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Power Generation and Distribution System of Modern Civil Aircraft

Swapnil Srivastava
STUDENT M.Tech. (POWER ELECTRONICS & DRIVES) Saroj Institute of Technology & Management, Lucknow (U.P.)

Abstract
As the aircraft industry is moving towards the all electric and More Electric Aircraft (MEA); is the future trend in adopting single power type for driving the non-propulsive aircraft systems; i.e. is the electrical power. The trend in the aircraft industry is to replace hydraulic and pneumatic systems with electrical systems achieving more comfort and monitoring features. The structure of MEA distribution system improves aircraft maintainability, reliability, flight safety and efficiency. Moreover, MEA reduces the emissions of air pollutant gases from aircrafts, which can contribute in significantly solving some of the problems of climate change. However, the MEA puts some challenges on the aircraft electrical system, both in the amount of the required power and the processing and management of this power. MEA electrical distribution systems are mainly in the form of multi-converter power electronic system.
Keywords: More electric aircraft, Power converters, Electric actuations, VSCF.

I. INTRODUCTION

Recently, the aircraft industry has achieved a tremendous progress either in civil or military sectors, for example some currently commercial airliners operate with weights over 300 000 kg and have the ability to fly up to 16 000km in non-stop journey at speed of 1000 km/h.

The non-propulsive aircrafts systems are typically driven by a combination of different secondary power types such as hydraulic, pneumatic, electrical and mechanical power. These powers are extracted from the aircraft main engine by different disciplines. For example, mechanical power is obtained from the engine by a driven shaft and distributed to a gearbox to drive lubrication pumps, fuel pumps, hydraulic pumps and electrical generators. Pneumatic power is extracted by a bleeding compressor and used to drive turbine motors for the engine start systems, wing anti-icing and Environmental Control Systems (ECS), while electrical power and hydraulic power are distributed throughout the aircraft for driving subsystems such as flight control actuators, landing gear brakes, utility actuators, avionics, lighting, galleys, and weapon system in case of military aircraft.

The trend is to use the electrical power for extracting and distributing the non-propulsive powers. This trend is defined as MEA. The MEA has been questioned for several decades since W.W. II. Nevertheless, due to the lack of electric power generation capabilities and volume requirements of the required power conditioning equipments, the focus has been drifted into the conventional power types.

The adoption of MEA in the future aircraft either in civil or military sectors results in tremendous benefits such as:

1. Removing hydraulic systems improves the aircraft reliability, vulnerability, and reduces complexity, redundancy, weight, installation and running cost.
2. Employing electrical starting for the aero-engine through the engine starter/generator eliminates the engine tower shaft and gears, power take-off shaft, accessory gearboxes, and reduces engine starting power especially in the cold conditions.
3. Using the Advanced Magnetic Bearing (AMB) system, which could be integrated into the internal starter/generator for both the main engine and auxiliary power units, allows for oil-free, gear-free engine.

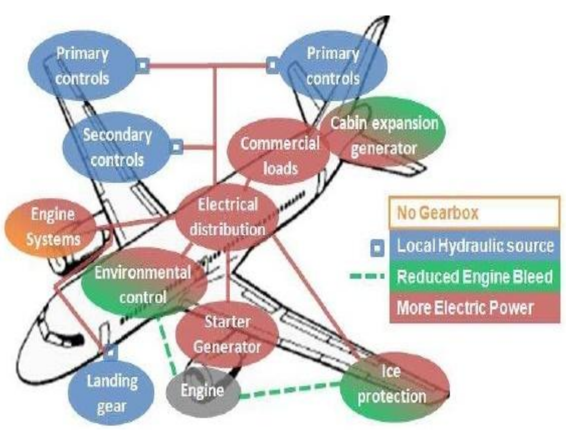

Fig1: More electric aircraft outline

II. ELECTRIC POWER GENERATION IN MEA

The MEA represents recently the major driver for increasing the generation of the electric power. Moreover, the MEA directs the research into new generation options. Fig, 2 shows different electric power generation disciplines used in aircraft. These schemes are summarized in the following.

1. The constant frequency (CF) options are the most common. However, the need for unreliable gearbox to match between the engine speed and the generator requirements of fixed speed makes the CF expensive and cumbersome. The CF is alternatively termed Integrated Drive Generator (IDG).
2. Variable Speed Constant Frequency (VSCF) DC link system is now the preferred option for the most new military aircraft application and some commercial aircraft. Currently, the range of VSCF DC link system has been widened due to the recent advancements in field of high power electronic switches. VSCF DC link option is generally characterized by simplicity and reliability.
3. Variable Speed Constant Frequency (VSCF) Cycloconverters convert directly the variable frequency AC input power into AC power with fixed frequency and amplitude. The power generation efficiency of the cycloconverters increase as lagging power factor decrease, which would be beneficial if this technique, is applied to motor loads with significant lagging power factors.

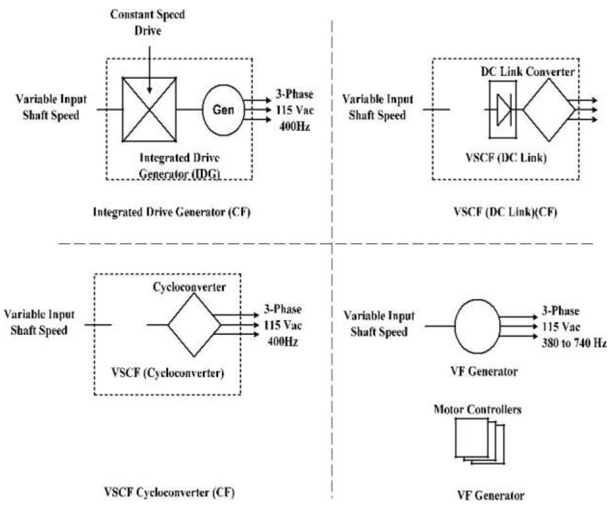

Fig2: Aircraft Electrical Power Generation Options

The current generator technology employed on most commercial and military aircraft is the three-stage wound field synchronous generator. This machine is highly reliable and inherently safe, as the field excitation can be removed, which de-energizes the machine. Therefore, the rating of the three-stage synchronous generator has increased over the years reaching to 150KVA on the Airbus A380. However, the anticipated increased electrical power generation requirements on the MEA suggests that the high power generators may be attached directly to the engine, mounted on the engine shaft and used for the engine start in Integral Starter/Generator (IS/G) scheme. The harsh operating conditions and the high ambient temperatures push most commonly materials close or beyond their limits, therefore innovations in materials, processes and thermal management systems are required.

Induction, switched reluctance, and permanent magnet machine types have been considered for application in MEA due to their rugged features. However, the induction generator requires complex power electronics and is considered unlikely to have the power density of the other machines.

The Switched Reluctance (SR) machine has a very simple robust structure, and can operate over a wide speed range. The power electronics is comparatively simple. Moreover, the machine is inherently fault-tolerant.

The fault -tolerant Permanent Magnet (PM) generator is considered to be one of the most attractive options for the MEA. It has a high kW/mass ratio and a good efficiency throughout a wide speed range. Additionally, the reliability, ruggedness, and ease of cooling are also positive features.

III. POWER DISTRIBUTION AND MANAGEMENT SYSTEM

The aircraft power system usually consists of a combination of 115V 400Hz AC for large loads and 28V DC for avionics, flight control and battery-driven vital services. However, adopting the new generation options as VF requires using power electronics to convert all the motor/generator outputs into a single high-Voltage DC Distribution system.

Three different candidates for implementing the proposed Electrical Power Distribution System (EPDS) in the MEA are briefly reviewed in the following. These are:

1. Centralized EPDS
2. Fault-Tolerant EPDS
3. Advanced Electric System (AES)
4. Semi-distributed EPDS

1. Centralized EPDS

The centralized EPDS is a point-to-point radial power distribution system as shown in Fig. 3. It contains only one distribution centre. The generators supply this distribution centre, where the electrical power are processed and fed to the different aircraft electrical loads. The distribution centre is normally positioned in the avionics bay, Fig. 3, where the point of voltage regulation is located. In this system, each load is supplied individually from the power distribution centre.

The main advantages of the centralized EPDS are:

1. Ease of maintenance, since all equipments is located in one place, avionics bay.
2. Decoupling between the loads; thus the disturbance in a load is not transferred to the other.
3. Fault-tolerant, as the main buses are highly protected.

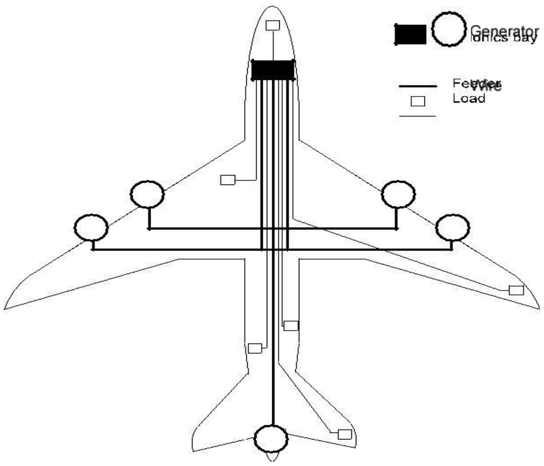

Fig. 3. Centralized EPDS for the MEA

2. Fault-Tolerant EPDS

The typical fault-tolerant EPDS for two engine aircraft consists of two switches matrices, six multi-purpose converter, six generators and anticipated loads.

The electrical power sources are connected to the source switch matrixes, while the loads are connected to the Load switch matrixes. The switches in the matrices can be constructed with conventional contactors, unique new multi-position rotary contactors or solid-state contactors. The fault-tolerant EPDS has the advantages of:

1. The ability to start the aircraft engine by using Generator/Starter scheme
2. High redundancy

The fault-tolerant EPDS has the disadvantage of faults in source/load switch matrices interrupts the operation of the other generators/loads.

3. Advanced Electric System (AES)

The Advanced Electric System (AES) is flexible, fault-tolerant system, which is developed to replace the conventional centralized manual or semi–automated power distribution system with a redundant microprocessor-based system. The electrical power are supplied from the generators, APU, battery and ground sources to the primary power distribution, where the Contactor Control Units (CCU) and high power contactors are located. The aircraft loads are supplied via the Relay Switching Units (RSU). The AES is controlled by either of the two redundant Electrical load Management units (ELMU). The CCU performs control and protection on the power which is processed through the quad redundant AES data bus. The Remote Terminal (RT) units control the RSU.

The AES is superior to the centralized. This is because the AES has the following advantages:

1. AES reduces the aircraft life cycle cost, as the reconfiguration of the system in the event of an aircraft modification or upgrade can easily be accommodated
2. AES can detect deviant conditions of current/Voltage and provide instant load shut-off
3. A major reduction in the weight and wiring in the AES is achieved due to the elimination of circuit breaker panels from the flight deck stands.
4. The system can be easily upgraded.

The AES has the disadvantage of concentrating the distribution and the management of power supplied by the generating units/sources into a single unit; therefore a fault in this unit may interrupt the operation of all aircraft loads.

4. Semi-Distribution EPS

The main Alternative version of the conventional centralized EPDS is semi-distributed architecture. The architecture utilizes a large number of Power Distribution Centers (PDCs), which are scaled down versions of PDC in the centralized system. The PDCs are distributed around the aircraft in such way to optimize the system Volume/weight and reliability. They are located along the fuselage and supply the most adjacent loads.

The semi-distributed EPDS has a number of advantages, such as:

1. Wires with small weight/Volume are being employed in the semi-distributed EPDS, which decreases the overall system cost and increases its efficiency and reliability.
2. Using a large number of distribution centers increases the level of redundancy in primary power distribution paths.
3. A high efficient operation of the EPDS is realized due to the reduced Voltage drops across the distribution network.

Locating the distribution centers near to the loads improves the system power quality, and reduces the Electromagnetic Interferences (EMI).

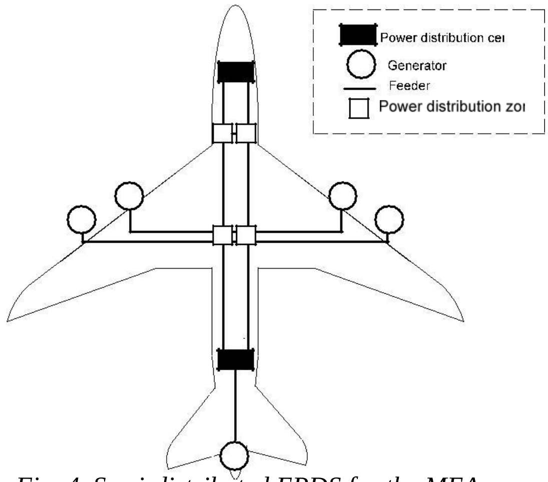

Fig. 4. Semi-distributed EPDS for the MEA

IV. CONCLUSION

Replacing the conventional non-propulsive aircraft power, mechanical, hydraulic and pneumatic with single electric power is known as MEA, and considered as the future trendsetter. The MEA improves the aircraft reliability, affordability, fuel consumption. Moreover, MEA reduces cost of ownership, operation and maintenance cost. However, the implementation of MEA requires innovation in the areas of power generation, distribution and management.

Embedding the electrical generator into the aero-engine is considered to be key issue in generating the large amounts of power, as it removes the cumbersome matching gearbox.

The SR and fault-tolerant PM machines are increasingly being adopted in the MEA, which returns to the high kW/mass ratio and the inherent fault tolerance.

The conventional centralized EPDS is point-to-point, radial system. This system is bulky and heavy; therefore, a number of candidate solutions were advised to replace it.

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