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Optimizing the Weight of an Aircraft Power Supply System through a +/- 270 VDC Main Voltage

***Abstract**. This paper deals with an onboard power supply of +/- 270 V DC (HVDC, high voltage DC). Conventional aircraft grids have a main voltage level of 115 V AC with a variable frequency of 360…800 Hz. Changing to a HVDC-grid has a lot of advantages. Higher voltage means lower cable weight. Furthermore, the electrical converter architecture can be optimized. Especially the converters inside the loads can be build much lighter when using a +/- 270 V DC supply. This paper gives an overview of the electrical architecture on a modern short- and midrange aircraft and the effect of a +/- 270 V DC power grid thus focusing on the converter architecture in a modern aircraft.*

***Streszczenie.** Praca dotyczy źródła zasilania w samolotach o parametrach +/-270 V DC (HVDC, high voltage DC- wysokie napięcie DC). Konwencjonalne samolotowe sieci zasilające mają napięcie zasilania o poziomie 115 V AC ze zmienną częstotliwością 360…800 Hz. Zmiana na sieć HVDC ma wiele zalet. Większe napięcie oznacza mniejszą grubość kabli. Ponadto struktura przekształtnika elektronicznego jest zoptymalizowana. Szczególnie przekształtniki w środku obciążenia są budowane jako znacznie lżejsze gdy używa się zasilania +/-270 V DC. Praca przedstawia opis elektrycznej architektury nowoczesnych małych i średnich samolotów oraz efekty źródła zasilania +/- 270 V DC w ten sposób skupiając się na architekturze przekształtników w nowoczesnych samolotach. (**Optymalizacja wagi systemów zasilania samolotów poprzez zastosowanie napięcia typu +/- 270 V DC**).*

Keywords: DC aircraft grid, optimizing the converter weight, optimizing the fuel cell integration.
Słowa kluczowe: Sieci zasilające DC w samolotach, optymalizacja masy przekształtnika, optymalizacja integracji ogniw paliwowych.

Introduction

A major activity of the aviation industry is the reduction of emissions in combination with cost efficiency. On the one hand eco-friendly aircraft save the airlines money because of the forecasted rising fuel prices in the future, on the other hand environmental pollution will become increasingly a problem for human society. The main part of development is focused on reducing weight and because of that directly reduced fuel consumption. The electrical systems use only 0.2 % of the whole engine power [1] at cruise, so savings in the electricity consumption have only a small effect on aircraft fuel consumption. Weight savings on the other hand have a positive “snowball effect”. For example, saving one kilogram in the equipment means also a possible weight reduction of the aircraft structure and the engine by an additional 600 g. Saving of 1.6 kg of the aircraft weight translates into lower fuel consumption and an extended performance.

In conclusion saving weight has an impact on aircraft performance or – at the stable performance level – a huge impact on eco efficiency and fuel consumption. Saving one kilogram of weight will reduce costs by approximately 4500 $ [2] at a short- and midrange aircraft over a 20 year period of operation.

As part of the project "cabin technology and multifunctional fuel cell systems" the institute of Electrical Power Systems of the Helmut-Schmidt-University is dealing with a high-efficiency onboard power supply.

A conventional aircraft grid is based on a main bus voltage of 115 V AC (360…800 Hz). Some newer developments [3] [4] use 230 V AC. Recent concepts try to integrate a +/- 270 V DC voltage level into the aircraft [3] [4].

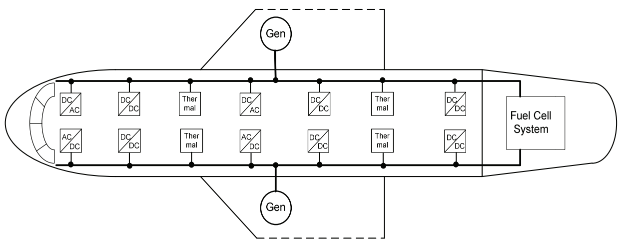

Fig.1. Aircraft onboard power grid

In addition to the higher main bus voltage the traditional auxiliary power unit (APU) could be replaced by a multifunctional fuel cell system to reduce pollution during ground operation. It has many advantages over the traditional APU [5] [6].

Integrating such a fuel cell system makes an adaption of the primary aircraft grid necessary. For that a +/- 270 V DC voltage level is an possible option in the future as well. Fig. 1 shows a fuel cell fed grid on modern aircraft with the different load types. This paper deals with the use and integration of this new voltage level in the cabin and cargo system.

Most loads in a modern aircraft are supplied with internal converters. This paper focuses on the converter architecture. The effect of a higher voltage level on the weight of the cable systems is presented in other papers [7]

Converters in the aircraft

In conventional aircraft the chain of converters is small and consists normally of one or two converters. Fig. 2 shows loads which are connected to the AC grid. The only converter here is the switching power supply in the loads. Loads which are supplied by 28 V DC could have two converters: The central transformer rectifier unit and one possible DC/DC converter in the load.

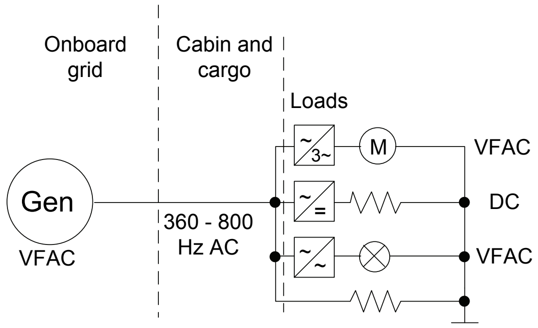

Fig. 2. Converters in conventional aircraft power supply system

Change to +/- 270 V DC Grid

On a modern aircraft the main bus could have a voltage of +/- 270 V DC. Especially, if a fuel cell system would be integrated, the step to a high voltage DC (HVDC) grid is recommended. Fig. 3 shows a grid with HVDC and conventional cabin and cargo systems which have an operating voltage of 115 V 400 Hz AC. A main converter feeds the cabin and cargo grid. The HVDC grid is either being fed by a fuel cell system with a DC/DC converter or being fed by the engine driven generators over a rectifier unit (AC/DC-converter).

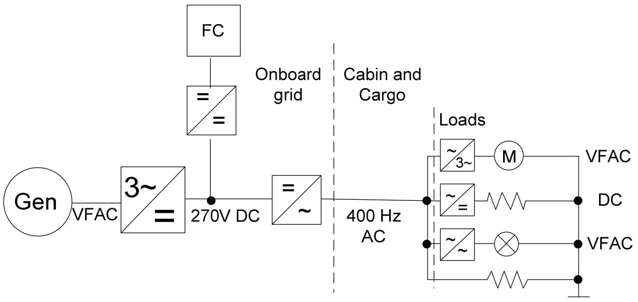

Fig. 3. Converters in a modern aircraft power supply system with conventional cabin and cargo loads

Fig. 4 shows the architecture with a DC-supply for the cabin and cargo systems without a 400 Hz AC converter.

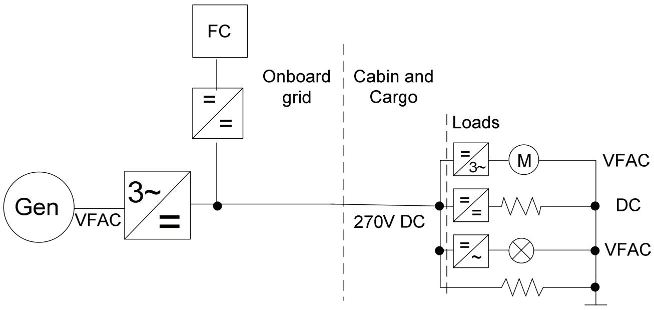

Fig. 4. Converters in a modern aircraft power supply system with adapted cabin and cargo loads

Types of converters in an aircraft

The type of the particular converter in an aircraft depends on the supplying voltage. Especially converters which have an AC input or output voltage need filters or PFCs (power factor corrections) to reduce the harmonics which are produced by a rectifier or the inverter. Fig. 5 shows the input current of a conventional full-wave rectifier. The problem is that the stabilizing capacitor inside the rectifier is only charged at the voltage maximum. The harmonic current characteristic of this kind of rectifier is poor. In conventional energy supply grids these rectifiers are only allowed up to a power of 75 W [8].

In aircraft applications all loads have to abide fix harmonic current rules, too. The ratios of allowed harmonic currents are referenced to the fundamental component of the load current. Therefore all loads have to use filters to eliminate the harmonics.

To reduce the input harmonics active or passive PFC can be used. Especially active PFCs can reduce the harmonic currents significantly. Mainly in “weak” aircraft grids with high grid impedance (compared to conventional power grids) it is particularly important to reduce harmonic currents to ensure the voltage THD (total harmonic distortion) stays in the allowed range.

The active PFCs work with a boost converter behind the full wave rectifier. The controller of the boost converter controls the input current so that it is proportional to the input voltage. The drawback of this system is the complexity and the system weight. The boost converter has to lift the voltage from nearly zero to the link voltage of the converter.

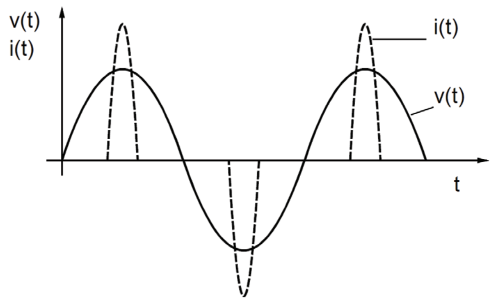

Fig. 5. Input current of a conventional full-wave rectifier with sinusoidal input voltage [9]

Fig. 6 shows block diagrams of the four possible converter types onboard an aircraft. In addition the power density of all blocks and the whole converters are given. The weights are based on supplier specification and technical literature [9] and for a converter power smaller than 5 kW.

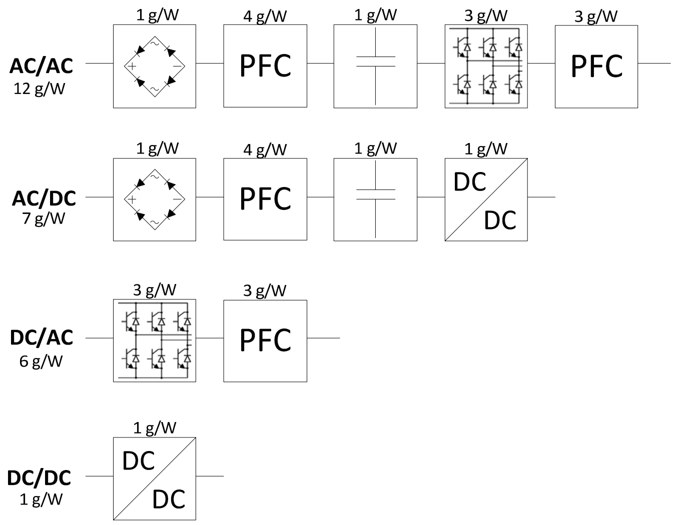

Fig. 6. Power density of different converter types for aircraft application with a power less than 5 kW

AC/AC-converter

The AC/AC-converter is the type with the most complex topology. In addition to the rectifier, the inverter and the DC-link, two PFCs are installed to keep the harmonics in the allowed range. The overall power density is approximately 12 g/W. The output PFC is simpler because the output load defines the filter and not the harmonic current requirement of the grid. Furthermore the PFC output does not need a boost converter like the input PFC to guarantee the sinusoidal current at the output.

AC/DC-converter

The AC/DC-converter has on the input side the same components as the AC/AC converter. But on the output side the inverter is replaced by a DC/DC converter to stabilize the voltage on a defined level. The power density of this converter type for aircraft application is 7 g/W. For comparison an AC/DC converter for a mobile computer has a power density of approximately 5 g/W, without overload ability.

DC/AC-converter

The DC/AC-converter has on the output side the same components as the AC/AC-converter. A DC-link and a rectifier with a PFC are not necessary. That leads to a higher power density of 6 g/W.

DC/DC-converter

DC/DC-converters are very small and light because of electronic components with a high power density. A DC/DC-converter only needs a small number of electronic components which leads to an average power density of 1 g/W.

Converters for power greater than 5 kW

For architectures with converters greater than 5 kW higher power densities are given. Especially the rectifier (AC/DC-converter) have, compared to the other ones an over proportional high power density. The respective densities are shown in table 1.

Table 1. Power density of onboard aircraft converters greater than 5 kW

Converter type	Power density
AC/AC	1.43 kg/kW
AC/DC	0.51 kg/kW
DC/AC	0.95 kg/kW
DC/DC	0.17 kg/kW

Analysis of the loads

This chapter deals with the ELA (electrical load analysis) of the cabin and cargo systems on a modern short- and midrange aircraft. For these studies all loads in an aircraft power supply system have been manually allocated by their characteristics like internal voltage or power characteristic at voltage drops.

Load demand of the cabin and cargo systems

The maximum overall power demand of the cabin- and cargo-system of a modern short- and midrange aircraft is approximately 105 kW. The following calculations are based on that power demand.

Fig. 7 shows the percentage distribution of the cabin and cargo load types weighted to power. It can be seen that constant power and ohmic loads are almost equally distributed. The load type is quite important, especially in fuel cell grids. The load current characteristic is essential for the size of the entire energy supply system.

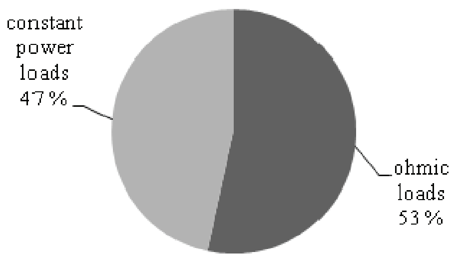

Fig. 7. Load types in the cabin and cargo area weighted to power

The power consumption of constant power loads is independent from the input voltage (1). The load current is inversely proportional to the input voltage.

(1) $P = const. \quad , \quad I \sim 1/U$

Ohmic loads have the contrary characteristics. The load current is proportional to the input voltage (2).

(2) $P = U \cdot I \quad , \quad P \sim U \quad , \quad I \sim U$

In a nutshell the load current is constant and not independent of the input voltage.

Types of loads on the aircraft

Fig. 8 shows the quantitative distribution of the internal voltage of all loads. The number of the different kinds of loads is in the same range.

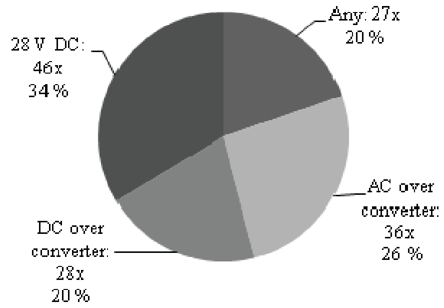

Fig. 8. Internal voltage of the load types in the cabin and cargo area weighted by the quantity

Half of the loads are DC loads such as In-flight entertainment systems or other microelectronics. The other half are thermic loads, AC motoric loads or lights.

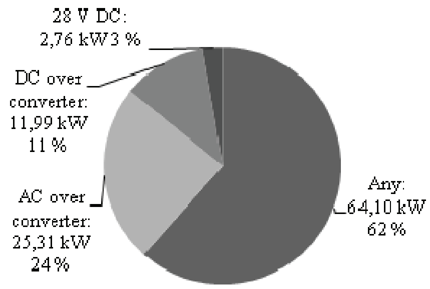

Fig. 9. Internal voltage of the load types in the cabin and cargo area weighted to power

Fig. 9 shows the distribution of the internal voltage of all loads weighted to power. The relative part of loads which can operate with all kind of voltages (e.g. thermal loads) is the greatest one. These loads should be connected to the voltage of the main bus bar. The rest of the loads operate with AC or DC. The key is to reduce the weight of the converters here.

Optimizing the cabin and cargo systems with +/- 270 V DC power supply

This chapter deals with possible optimization of the three given architectures. The basis upon which all weight calculations are made is the power of the cabin and cargo system. The part of the converter weight for other aircraft systems is not part of this consideration for an easier comparability of the cabin systems. The absolute weight for the considered system is calculated correctly because of the nearly constant power density.

State of the art – 115 V AC supply

The converter architecture of a conventional AC grid is simple. The internal voltage and the power densities (Fig. 6) are being used to calculate the weight of the converters. In a modern short- and midrange aircraft all converters would have a weight of approximately 400 kg.

Change to +/- 270 V DC grid

If the main bus bar voltage would change to +/-270V DC there are two possibilities for the cabin and cargo systems. The first one is to supply the loads with 115 V 400 Hz AC with a main DC/AC-converter. The second possibility is to adapt the loads to the new main bus bar voltage.

Changing the architecture would not affect the weight of the AC/DC-converter at the engine generator and the weight of the DC/DC-converter of the fuel cell system. Table 2 shows the power densities of the main converters. Oversizing of 20 % is taken into consideration.

Table 2 Weight proportion of the cabin and cargo systems on the main converters in the aircraft

Converter type	Location	Weight
AC/DC	Generator	66 kg
DC/DC	Fuel cell	22 kg
DC/AC	Cabin entry	125 kg

The internal converters of the cabin and cargo loads would weigh 170 kg. Compared to the 400 kg of a conventional cabin, the DC voltage has a weight benefit.

Optimization potential of +/- 270 V DC supply on the aircraft converter architecture.

The key is the overall converter weight of the conventional architecture. In this example the weight is approximately 400 kg. A change of the main bus bar voltage to +/- 270 V DC with a conventional 115 V 400 Hz AC cabin would increase the overall weight to 624 kg (+224 kg) because of the aircraft converters.

The overall weight of the cabin and cargo load converters with a +/- 270 V DC supply is 258 kg. Compared to the standard AC system a saving of 142 kg seems possible.

Compared to an aircraft with +/- 270 V DC main buses and a conventional cabin, weight savings up to 366 kg seem possible on a normal short- and midrange aircraft.

Conclusion

In conclusion a +/- 270 V DC system has a lot of benefits. Especially the loads have a big potential for weight savings on a modern aircraft. Half of the loads (weighted on power 38 % of the loads) operate with internal switching power supplies. These add 400 kg to the weight because of the required components for the power quality (PFCs). A DC supply could reduce the weight of these devices by 230 kg. In addition a conventional 115 V 400 Hz AC cabin needs a main converter if the main bus bar is DC. Additionally a supply with high voltage DC makes the main converter obsolete and saves up to 125 kg. The reduction of cable weights is given in [7], but not the focus of that paper.

Summarizing a +/- 270 V DC supply for the cabin and cargo systems is highly advisable.

Acknowledgement

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