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## OVERVIEW OF AIRCRAFT TECHNOLOGY SOLUTIONS COMPATIBLE WITH THE CONCEPT OF MEA

### PRZEGLĄD ROZWIĄZAŃ TECHNOLOGICZNYCH SAMOLOTU ZGODNYCH Z KONCEPCJĄ *MORE ELECTRIC AIRCRAFT* (MEA)

#### Abstract

The purpose of this paper is to present some selected issues relating to the alternative application of the perspective concept on the plane board MEA (More Electric Aircraft), instead of the traditional solution, in terms of power (pneumatic and hydraulic systems). In the context of the analysis of this trend, particular attention is paid to the major advantages that aeroplanes have, made in accordance with the new technology and problems in autonomous systems of electricity generation (electric power grid of aircraft). Considering that the largest growth of the above trend of electric aircraft (MEA) applies to civil aviation, the most important role in this paper was assigned to civilian aircraft (Boeing, Airbus) in the context of power distribution in electro-energy systems. In addition, a review of air sources of electricity (electric power) generation was made for particular types of energy sources (generators, generator-starters, transformers, converters, etc.) and advanced on-board autonomous power systems ASE (Autonomous Electric Power Systems), used in most modern aircraft constructions (passenger and military aircraft). In the final part of this paper, based on a literature review of electric aircraft concepts (MEA) and a brief analysis, the main conclusions arising from the application of this trend in modern aviation are presented.

*Keywords: More Electric Aircraft, Aircraft Electric Power Systems, electric machines*

#### Streszczenie

Przedmiotem niniejszego artykułu jest przedstawienie wybranych zagadnień związanych z alternatywnym zastosowaniem na pokładzie samolotu perspektywicznej koncepcji MEA (*More Electric Aircraft*) zamiast rozwiązania tradycyjnego w zakresie zasilania (układy pneumatyczne i hydrauliczne). W kontekście analizy tego trendu szczególną uwagę zwrócono na główne zalety samolotów wykonanych zgodnie z nową technologią oraz na problematykę autonomicznych systemów wytwarzania energii elektrycznej (sieć elektroenergetyczna samolotu). W związku z tym, że największy rozwój omawianego trendu zelektryfikowanego samolotu (MEA) dotyczy lotnictwa cywilnego, najistotniejszą rolę w niniejszej pracy przypisano samolotom cywilnym (Boeing, Airbus) w kontekście rozdziału mocy w systemach elektroenergetycznych. Ponadto dokonano przeglądu lotniczych źródeł wytwarzania energii elektrycznej (mocy) dla poszczególnych rodzajów źródeł energii elektrycznej (prądnice, prądnico-rozruszniki, transformatory, przetworniki itp.) oraz zaawansowanych pokładowych autonomicznych systemów elektroenergetycznych ASE (*Autonomous Electric Power Systems*), stosowanych w najnowocześniejszych konstrukcjach lotniczych (samoloty pasażerskie i wojskowe). W końcowej części artykułu, na podstawie przeglądu literatury przedmiotu z zakresu koncepcji zelektryfikowanego samolotu (MEA) oraz krótkiej analizy, przedstawiono główne wnioski wynikające z zastosowania powyższego trendu we współczesnym lotnictwie.

*Słowa kluczowe: MEA, lotnicze elektryczne systemy zasilania, maszyny elektryczne*

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## 1. Introduction

A dynamic development of electrical machines in both civil aviation (A-380, B-787) and army aviation (F-22 Raptor, F-35) can be observed – this is caused by the introduction of modern technologies, PES (Power Electronic Systems) [2], devices and materials [1, 3] as well as advanced avionic devices and systems. These changes are related to the realization of the More Electric Aircraft concept (MEA), which was formed as a part of wider concept – MOET (More Open Electrical Technology). The idea of the MEA concept is to replace pneumatic and hydraulic devices with electrical devices. As a result, instead of having three different generation and distribution systems onboard modern aircraft, there is only one used – an electrical system. The most significant as well as most important benefits of the development described above are: increase of reliability; decrease of operational cost; limitation of harmful substances emission. Therefore, the MEA concept will probably be fully adapted in the near future in the area of aircraft power, especially on civilian aircraft. In modern aircraft electrical power systems, designed according to the MEA concept, universal, high voltage and hybrid connections of DC systems and AC systems should be used. Thus, both generation and distribution of electrical power onboard an aircraft are essential types of multilevel processing of electrical power. Electrical systems (DC and AC) of modern aircraft use a variety of voltages. These are four types in use: 405 VAC variable frequency; 200 VAC constant frequency; 28 VDC; 270 VDC.

## 2. Electrical power generation by autonomic electrical systems

The range and level of power used in different types of technologically advanced aircraft gradually increased for many years, as can be seen in the Figs. 1 and 2.

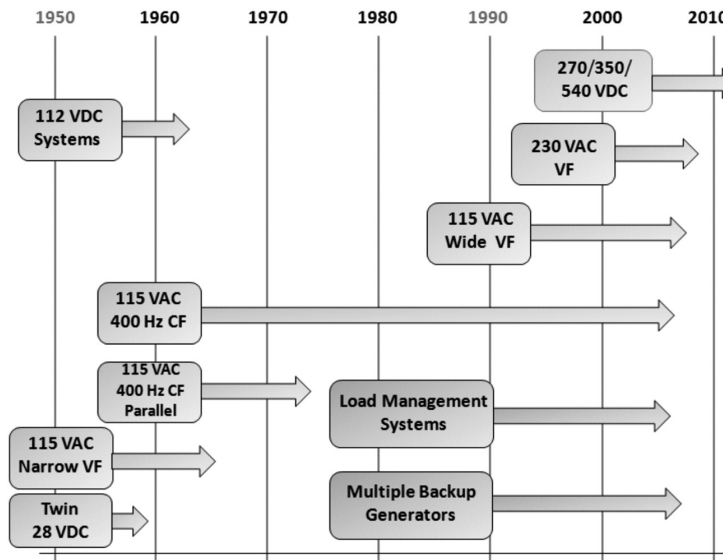


Fig. 1. Electro-energy Systems Evolution of Aircraft [4]

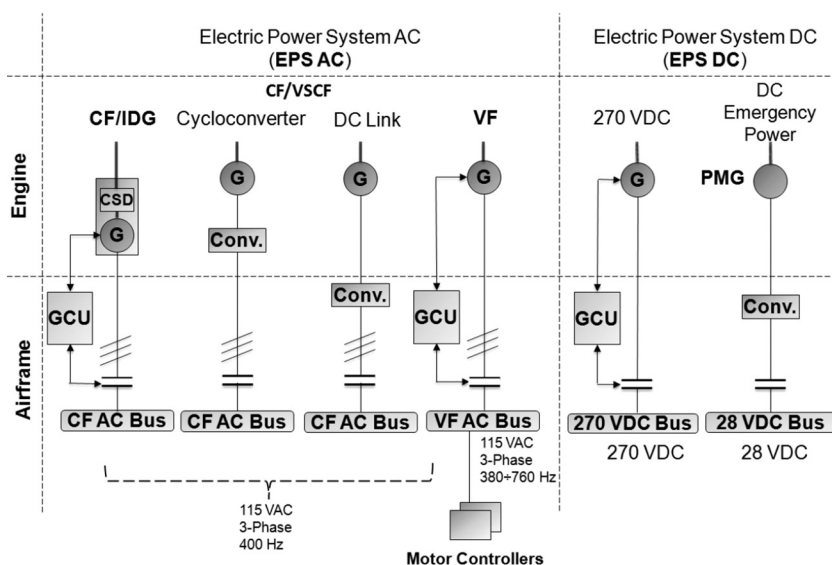


Fig. 2. Electrical Power Generation Types [4]

Examples of generators in use and types of autonomic electrical systems are summarized in Table 1.

Table 1

## Recent civil and military aircraft power systems developments [4]

Generation Type	Civil Application		Military Application	
<b>IDG/ CF</b> [115 VAC/ 400 Hz]	B777	2x120 kVA	Eurofighter Typhoon	
	A340	4x90 kVA		
	B737NG	2x90 kVA		
	MD-12	4x120 kVA		
	B747-X	4x120 kVA		
	B717	2x40 kVA		
<b>VSCF</b> (Cyclo- converter) [115 VAC/ 400 Hz]			F18C/D	2x40/ 45 kVA
			F18E/F	2x60/ 65 kVA
<b>VSC</b> (DC Link) [115 VAC/ 400 Hz]	B777 (Backup)	2x20 kVA		
	MD-90	2x75 kVA		
<b>VF</b> [115 VAC/ 380+760 Hz Typical]	Cobal Ex	4x40 kVA	Boeing JSF	2x50 kVA
	Horizon	4x25 kVA		
	A380	4x150 kVA		
<b>VF</b> [230 VAC]	B787	4x250 kVA		
<b>270 VDC</b>			F-22 Raptor LM F-35	2x70 kVA

It was dictated by the MEA concept as well as the dissemination of digital technology, the intensive development of which led to revolutionary changes in the field of signal processing. From 1940 to 1950, the standard voltage of electrical sources (generators, starter/generators) was 28 VDC. Batteries (1 or 2 units) were an emergency power source in the case of primary power sources damage and protected essential loads – this increased the safety of flight. In turn, the voltage of 200 VAC was dedicated to power AC loads. This type of voltage (200 VAC) with a constant frequency, was in use from 1960. Variable frequency generators began to be used in aviation from 1990 as a power source for high power loads and as a standby generator. Variable speed, constant frequency power sources started to be used in aircraft from 1990. The need to use these sources was caused primarily by problems encountered in maintaining constant generator speed during changes to the main engine speed – CSD (Constant Speed Drive) – by use of standard AC electrical sources (115 VAC constant frequency at 400 Hz generators), because it needs to use complex hydromechanical gear. Power generated in this way by AC variable frequency generators is being processed to 115 VAC at 400 Hz by power converters. These systems are being used on technologically advanced civil aircrafts (Boeing, Airbus). The mentioned companies intensively increase the range and level of power being used on their latest aeroplanes, such as 800 kVA on the Airbus A-380 and 1400 kVA on the Boeing B-787. Analysis of the chosen power systems are described below in an appropriate order.

### 2.1. Constant Frequency/IDG Generating System (CF/IDG)

Integrated drive generators used on conventional aircraft have a constant speed, obtained by complex hydromechanical gear and processed by the source presented in Fig. 3 (1). Initially, AC generators worked at 115 VAC in 400 Hz electrical systems. The task of the hydromechanical gear in CF/IDG systems is to maintain a constant generator speed at variable main engine speeds. The disadvantage of this solution is the high operational cost caused by the hydromechanical gear.

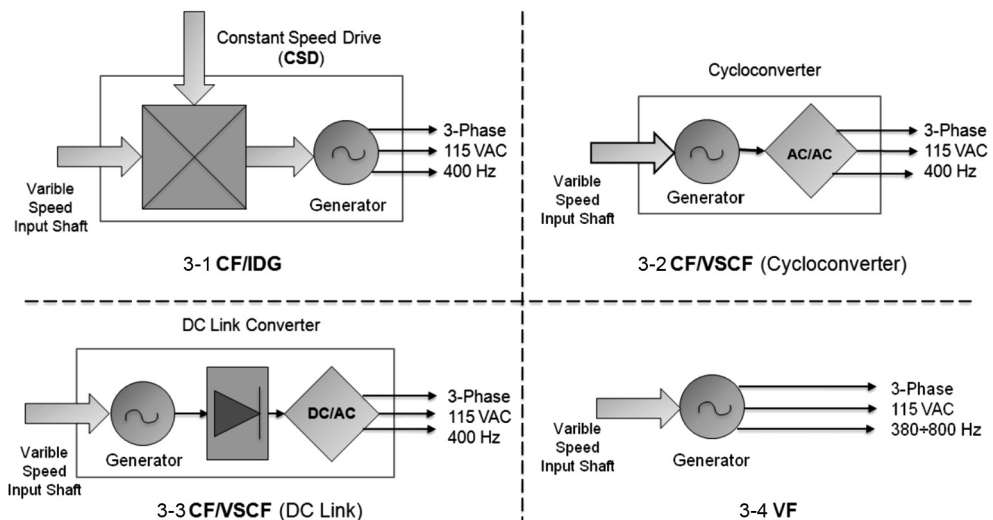


Fig. 3. Electric Power Generation Development of Civil Aircraft [4, 5]

## 2.2. CF/VSCF Generating System

Due to the fact that in this solution, engine output speed is variable, output frequency of the generator is also variable. To supply AC power with a constant frequency of 400 Hz, there is a DC converter (DC Link) applied in the electric circuit between the generator and the load of the AC converter – this is presented in Fig. 3 (2). For this purpose, AC/DC and DC/AC converters or cycloconverters (AC/AC converter) as shown in Fig. 3 (3). CF/VSCF system, converting variable frequency power from the AC generator to 115 VAC at 400 Hz by using power electronic converters was applied in civil aircrafts (B-737, A-340). Using a DC link can gain additional benefits in terms of supplying high power loads and charging batteries.

## 2.3. VF Generating System

In VF generating systems, engine speed is variable, therefore, the frequency of the generator is also variable in the range 380–800 Hz, with an output voltage of 200 V. It should be noticed that variable frequency in the VF generating system is the simplest, the cheapest and the most reliable form of generating power. Moreover, AC voltages have a significant impact on aircraft subsystems, such as engines, controlling devices and protecting devices existing on the aircraft [4, 5].

## 2.4. Auxiliary Power Unit (APU)

APU (Auxiliary Power Unit) power, being used by aircraft systems in normal flight conditions is generated by AC generators driven by the main engines. The aircraft electrical system is powered by two engines driving the generators controlled by an integrated drive, e.g. GEN1 (first generator) is driven by the first engine, whereas GEN2 (second generator) is driven by the second engine. The third AC generator 3x200 V at 400 Hz is driven by the APU generator, which is able to replace one or two main generators (GEN1 and GEN2).

## 2.5. Emergency Power Source (Emergency Generator)

RAT (Ram Air Turbine) or fuel cells are emergency sources of power in case of main generators or APU (Auxiliary Power Unit) damage. An emergency AC generator with output voltage of 3x200 V at 400 Hz is driven by a hydraulic RAT system, designed for automatic emergency powering (in case of all main generators damage). Fuel cells are used as an emergency DC power source. For proper operation, it needs the power supply from converters, whereas batteries are used to provide emergency power in the case of alternative or emergency power source damage.

## 2.6. Ground Power Unit (GPU)

In order to perform maintenance on the ground – a ground power unit (GPU) is necessary for technical maintenance and to check each system in voltage state. The GPU is powered by a 3-phase 200 VAC at 400 Hz voltage, as in the case of supplying by AC generators.

### 3. Electrical power generation by autonomic electrical systems

#### 3.1. Conventional Solution

Electrical system structures depend primarily on the purpose and type of aircraft (civil or military), level of load power, types of electrical power (voltages) necessary to supply loads and quality requirements of aircraft user. An example of the conventional aircraft electrical system of a Boeing B-767 is presented in Fig. 4.

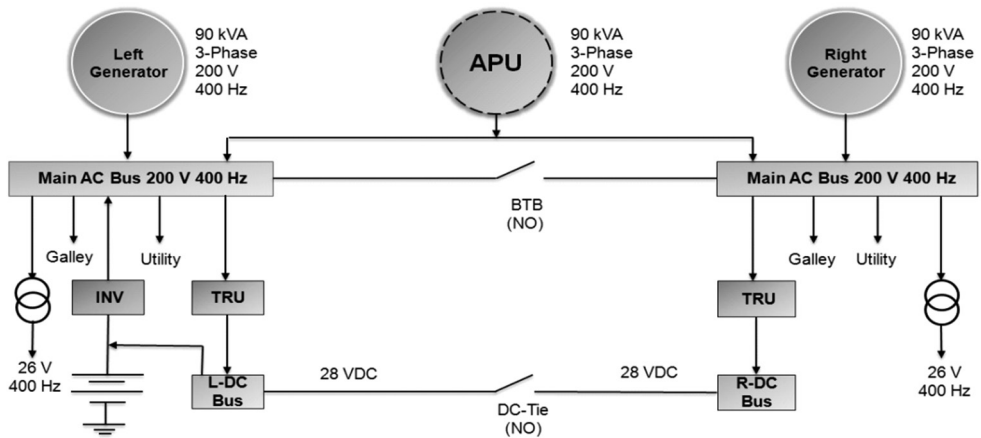


Fig. 4. Conventional B-767 Aircraft Power Distribution System [4, 6]

Conventional aircraft electrical systems have different structures depending on the composition of the electrical power sources and the type of converters – it can be designed as one-channel, two-channel or mixed. DC power is provided by a generator or a starter/generator (DC power system) and brushless generator (AC power system). In the case of a DC system, power is provided by a DC generator, which is driven by the main engine (main gearbox) directly. In multiengine aircraft, DC generators are used, working parallel with electrochemical cells (batteries) enabled. Converters (machine or static) provide AC power with constant frequency and different values of voltage. Different solutions in conventional aircraft are electrical system structures with AC generator (in this variant there is no main source of DC power such as generator or starter/generator). In this solution, electrical power is generated by a primary source of power which is a 3-phase AC generator with collector rings 200 VAC or 3x200/115 VAC at 400 Hz. These generators are driven by the main engine (main gearbox, which is the typical source of power with constant speed), while the DC power, essential to supply loads and to load the battery, is converted by a rectifying system (transforming and rectifying device), which is a secondary DC power source.

### 3.2. More Electric Aircraft (MEA) Concept

In modern aircraft electrical power system, called Power-By-Wire (PBW), MEA and latest perspective trend AEA (All Electric Aircraft) it is assumed that the only and most important power is electrical power (aircraft partially or fully electrified). Moreover, most conventional systems (heavy and unreliable hydraulic and pneumatic systems) will be replaced by electromechanical or electrohydraulic equivalents, increasing the reliability of the aircraft and reducing operational cost. Advanced PES (Power Electronic Systems), controlling systems, engine drives and electric machines affect the development of advanced technologies which use a CF/VSCF generating system. The main benefit of this solution is usage of improved and more efficient systems (starter/generators) which can operate in motor mode, providing a starting function for engines of jet-propelled aircraft. Other advantages of a CF/VSCF generating system are improved reliability, decreased service and maintenance costs and a shorter work cycle. This systems uses 3-phase, synchronous AC generators and solid-state converters. Converters of this type consist of a rectifier (converting AC power to DC power), an intermediate circuit and an inverter (converting DC power into constant frequency 3-phase AC power). The power distribution of a CF/VSCF generating system is presented in Fig. 5.

In the generating mode of a CF/VSCF system, aircraft engines with variable speed provide mechanical power to the input of the electrical generator. Then, the electrical generator provides AC power with variable frequency to the bidirectional power converter, which provides constant frequency AC power to the main bus. In motor mode constant frequency AC system, through bidirectional power converter, provide power to input of electrical motor, which operate as starter of aircraft engine. In addition, synchronous, induction, switch reluctance electrical machines competes with CF/VSCF generating systems with starter/generators with 270 VDC voltage is presented in Fig. 6.

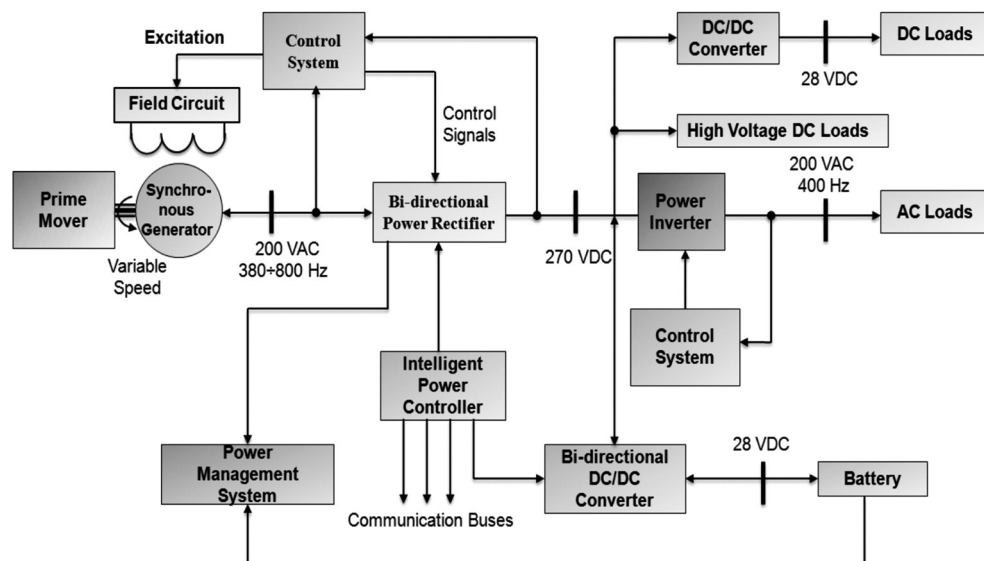


Fig. 5. More Electric Aircraft (MEA) Power Distribution System [6]

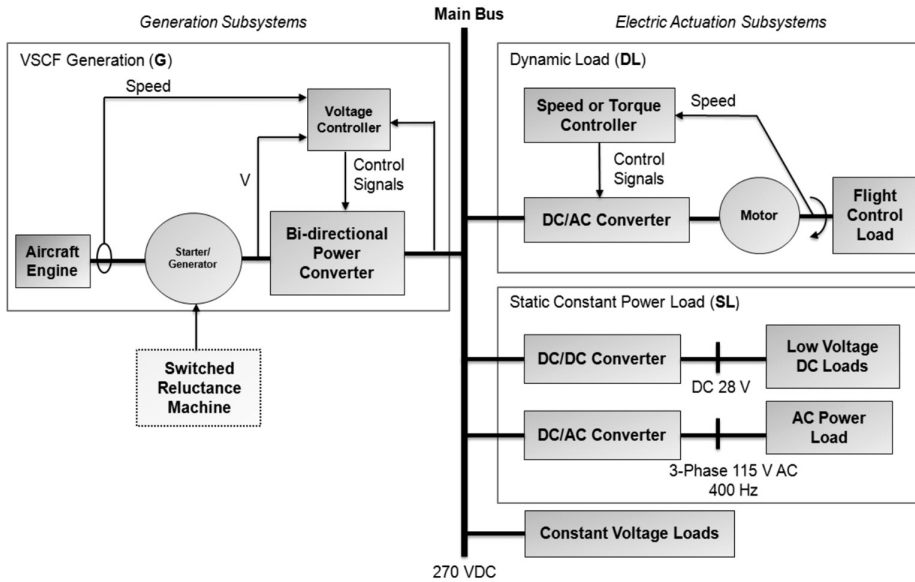


Fig. 6. 270 DC Power System for MEA [7]

### 3.3. Technologically advanced developments of modern aircrafts (B-787, A-380)

The distribution system on modern aircrafts B-787/A-380, presented in Fig. 7 consists of a main generator, with 1 MVA range of power and an auxiliary power unit, with a 450 kVA range of power.

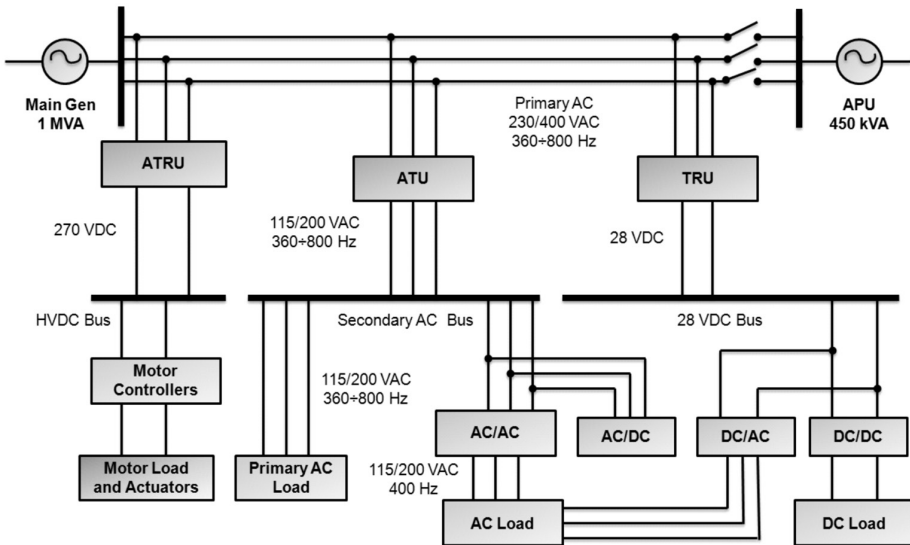


Fig. 7. B-787/A-380 Aircraft Power Distribution System [4, 7]



The primary AC bus is characterized by a high range of voltage with a value of 400 V and a frequency between 360 and 800 Hz, instead of 200 V in previous systems. The primary AC bus supply high voltage DC bus with 270 HVDC (High Voltage Direct Current) through the autotransformer of the ATRU (Auto-Transformer Rectifier Unit), standby AC bus with a voltage of 200 V and a frequency between 360 and 800 Hz through the ATU (Auto Transformer Unit), the 28 VDC bus through the TRU (Transformer Rectifier Unit) and the main AC loads. When an emergency power source is enabled, the main electrical power distribution system focuses input electrical powers, which may be provided by the main generator, APU, GPU or RAT.

#### 4. Conclusions

With the development of advanced technology in the field of electrical machines (MEA technology) they began to look for solutions that would be able to meet the demands of today's aircraft in the context of power and electricity generation (PES, switch reluctance starter/generators 270 VDC). MEA technology is the future trend of the aircraft, as elements of its development are the ecological, economic and quality factors, which are also its main advantages. The replacement of mechanical, hydraulic and pneumatic power onboard the aircraft with one kind of energy (electrical) is the most important innovation of MEA/AEA technology. Based on the findings of the European aircraft energy optimization project, POA (Power Optimized Aircraft) and using a local onboard DC distribution system PDS (Power Distribution System) provides opportunities to reach the optimal benefits by individual onboard subsystems, which include: reducing the weight of actuator systems; increased equipment reliability; easier maintenance; lower operating costs; increased flight safety. Thus, the PDS is a local network of aircraft supplying important receivers, systems, installations and onboard systems necessary for the safety of the flight e.g. flight control, landing system, fire protection, anti-icing systems, etc. This article reviews chosen solutions of power systems and signaled an analysis of electricity distribution management of advanced power systems for both conventional aircrafts as well as those compatible with the MEA technology and modern constructions (A-380, B-787) which showed that MEA/AEA concepts are feasible in the near future. In addition, these aircraft are characterized by a higher power range, generated by onboard sources. For MEA aircraft, it is a power of 1 MVA, while for conventional aircraft – 90 kVA. Furthermore, systems advanced in terms of power electronic (PES) i.e. electronic switches and control devices are able to generate and manage the onboard energy of the multi-voltage power and a variable and constant frequency. Aiming towards solutions of aircraft compatible with the concept of MEA, it should be noted that it is characterized by the performance of the entire aircraft, increased reliability, flexibility and efficiency. In summary, MEA technology is continually evaluated and has a huge potential in terms of weight, quality and operating costs, while traditional systems, sources and applications are on the line, which distance from the curve continuously decreases (asymptotic growth).

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