OPTIMIZATION OF THE ENERGY-SUPPLY-STRUCTURE OF MODERN AIRCRAFT BY USING CONVENTIONAL POWER SYSTEM TECHNOLOGIES

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ABSTRACT

Within the concept of "more electrical aircraft", in which hydraulic and pneumatic systems are replaced with electrical systems, there is a growing demand of electrical power on board of aircraft. Besides the generation, the distribution of the electrical energy has an optimization potential as well. The protection of the generation and distribution system comes to the fore with the increased amount of electrical power. The technologies used for the conventional power supply are considered and their applicability on board of aircraft is investigated.

INTRODUCTION

The replacement of the hydraulic and pneumatic with electrical systems on board of aircraft (known as the concept of "more electric aircraft") has led to an increase of the demand of electrical power (Figure 1). For this purpose, the adaption of the present electrical infrastructure is necessary. The new market solutions have to withstand the economic pressure and on the other hand meet the increasing ecological standards.

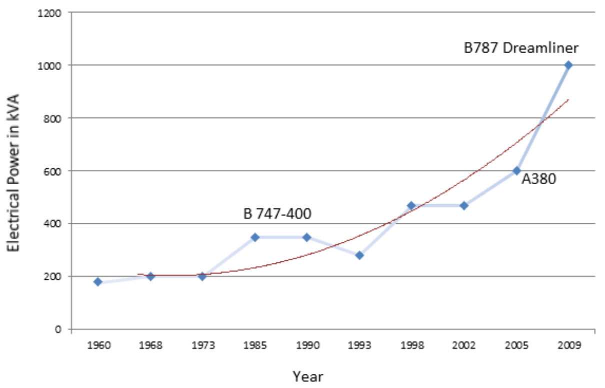

Figure 1 Installed generator power

The concept of "more electric aircraft" is one of the main research areas in the department of *Electrical Power Systems* at the *Helmut Schmidt University* in Hamburg, Germany. Within the project "Cabin Technology and Multifunctional Fuel Cell Systems", the on-board high efficiency power supply with Fuel Cells (FC) is investigated.

This paper highlights at first the optimization procedures for the energy-supply-structure which are already being used for modern aircraft. The technologies used for conventional power supply systems are subsequently examined and their applicability on-board of aircraft is investigated.

TECHNICAL BACKGROUND

Frequency variable 115 V AC grids with frequencies of 360…800 Hz combined with a 28 VDC grid are state of the art on-board of modern aircraft. The entire grid is star cabled with independent sub grids for each generator. Parallelization is not allowed to handle the high short-circuit currents of the generators. The main disadvantage of this structure is that every sub grid has to manage its own maximum peak demand in certain failure and load cases. The demand power could not be allocated from the available generators combined altogether. Therefore these generators as well as the power supply system are oversized. The planned introduction of new technologies on board of aircraft, e.g. Fuel Cell Systems (FCS), for the purpose of replacement of the Auxiliary Power Unit (APU) requires further consideration for the layout of the grid. Especially a FCS would have a higher comparable weight on that conventional grid structure.

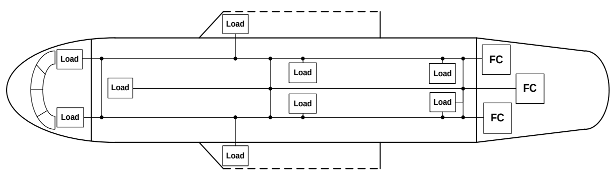

Figure 2 Interconnected aircraft grid with three fuel cell systems

The optimal integration of a FC to the on-board power system requires the adaption of the existing grid architectures. When a FC supplies the on-board grid, it has to satisfy the existing high availability standards. For this purpose several FCs should be both in parallel and simultaneous operation (Figure 2). Simultaneous, to provide the availability and parallel, to provide the requested power with a low overall weight. The parallel connection on one bus-bar could lead to an interconnected power structure with multiple supplies. This requires a special grid protection for failure cases and for the handling of the high power demand in the cabin.

Layout of modern aircraft energy supply grid

The electrical network architecture of an aircraft is basically made of five components - the power generation units, the distribution system called Primary Electrical Power Distribution Centre (PEPDC), the protection system, the transmission system and the loads - as shown in the Figure 3.

Figure 3 Aircraft electrical power distribution system

The electrical architecture in conventional aircraft demands a star cabling, whereby each load is supplied directly from the main power supply through protected feeders. The protection is realized via circuit breaker panels.

On newer aircraft the main power distribution PEPDC is extended with a Secondary Electric Power Distribution Centre (SEPDC) and several Secondary Power Distribution Boxes (SPDBs). A new protection technology was introduced via Solid State Power Controllers (SSPCs). The SSPC provides a status output signal, containing information over the switching status, temperature, voltage level and current. It will trip off if any of these values reaches a defined critical condition and restores to its initial condition when the fault is cleared [1]. The SPDBs supply electrical load in the cabin and cargo and protect the feeders between SPDBs and loads. Furthermore they provide state-of-the-art maintenance and power management functions.

Topology optimization

As mentioned in the previous section, electrical aircraft architectures have developed continuously. These further developments serve to optimize the electrical cabling network in terms of weight, volume, maintenance facilities as well as reliability and safety. All these factors are highly important in the field of aircraft manufacturing.

Further possibilities to improve the aircraft architectures can be achieved with the analysis of other electrical network topologies. In this analysis, the SPDBs network topology with a decentralized AC-DC power distribution is used, because these kinds of architectures have weight advantages [2] compared to other topologies.

With the integration of several power sources in the electrical network, the layout of ring and/or meshed networks are both possible. Furthermore the cabin feeder network can have an interconnected design in order to reduce the weight. Such networks require adequate protection mechanisms, to keep the availability high, as well as a new grid regulation, due to the parallel operation of the multiple power sources.

ADAPTION OF LAYOUTS BY USING CONVENTIONAL POWER SYSTEM TECHNOLOGIES

In the field of the conventional power supply there is much more potential for the optimisation of the electrical network architectures. Load management is one of the technologies that is already being used and will be further developed. Other investigations are considered in the following subsections.

High Voltage DC

In conventional energy supply systems, high voltage DC (HVDC) links have been known for years for point-to-point electrical power transmission. The rising demand for the transmission of higher amounts of electrical energy on modern aircraft leads to the necessity of introducing higher voltage DC grids on-board of aircraft as well. Electrical grids with up to 540 VDC (or ± 270 VDC also called HVDC) are planned. The higher voltage has several positive effects. The first is the decrease of the cable cross section, due to the reduced current flow while transmitting the same electrical power, which leads to weight savings. Voltage levels can be increased in conventional power grids as well, to increase the transmitted power.

An additional advantage is the reduction of the power losses due to the higher voltage level and the use of DC networks, which eliminate the reactive power consumption. For these reasons DC links are used for long point-to-point connections in conventional power grids. Due to reduced power losses in the electrical grid, the environmental conditioning system has a lower thermal power demand.

A further benefit of the use of HVDC is a weight reduction because of lighter electrical converters. AC-supplied converters have to be equipped with passive or active filters (Power Factor Correctors - PFC) so that they can be supplied by sinusoidal input currents. As to be seen in the following sections, this is especially important on a grid with high grid impedance, like an aircraft grid.

Multiple fed grids

Most conventional power supply systems have a high number of electrical power generation devices. This extension on-board of aircraft leads to several advantages. The capacity utilization is optimized and the regulation power of the grid does not have to be produced by each single power generation unit. Furthermore the base power and the intermitted power could be provided

by different power generation units. Hence every generation device is optimized regarding to its costs and efficiency. Therefore each power unit could be operated with a nearly 100 % loading.
Almost the whole electrical power for the aircraft grid is driven from the kinetic energy of the main engines. However, only a small portion of the engine power is converted into electrical power. To provide regulation power, it is sufficient to oversize the generators. Consequently, star wired grids with one generator are a good solution for aircraft with a low power demand not only because of the drawbacks of a parallel connection (higher short circuit currents and complex power regulation).
For more electric aircraft with much higher electrical power demands, the architecture could be modified. For availability and redundancy, the generators on aircraft (and especially FCS) have to be split into several subsystems. Furthermore the subsystems could be connected in parallel to the grid to bundle the power. Hence the regulated power of each generator could be reduced and especially the sizing of FCS can be minimized. In addition, the allocation of the generating units for base and regulation power supply is possible as well. FCS could supply all long-term loads whereas short intermitted loads (like an electric engine start) could be supplied by energy storage units.
AC-generators (synchronous generators) cannot be connected in parallel due to the variable frequency resulting from the angular velocity of the engines. Therefore, parallel connections are only possible on a DC grid with rectifier units or on an AC grid with frequency inverters.
Another problem of the parallel connection is the power balancing and control of the inverters. However, the control strategies used for wind turbines could serve as a starting point for this application.

Electrical protection concepts

Because of the star-wired architecture of the conventional aircraft grids, an electrical protection with a simple overcurrent mechanism is sufficient to achieve a high availability. For this task, fuses and circuit breakers are used. Figure 4 shows an Overcurrent Protection (OP), which is used for simple grid architectures in conventional energy supply systems.

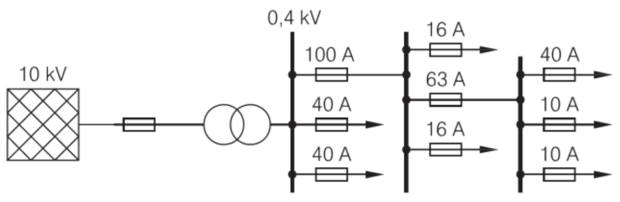

Figure 4 Overcurrent Protection [4]

However, for more complex architectures with meshed grids, such a protection mechanism with a fixed trip time is not suitable.
The new challenge is to develop a grid protection mechanism with integrated FCS, necessary for future aircraft types. Due to the FCS there are two major requirements for the electrical protection system. The first one is the new architecture (e.g. Figure 2) which is much more complex to protect compared to the traditional star-wired architecture. The second one is that FCS, unlike to conventional electrical generators, cannot deliver an over current which is sufficient to detect a short circuit. The highest possible output current of a FC is not much higher than the rated current. Depending on these requirements, new protection mechanisms have to be developed for aircraft applications [5].

Stepped-Curve Overcurrent Protection

In conventional energy supply systems different concepts are known for the protection of complex grid structures. For a doubly fed grid, a protection based on Stepped-Curve Overcurrent (SCO) is a possible method to separate failures. Therefore all contactors are supplemented with direction elements in order to activate the protection mechanism only for a specific current direction. This is a possible concept which could also be used for aircraft applications.
In this special case, a short circuit should be detected by measuring the voltage drop or the node impedance. Depending on the SCO mechanism, each one of the contactors should open the circuit at a different, previously defined response (trip) time. The response time depends on the load flow (current) direction. For the activation of the direction elements, only a small current flow is sufficient. This fits very well with the behaviour of FC current.
However, if there are a large number of contactors the response time could be too long.

Impedance-Protection

Depending on the availability requirement of the certain electrical grid it could be possible to create an electrical ring structure to connect the FCS and the aircraft loads. In that case the SCO protection mechanism does not work. Using the impedance protection, which is also known in conventional energy supply systems, this problem could be solved. Also, the failure detection is possible by measuring the node impedance [5].
This impedance is detected by the measurement of the failure voltage against ground and the failure current at the installation point of the contactor. The measured impedance sets the tripping time. Closer to the fault position, the failure node impedance becomes smaller. With increasing distance to the fault position the failure node impedance also increases due to the cable resistance.
However, in compact distribution centres, where a large number of contactors are located closely together, the failure impedances are similar. This leads to a difficult

identification of the failure position. Especially the high impedance failures have to be treated separately.
The protection mechanisms explained in the previous sections, are specifically developed for multiple-fed grids operating under normal conditions.
The conventional aircraft frame is made of aluminium which was also used as an electrical return conductor. The body of the future aircraft is expected to consist of Carbon Fibre Reinforced Composite Materials (CFCRM). It is not suitable for an electrical return conductor. Therefore, a new electrical structure network (ESN) has to be developed. Based on the assumption that the ESN should be developed in a very weight-optimized manner, it leads to high impedance compared to those where an aluminium frame is used. For this purpose, this high impedance behaviour has to be considered. For conventional impedance protection, the failure impedance has to be zero to ensure that it works certainly. With a modified tripping characteristic of the impedance protection mechanism, this failure case can also be sufficiently separated.

Phase balancing

Asymmetries within a three-phase power system are caused through the process of reallocation of the single-phase loads between the phases. This problem is familiar in the conventional energy supply as well. Non-linear consumers boost these parasitics even more.
The use of active filters is a reliable technology for the reduction of these perturbations. The part which has to be compensated is fed out of phase into the network by these systems. Depending on the control response time, an almost complete compensation of the parasitics can be achieved.

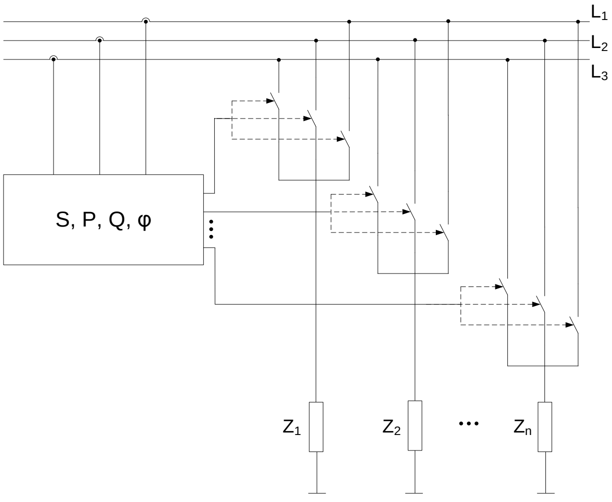

Figure 5 Reallocation of the single-phase loads

The aim for the electrical power systems of aircraft is the long-term reduction of the return conductor current caused by the asymmetries. Therefore the procedure does not have to be as fast as the one provided through the active filters. The only set-values which can be used to minimize the asymmetry are the impedances of the single phases. The impedance of each branch is calculated as the total impedance of single loads which are connected in parallel to this branch. The reallocation of the loads leads thus to the change of the values of the impedances in each phase (Figure 5).
The detection of the asymmetries can be achieved with the help of several power theories using either the rms or the instantaneous values of the phase-currents and the phase-to-phase voltages. These values can be directly measured. The calculated values are thus the set-values of the controller which can be designed as a learning system also taking into account the statistical data.

CONCLUSION

The growing demand of electrical power on board of aircraft enforces the investigation for the usage of further technologies which will lead to an optimized electrical power system both on the generation and the distribution levels. Some of these technologies, like higher voltage levels and multiple fed grids, are already used at the conventional power supply systems and can be modified for the use on board of aircraft.
For this modification further protection concepts for the electrical grid are necessary because of the much higher safety requirements. Stepped-Curve Overcurrent Protection as well as Impedance Protection can be combined for the purpose of failure detection and localization.
The reduction of the asymmetries in the three-phase electrical system on board of aircraft leads to further optimization of the network. Especially due to the replacement of the aluminium frame with a Carbon Fibre Reinforced Composite Materials body, this technology is advantageous concerning weight reduction.

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