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Review of Aircraft Electric Power Systems and Architectures

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Abstract—In recent years, the electrical power capacity is increasing rapidly in more electric aircraft (MEA), since the conventional mechanical, hydraulic and pneumatic energy systems are partly replaced by electrical power system. As a consequence, capacity and complexity of aircraft electric power systems (EPS) will increase dramatically and more advanced aircraft EPSs need to be developed. This paper gives a brief description of the constant frequency (CF) EPS, variable frequency (VF) EPS and advanced high voltage (HV) EPS. Power electronics in the three EPS is overviewed.

Keywords: Aircraft Power System, More Electric Aircraft, Constant Frequency, Variable Frequency, High Voltage.

I. Introduction

In early stage of the aircraft history, aircraft is driven by mechanical, electrical, hydraulic and pneumatic hybrid systems. An the end of 1970's, the idea of using electricity as dominant power source emerged and during this period the concept of More Electric Aircraft was proposed [1][2][3].

The first commercial aircraft "Fly by Wire" (FBW) was introduced by Airbus with A320 series in 1980's. The FBW technology can reduce the weight and volume of aircraft by replacing part of the mechanical and hydro-mechanical systems into electrical systems. In FBW system, power electrical systems generally use 115V with fixed frequency at 400Hz AC for high power onboard equipment and 28V DC for low power onboard equipment [4][5]. However, some onboard systems like flight control actuation, landing gear, de-icing device and engine starter/generator are still driven by hydraulic, pneumatic and mechanical hybrid systems which are inefficiency and heavy [6]. These defects foreshadow the wider implementation of electric power system in aircraft.

In order to remedy these defects and make flights much safer, reliable and environmental friendly, the "Power by Wire" [7] technology emerges as the times require. In PBW technology, most of the inefficient, heavy hydraulic systems were eliminated and replaced by electrical systems which have relatively higher efficiency, stronger fault-tolerant ability and lower weight. Therefore, the aircraft EPS capacity needs to sprint higher to meet the electrical equipment's requirements. For example, the electrical capacity of Boeing 787 has increased to 1MW during a normal flight [8]. Apparently, compared with conventional EPS, more advanced EPS is needed to achieve high availability, stability, efficiency and low weight, volume in MEA. Besides, less engine noise, emissions and fuel burn can be realized in MEA [9][10].

This paper introduces the structure of conventional and modern aircraft EPS. The advantage of MEA is discussed. Power electronic converters in aircraft EPS is also presented.

II. Constant Frequency EPS

2.1 Structure of Constant Frequency EPS

In constant frequency aircraft EPS, aircraft generators are three-stage Permanent Magnet (PM) excited wound field synchronous machines. A Generator Control Unit (GCU), which is not depicted in Fig. 1, acts as exciter field controller, regulating the output voltage.

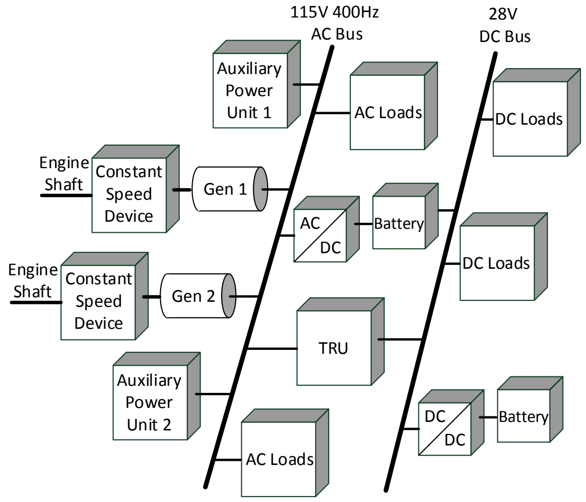

Fig. 1 CF Aircraft EPS

Fig. 1 shows the conventional CF aircraft EPS in which bus voltage is 115V at 400Hz AC and 28V DC. This power system employs constant speed device (CSD) [11] which is a mechanical gearbox. It converts the speed of the engine shaft from variable into constant. And the constant rotating speed shaft connected with the generator will then generate a CF power at 400Hz. As we can see from the figure, AC loads are directly powered by AC bus while the Transformer Rectifier Units (TRU) is used to convert the AC power into 28V DC.

2.2 Power Electronics in Constant Frequency EPS

In CF aircraft EPS, AC/DC converter and TRU are the main power converters. Generally, battery is used as an emergency power source. AC/DC inverter and Bi-directional DC/DC converter will connect the battery with the AC bus and DC bus respectively.

The DC power could be obtained conventionally from a DC generator. However, the space around the aircraft main engine is extremely limited to install other AC or DC generators. In addition, DC cable, which is extremely heavy and long, is also required to connect the generator with the DC bus [12]. For these reasons, TRU [12][13][14] is introduced to convert AC voltage to DC voltage, since it can be installed close to the DC bus, thus weight and volume of EPS could be reduced to a relatively lower level. Besides, TRU could also reduce harmonic currents and achieve lower THD. Topology of a typical 12-Pulse TRU is shown in Fig. 2.

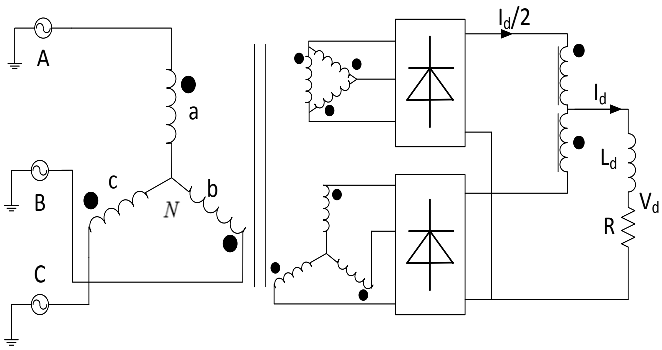

Fig. 2 Topology of 12-Pulse TRU

III. VARIABLE FREQUENCY EPS

3.1 Structure of Variable Frequency EPS

In variable frequency aircraft EPS, shown in Fig. 3, the frequency of primary AC bus is 360Hz-800Hz at 115V since the generator is connected with engine shaft directly. A variety kind of converter is employed to convert VF voltage to multi voltage levels, such as 115V AC and 270V DC.

It’s worth mentioning that the frequency of primary AC bus, which varies between 360Hz and 800Hz, is proportional to the engine shaft speed [15]. By using VF power system, the bulky, heavy, inefficient CSD could be removed from the aircraft. Thus, the aircraft EPS could achieve higher performance.

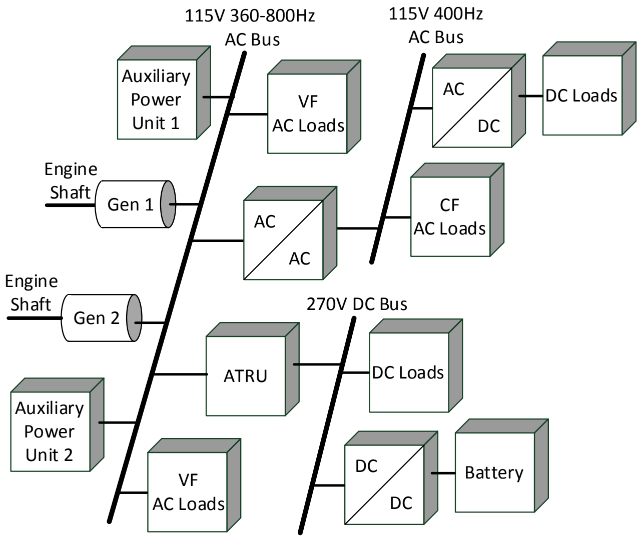

Fig. 3 VF Aircraft EPS

3.2 Power Electronics in Variable Frequency EPS

Since the primary AC bus has a variable frequency, Back-to-Back converter [16] is needed to power CF loads. These converters must be designed carefully to meet the volume, weight and harmonic requirements in aviation standard, such as DO-160 or MIL-704. Its topology is shown in Fig. 4.

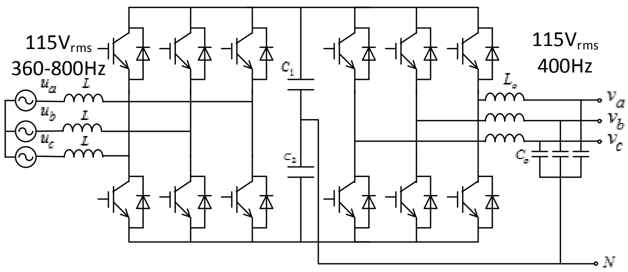

Fig. 4 Back-to-Back Converter Structure

Two PWM converters are employed in Back-to-Back converter. The first stage—high power factor rectifier, which adopt D-Q decouple strategy to control the active and reactive current, can make the power factor approximate to 1. Thus, current harmonic could meet higher standard [17]. The second stage—SPWM inverter could stable the bus voltage and frequency by utilizing voltage-current dual loop.

For DC bus, 270V DC voltage is chosen because it can be obtained directly by rectify 115V AC voltage. DC/DC converter is used to obtain multi DC voltage levels.

As we all know that autotransformer has much smaller size and weight than isolation transformer at same power level. So naturally, Autotransformer Rectifier Unit (ATRU) [14][18] replace the position of TRU. Fig. 5 shows the topology of the 24-Pulse ATRU. The ATRU utilizes phase-shifting windings to generate 4 groups of AC voltage. Each group has 15° phase difference [19], so that the output voltage can reach 270V.

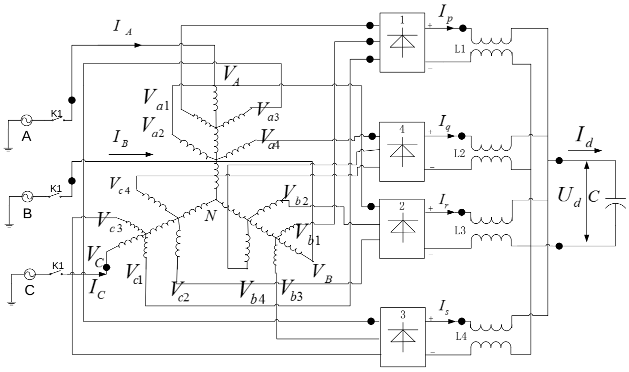

Fig. 5 Topology of 24-Pulse ATRU

Besides the converter aforementioned, Bi-directional DC/DC converter is used in VF aircraft EPS to charge/discharge batteries as the emergency power supply.

IV. FUTURE AIRCRAFT EPS

In later design of aircraft EPS, as the consequence of gradually substitute the hydraulic, pneumatic and mechanical system, there is an obvious trend towards increasing demand of electrical power. However, the feeder cable current in conventional 115V or 28V EPS will increase proportionally to power ratings. And this will definitely lead to higher power loss and cable weight.

As a consequence, increasing the voltage level in future aircraft EPS is an obviously better choice than continuing apply the 115V AC and 28V DC low voltage EPS. By doing this, the feeder cable current could be reduced dramatically. Also, lower cable weight, higher efficiency and lower consumption could be achieved [20][21].

4.1 High Voltage AC (HVAC) Aircraft EPS

Some newer aircrafts have been adopted HVAC power system (230V at 360-800Hz), such as Boeing 787. Compared with the conventional 115V EPS, power transmission loss and converter weight can be reduced by 50.7% and 42.5% respectively [21].

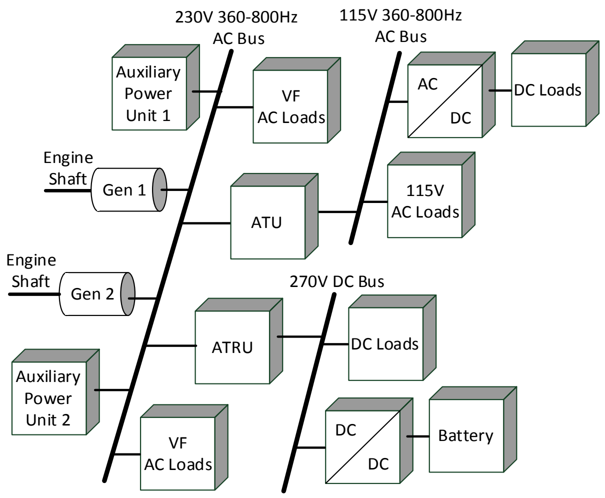

Fig. 6 HVAC Aircraft EPS

An example of HVAC EPS is depicted in Fig. 6. In this system, Auto transformer unit (ATU) is used to generate 115V variable frequency voltage. Buck Boost Converter Unit (BBCU), which consists of 2 DC-AC stages interfaced with a high frequency transformer, is used as the battery charger [22]. Its topology is in the figure below.

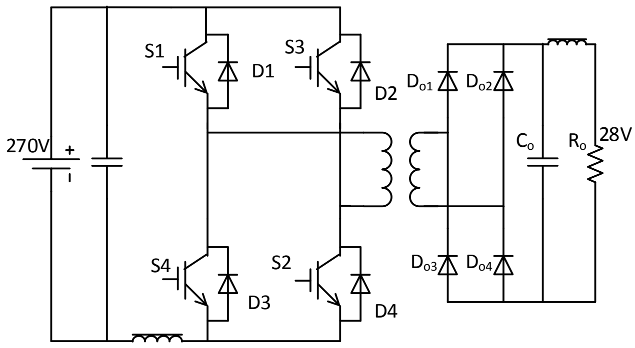

Fig. 7 BBCU Topology

4.2 High Voltage DC (HVDC) Aircraft EPS

Several possible architectures of HVDC aircraft EPS are analyzed in [23]:

- +/- 270V DC 2 phases with ground
- 270V DC 1 phase with ground
- +/-135V DC two phases with ground
- +/- 135V DC 2 phases without ground

The conclusion of [23] certifies that in most cases, HVDC EPS can save weight from 4% (270/0V architecture with 230V AC supply) up to 28% (270/0V architecture with 115V AC supply). Fig. 8 illustrates a typical 270V HVDC EPS.

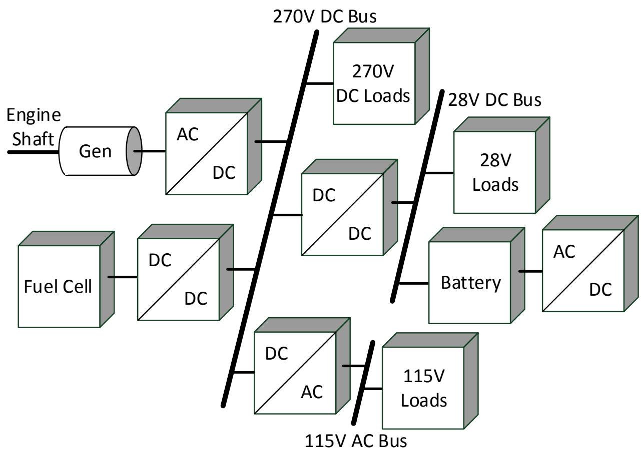

Fig. 8 270V HVDC Aircraft EPS

As we can see from Fig. 8, fuel cell system replaces the position of conventional APU which is driven by turbines. This is because the efficiency of turbine powered APU is typically less than 20% and also has undesirable noise and gaseous emissions [24][25]. Some topology had been proposed in [26] to integrate fuel cell system into aircraft

EPS. One of parallel architecture is depicted in Fig. 9. In this case, bi-directional DC/DC converter is employed.

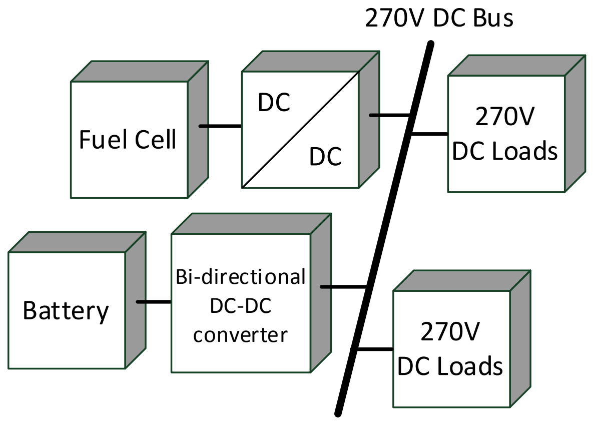

Fig. 9 Parallel Architecture of Fuel Cell System

4.3 Challenges of Future Aircraft EPS

At present, an electrical device cannot offer improved reliability but could increase availability thanks to the opportunity to isolate a subsystem in case of failure [27]. Although it is possible to anticipate failures in the near future through the behavioral modeling of systems coupled with fault-detection algorithms [28][29], but the better way is developing high reliable, high power density power electronic devices. For example, SiC based semiconductor [30][31] device is very promising since it can provide a significant reduction of switching losses, high temperature tolerance and fast switching capability.

In the converter level, the widely used PWM power converters which have a very complicate control strategy may lead to the whole distribution network suffering from an unstable situation. Several studies have been done to guarantee the converter operating in a stable region [32][33]. It's worth mentioning that sharing power electronic converters is an effective way to save mass [29][34].

As to the system level, integrated optimal design will be the major research field in the next decade since the conventional test and error method cannot ensure the system reach its most optimum operation point [29]. The integrated optimal design will balance the system mass, efficiency, thermal stability and power quality through an advance algorithm [35][36].

V. Conclusions

In this paper, CF, VF and HV aircraft EPS are summarized. The role of power electronic converters is presented. HV EPS will still be the future trend in aircraft as it is an effective way to deal with the increasing capacity of aircraft EPS. Many challenges are also put forward by HV EPS along with the increasing power capacity and power converters. Such as electromagnetic compatibility (EMC) [37], power density, harmonics, high voltage contactors, solid state power controller [38] and so on. To meet and finally triumph these challenges, researchers had proposed many effective way, such as SiC semiconductors and optimal design at the system level.

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