteria, which are specific energy and power, discharge time, life duration, energetic efficiency and auto-discharge rate. Other criteria, such as reliability, recyclability, technology maturity and so on, could be added. But they are not considered in this study because they are qualitative criteria (technology maturity) or they depend strongly on the use conditions (reliability for instance), and this kind of plot needs quantitative information.

For supercapacitor or Double-Layer Capacitor (DLC) systems, the specific energy is between 5 and 15 Wh kg^{-1} and the specific power is between 800 and 2000 W kg^{-1}, according to [3]. The time constant for supercapacitor discharge is rather low in comparison with time constants of other storage systems. The discharge time is about few seconds [3]. In these components, the electrical power is directly stored as electrostatic power without any energy conversion. Therefore, the stored electrical power can be quickly supplied and the number of cycles is high: between 100,000 and 500,000 [14]. An advantage is their energetic efficiency which is between 95 and 98% [3], [12] and a drawback is the quite important auto-discharge rate, which is about 5% a day [12].

As for Lithium-ion polymer secondary battery systems [15], the specific energy is between 120 and 140 Wh kg^{-1} and the specific power is between 10 and 1000 W kg^{-1}. Their discharge time is about several minutes or hours. Actually, it depends on the discharge current-rate. The life duration of Lithium battery is higher than life duration of other battery technologies (Nickel or Lead). The number of cycles is around 1500 for Lithium-ion polymer batteries. This kind of battery has also two advantages: an excellent energetic efficiency (close to 100% because of the non-aqueous electrolyte) and a low auto-discharge rate, which is between 0.1 and 0.5% a day.

The comparison between supercapacitor and Lithium-ion polymer battery systems is given on the spider web diagram on Fig. 1. These components are complementary in terms of energetic performances. Indeed, supercapacitors are usually considered as a power source, able to provide or recover power peaks; whereas secondary batteries are considered as an energy source, capable of providing power during a long time. Moreover, they are complementary on other characteristics, which are as interesting as energetic performances: discharge time, life duration (number of cycles) and auto-discharge.

Table 1
Evaluation scale for criteria to compare Electrical Energy Storage System characteristics.

Level	1	2	3	4	5
Specific energy [Wh kg^{-1}]	<5	5 – 30	30 – 100	100 – 200	>200
Specific power [W kg^{-1}]	10 – 10^2	10 – 10^3	10^2 – 10^3	10^2 – 10^4	>10^4
Discharge time [s]	<0.01	0.01 – –1	1 – 100	100 – 10^3	>10^3
Number of cycles	<10^3	10^3 – 2.10^3	2.10^3 – 10^5	10^5 – 10^6	>10^6
Efficiency [%]	<50	50 – 75	75 – 90	90 – 98	>98
Auto-discharge [% a day]	>5	1 – 5	0.5 – 1	0.1 – 0.5	<0.1

3. Sizing of Electrical Energy Storage Systems

Sizing of Electrical Energy Storage Systems consists in determining the appropriate cell and the necessary number of cells for each system in order to meet the energetic requirements of the application, while considering the environment constraints and their own technological limits.

First, the input data of the EESS sizing tool are the required performances, that is to say the energetic characteristics, such as energy and power, which EESS can provide or recover. The energetic requirements of the application are usually represented in the form of load profiles [16], [17] or driving cycles [4–6]. Therefore, the load profile defined for our application (aircraft) is given and the way to share out this profile between both storage components is explained.

Then, the constraints applied on the whole system by its environment are reviewed. Indeed, various constraints have to be taken into account to size EESS.

After the definition of the input data and the environmental constraints, the sizing tool is described through algorithms, and the optimization criterion is specified. In aircraft, the criterion to be minimized is the weight as critical for this application. It could be of course other criteria in other applications, such as cost [17], volume, internal resistance to reduce the losses due to Joule effect, and so on.

Finally, the sizing results are given. The output data of the sizing tool are the appropriate cell and the number of cells for each EESS, their energetic performances and the global weight of the storage systems.

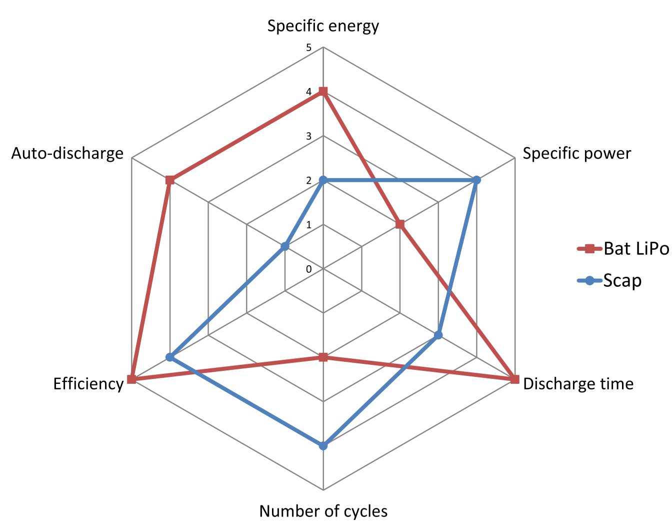

Fig. 1. Spider web diagram for comparison of supercapacitor and Li-ion polymer battery characteristics.