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Changes of On-board Power Systems of Modern Aircraft in the Context of Wider Electrification

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Abstract:

This article analyzes the changes of on-board electrical power systems of modern transport aircraft with a higher degree of electrification, so-called MEA (More Electric Aircraft) compared to the traditional architectures, in the field of standardized electrical power parameters. Developments in this field are characterized by increased requirements for power of installed power sources and switching to higher voltage values and source units with a non-stabilized frequency value of the generated voltage, so-called frequency wild systems.

Keywords:

aircraft, electrification, power systems

1. Introduction

The on-board electrical power supply system (Fig. 1) represents the sum of technical devices for the generation, conversion and distribution of electric power on the aircraft. It consists of a system for electricity generation, i.e. power sources and converters (generators, current and voltage converters and accumulators), devices for stabilizing their voltage and frequency, devices for parallel operation, protection and control and systems for electricity distribution serving to transfer electricity from the generator to the distribution devices and from them to the appliances [1]. Electricity parameters must be kept within standardized limits at the control points and at the appliance terminals, while maintaining sufficient robustness of the system.

2. Traditional On-board Electrical Power Systems

The oldest and operationally most verified systems are DC low-voltage systems used on board of small and medium-sized aircraft. The main source of electricity is a DC

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power generator of a conventional design powered by an aviation engine via a reducer. Power sources for alternating current appliances (with constant frequency) are secondary power sources – rotary or static converters [2]. The emergency source of electricity for the supply of vital appliances is a rechargeable battery. As an auxiliary source, a DC generator driven by a ram air turbine or a generator in an auxiliary power unit can be used. It is a simple and reliable power supply system, the main disadvantage of which is the power limitation of the installed power unit (12-18 kW) given by the low voltage value (28 V) [3].

The increase in the complexity and number of aircraft electrical equipment, the transition to reactive aircraft engines and automated aircraft management systems, the introduction and expansion of radar technology, and the construction of large aircraft with a large number of electrical appliances led to the transition to higher network voltage values in the 1950s and the introduction of alternating electrical power systems (115 V / 400 Hz) [4]. Their advantage is better performance parameters at the same / lesser weight of conductors of distribution system and electromotive load, higher power transfer (U ↑ I ↓), simple way to obtain different voltage values (transformation / rectification), possibility of backing up critical loads from accumulator batteries and better performance of the AC generators (more power, 3-phase system, non-contact electrical machines). The development of standardized / normalized voltage values of aircraft electrical systems is shown in Fig. 2.

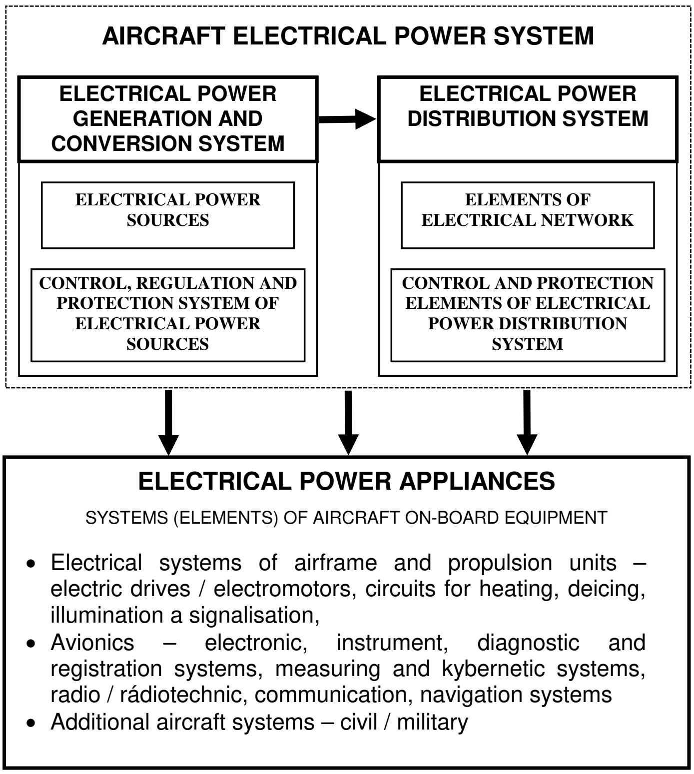

Fig. 1 Block diagram of on-board electrical power supplying system

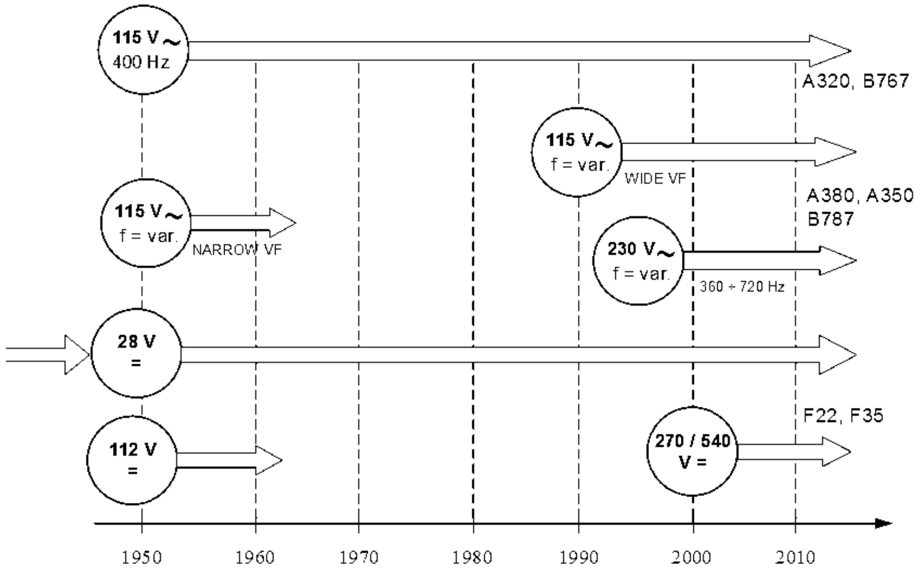

Fig. 2 Development of standardized voltage values of airborne aircraft electrical systems

The design concepts of the individual elements of the power supply system depend on many factors; the substantial concept is the type of aircraft, the reliability and quality requirements of the electrical power supply, operating conditions, and so on.

Depending on the type of generation of primary electrical power, the conventional on-board electrical power systems can be divided into three basic groups [5]:

- DC: low voltage 28 V, medium voltage 270 V,
- AC: with variable frequency, with a constant frequency of 400 Hz,
- Hybrid / Mixed: with a single and alternate power generation channel.

The structural diagrams of electrical power systems with division according to primary power generation are shown in Figs 3 and 4.

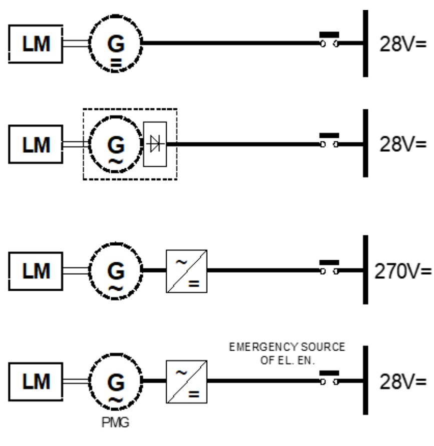

Fig. 3 Structural diagrams of DC power systems

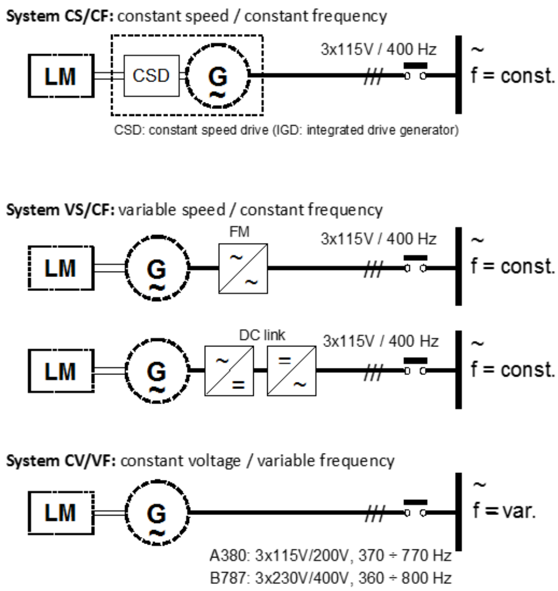

Fig. 4 Structural diagrams of AC power systems

Normalized electrical power parameters (U, f) in primary and secondary aircraft distribution networks are standardized according to MIL-STD-704F [6], MIL-STD-1275D [7], MIL-STD-461E [8], MIL-STD-810F [9].

3. On-board Electrical Power Systems of Modern Concept

The development of modern aircraft, coupled with an increase in the level of electrification of on-board systems, brings new requirements to ensure a reliable and uninterrupted power supply with electricity and its normalized parameters. An increase in the number of power loads such, as electric drives of compressors in the air conditioning system and in the flight control system, and electrical de-icing systems leads to increased demands for their power supply.

The required power of installed electrical generators is growing sharply and it is clear that this trend will continue. For large transportation aircraft systems, there is a transition from the values of several tens of kVA to the values of hundreds of kVA, for instance Airbus A380 has approximately 900 kVA and Boeing B787 about 1500 kVA [10]. The scheme of the modern aircraft electric power system is depicted in Fig. 5, where: (E – engine, STG – starter / generator, B – battery, ATRU – autotransformer rectifier unit, TRU – transformer rectifier unit, TR – transformer, DC/DC converter).

An increase in these performance requirements has been reflected in the development of on-board electrical power systems of modern aircraft in the following changes:

- the transition from alternating systems with a stabilized frequency value of 400 Hz to systems with a non-stabilized frequency value from 360 Hz to 720 Hz,
- the transition to higher operating voltage network values:
  - ➢ DC power supply 270 V and ± 270 V / 540 V (HVDC – High Voltage DC),

- AC power supply from $3 \times 115/200$ V to $3 \times 230/400$ V at $f \neq$ constant (HVAC – High Voltage AC),

- the transition to new types of decentralized distribution systems in primary and secondary distribution systems (PEPDC – Primary Electrical Power Distribution Centers, SEPDC – Secondary Electrical Power Distribution Centers, SSPC – Solid State Power Controllers, SPDB – Secondary Power Distribution Boxes).

Electrification of on-board equipment of modern transport aircraft brings new challenges for the technical solution of individual parts of power supply systems:

- wider use of semiconductor converters and increasing electrical load values cause an increase in the temperature of the on-board equipment and higher demands on its cooling,
- the power semiconductor switches / converters cause electromagnetic interference (EMI), i.e. interaction of electronic systems,
- the variable frequency value of the generated voltage in the new power systems requires new approaches in the design of the electromotive loads and in the design of the power converters and the protection,
- the introduction of a higher DC voltage (HVDC) requires increased demands for the cables insulation, switching elements and DC contactors.

In the classic architectures of the power systems of transport aircraft, a standard AC distribution system with a voltage of 115 V / 400 Hz is used. All elements of the electrical network (contactors, relays, circuit breakers, switches) are adjusted to this. The AC system uses a zero point, so the protection is simple, just like in a DC network. The limiting factors of traditional AC distribution systems include:

- problematic parallel cooperation of electric generators (their synchronization is necessary),
- AC electric motors for drives, pumps and electric air conditioning systems – In order to control their velocity and torque, the input voltage and frequency must vary widely; electric power converters are necessary for their power supply (the AC voltage must first be rectified to a DC and then inverted to an AC with variable voltage and frequency) [11],
- the need to manage the reactive power in the electrical network as a function of the AC frequency,
- the power load distribution circuits (wing deicing system, air conditioning system) must meet the requirements for high current load (usage of large cross-section wires).

Increased power requirements are realized in on-board distribution systems of modern transport aircraft by moving to higher operating voltage values that have not yet been used in aviation. This allows to use smaller cross-sections of the power wires while maintaining the transmitted power (at a higher voltage, the current value is smaller).

However, transition to higher network voltage (above 270 V) in air traffic conditions also brings additional challenges:

1. Conventional AC power systems (115 V / 400 Hz) operate reliably up to a height of about 18 km, at a temperature of 55 °C to 200 °C, within a wide range of changes in humidity. In modern power systems with higher voltage, however, the change in atmospheric conditions causes undesirable effects

mainly associated with the limited switching capacity of active and passive electrical switches.

2. The transition to higher on-board network voltage values is also affected by other areas of air traffic. Moreover, the existing airport infrastructure (technical equipment and the environment) must be adapted to a new type of power supply. Ground equipment for on-board systems supply is now adapted to long-term standardized voltage values of 115 V / 400 Hz. From the point of view of protection against dangerous contact voltage and interference (unwanted electromagnetic radiation of electrical circuits), it is also important to properly perform the grounding of power components of on-board electrical power systems (introduction of an isolated neutral point in systems with higher DC voltage and grounding points of airframe). The on-board equipment for passengers (for instance galleys) on new passenger aircrafts must be adapted to higher voltage network values.

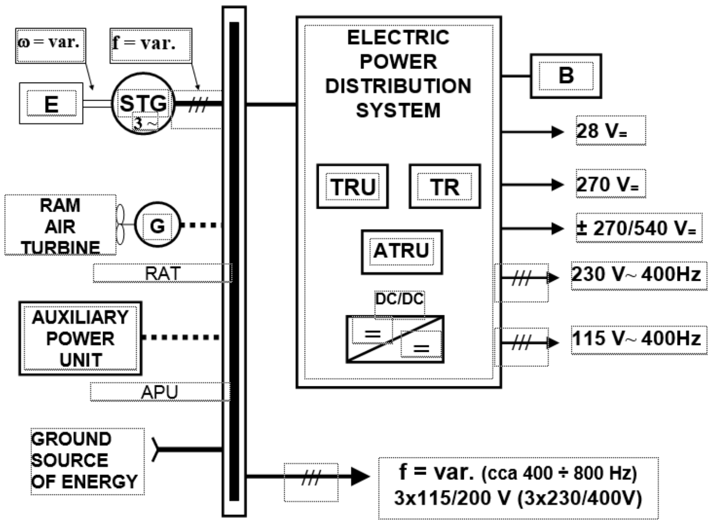

Fig. 5 The scheme of the modern aircraft electric power system

4. Fuel Cells

Significant changes of back-up power sources of next generation aircraft compared to traditional aircraft concepts will be in use of the fuel cells instead of the traditional APU turbines. As an example, a fuel cell, based on the principle of hydrogen and oxygen conversion, with an electrical power of 20 kW, which was used in the Technical Thermodynamics tests of the German Aerospace Center on the Airbus A320 aircraft is described [12]. These tests were carried out under normal operating conditions (with respect to vibrations, EMI, tilts) up to 12 km. The primary goal of the fuel cell systems in aircraft is to avoid inefficient flight operation phases by supporting electrical energy. The electrical efficiency of this system is around 50 %, while the efficiency of the APU is only 20 % (at partial load). Fuel cells will serve as a power supply to drive the electrical pumps of the backup hydraulic circuit and also as a drive for the ailerons. Further utilization of fuel cells will be in the production of water

(50 liters per hour) and inert gases. Such water can be utilized in toilets and kitchens and so reducing the volume of water tanks and thus the weight. Inert gas (containing only 10 % oxygen) can be used to fill fuel tanks to prevent explosion. The heat generated by fuel cells can be used for de-icing. Another usage of fuel cells might be in the power supply of the nose gear electric control or during taxiing.

5. Conclusion

The development of aircraft projects based on the complex design of their power systems has enabled to reduce the complexity of systems and to cut their weight. The gradual elimination of non-electrical energy sources and the transition to one type of energy – electricity, brings about an increase in overall energy efficiency, flexibility and availability of power. These activities in the development of the construction of new aircraft with a wider use of electric power are fulfilling the realization of the All-Electric-Aircraft. In connection with the environmental trend of reducing the fossil fuel consumption and the associated emissions, vibrations and noise, the fulfilling of the vision of emission-free aircraft is becoming a reality, i.e. aircraft with electric propulsion – Electric Aircraft (EA), Hybrid Electric Aircraft (HEA) [13, 14].

As a part of these new visions of aircraft development, various non-traditional solutions and approaches are also sought. The new dimension to electrification of new generation aircraft provides the possibility of using superconducting technologies in the construction of electric wires, switches and power converters – Superconducting Electric Aircraft (SEA) [15].

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