Ideas for Future Electric Aircraft System

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Abstract – This design paper proposes few improvements on the existing electrical network in the aircraft system. It also suggests improvement in the starter circuitry by introducing super capacitors to reduce the number of batteries onboard to ensure improved safety and reliability. It proposes higher frequency of power distribution owing to several benefits. There are several advantages of high frequency AC power distribution over conventional DC distribution and low frequency AC power distribution. This paper explores the idea of employing switched capacitor and switched inductor converters to design multi-level inverters for high frequency AC power supplies for power distribution.

Keywords – Electric Aircraft, Multi – level inverters, Switched – Capacitor, Switched – Inductor.

I. INTRODUCTION

High frequency AC (HFAC) power distribution systems (PDS) have been popular since the 1980s when NASA proposed a 20 kHz, 440 V_{rms}, for their space station [1] & [2]. Since then HFAC PDS has emerged as a popular research area and has had several applications utilizing it. HFAC PDSs find application in telecommunication, renewable based micro-grid and computer power supply, aerospace and lighting systems. A comprehensive review on HFAC systems has been done in [3].

Basic power distribution architecture of HFAC PDS and DC PDS is clearly shown in Fig. 1 and Fig. 2. HFAC PDSs offer several benefits in comparison to conventional DC distribution systems. They include –

- Cost reduction due to reduction in the number of power conversion stages.
- Overall improved efficiency
- DC PDS target low voltage high current PDSs. Such systems are extremely difficult to design and demand novel control and converter topologies for efficient operation. On the other hand, a high voltage AC, low current system can be easily realized in HFAC system by using a simple HF transformer that easily steps up the voltage. This helps in minimizing the copper loss.
- Improved reliability with the number of power conversion operations decreasing thereby decreasing the semiconductor components
- Galvanic isolation with high frequency transformer
- DCPDS show poor dynamic response in comparison with HFAC PDS
- Higher power density owing to high frequency operation.

In spite of several exceptional advantages, there are a few drawbacks to the system as well, listed out below –

- Higher Electromagnetic Interference (EMI) effect hinders HFAC applications
- At high frequencies, skin and proximity effects increases leading to more loss.
- High frequency power distribution amplifies impedance in the transmission line which makes it difficult to transmit power
- Connecting high frequency inverters in parallel to realize higher power is difficult due to difference in phases of voltage.

This design paper discusses the advantages of employing HFAC PDS systems on aircraft and also explores the idea of switched capacitor and switched inductor based converters' role in designing multi-level voltage source and current source inverters respectively, for more electric aircrafts. Switched inductor converters can be derived using duality principle introduced by Prof. Cheng [4]. Switched inductor based converters are an attractive solution to be used current source inverters. Section II introduces aircraft power system standards and discusses about the existing aircraft power system and suggests improvement on the same. Section III looks into HFAC multilevel inverters employing switched capacitor and possibly switched inductor topologies. Concluding remarks are given in section IV.

II. POWER SYSTEM IN AIRCRAFTS

The power system design and components of an aircraft must be extremely robust and must meet certain stringent standards before they are allowed to be employed onboard. Some of the important standards include:

1. MIL-STD-704F – This standard focuses on the quality of electric power at the input terminals of the utilization equipment. However, this does not include EMI issues [5]
2. MIL-STD-461E – This standard is to control EMI characteristics of electrical equipment of aircraft. [6]
3. MIL-STD-810F – This looks into the stresses that the materials are under during the service period and material system performance requirements [7].
4. MIL-STD-1275D – This standard covers regulations for the 28 V DC power distribution systems in military vehicles including aircraft [8].

All the standards listed above are developed by the team of researchers from the department of defense, USA. The main focus of the standards is to ensure safety and compatibility among different systems onboard. All systems for an aircraft have to pass several such standards before they are employed in the aircraft.

Conventional power distribution system of an aircraft is shown in Fig. 3. With advances in enabling technologies

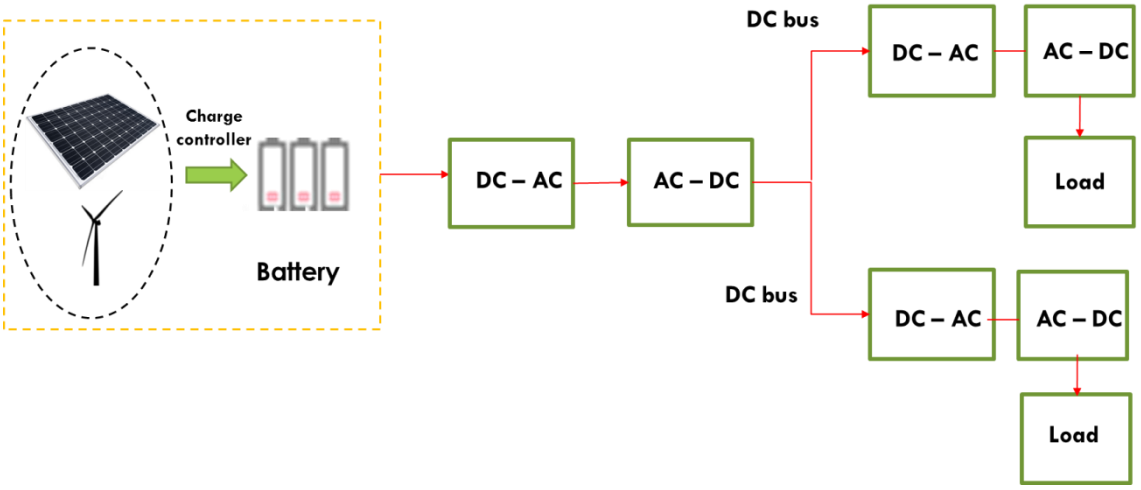

Fig. 1. General DC Power Distribution Architecture

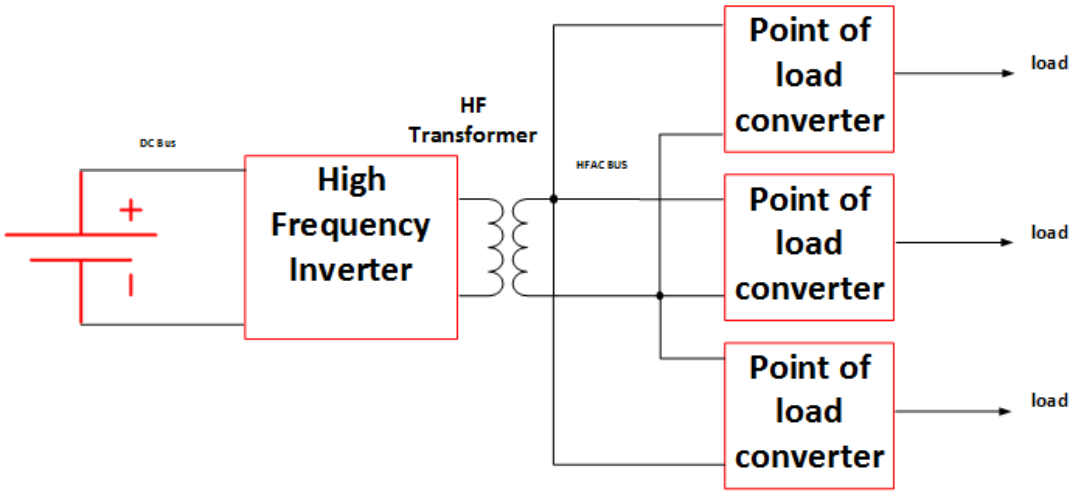

Fig. 2. HFAC Power Distribution Architecture

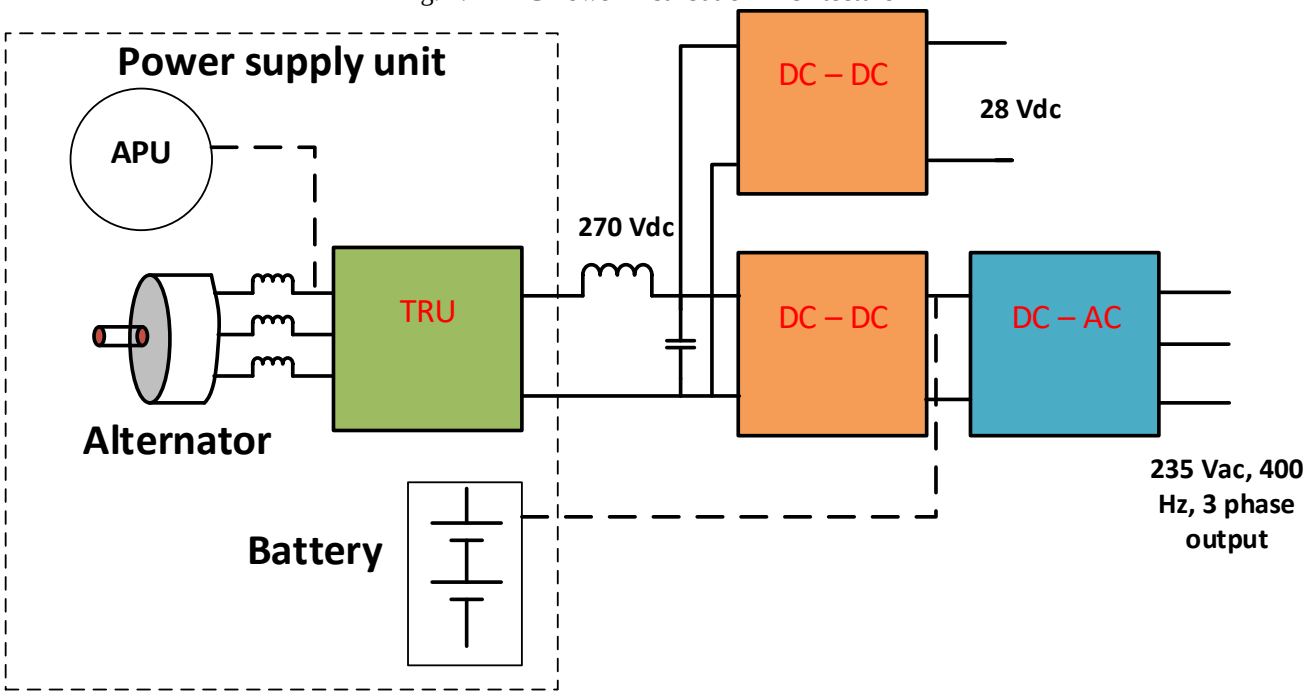

Fig. 3. Present aircraft electrical power system unit

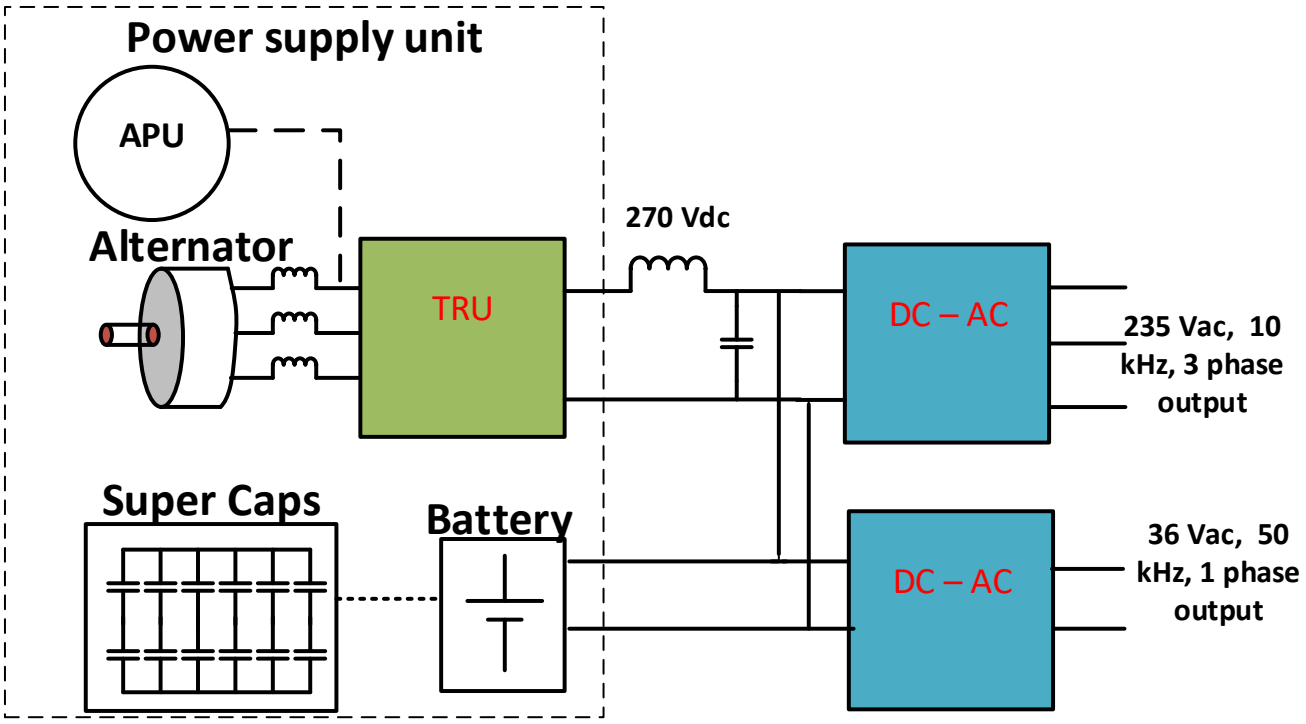

Fig. 4 Proposed electrical system architecture

like power electronics, motor drives, improved thermal management and better materials, all electric aircrafts will soon be a possibility. All electric aircrafts offer improved efficiency, reduction in cost, better reliability, maintenance, improved reliability, batter maneuvering capabilities, enhanced safety and greener systems. A recent example is the electrical system of Boeing's 787 dreamliner [9] [10].

From Fig. 3, it can be observed that the maximum distribution frequency is 400 Hz. There have been several papers on higher frequency range of power distribution for telecommunication, computer power supply, vehicular auxiliary power supply and micro grid applications [3]. It is imperative that we employ such systems inside aircraft for aforementioned advantages. The proposed system, in Fig. 4, replaces 28 Vdc system with a 36 V, 50 kHz power distribution system. The entire aircraft power distribution now is HFAC. This helps in higher power density operation which helps in reducing fuel consumption. HFAC operation, higher than 10 kHz, is safer for human than DC [11].

The new design also incorporates super capacitors into the system. The main purpose of introducing super capacitors is for its high power density. It can be extremely useful during starting of engine where traditionally bulky batteries are used. Additionally, super capacitors are much safer than batteries as they utilize electric field whereas batteries use chemical reaction for energy conversion. Due to the same reason, super capacitors have quicker response time in comparison to batteries. Ideally, one can expect a battery free future electric aircraft. However, this is possible only if research leads us to high energy density super capacitors or reliable fuel cell technology.

Super capacitors also play a crucial role in tapping the regenerative energy when the aircraft lands. Enormous weight thrusts onto the ground and this energy can be used by using the principle of regeneration of motors. Safe energy harvesting on a large scale is possible by employing large super capacitor banks that can sink in high magnitudes of current. This system design is not easy with only batteries as the power source as batteries have lower charging current rating in comparison with super capacitors and therefore all energy regenerated may not be successfully stored.

III. HF Multilevel Inverters

There are plethora of advantages that multilevel inverters offer in comparison to traditional ones [11][12]. In general, they include –

1. Better quality output voltage with lower distortions and *dv/dt.*
2. Input current drawn has low distortion.
3. Lower voltage rating and stress on semiconductor switches

HFAC multilevel inverters are possible by using simple switched capacitor techniques as elaborated in [13][14]. These inverters fully utilize the features of multilevel inverters and apply it to high frequency power distribution systems. These multilevel HFAC inverters can be employed in aircraft systems. A distributed power system consisting of several inverters to cater to different areas of the aircraft loads under a unified controller for the entire aircraft would be a novel and practical design. Using the duality principle [4], future electric aircraft with solar panels embedded onto them can employ multilevel high frequency switched inductor based current source inverters. An example of switched inductor based multilevel CSI derived from switched capacitor based has been shown in Fig.5.

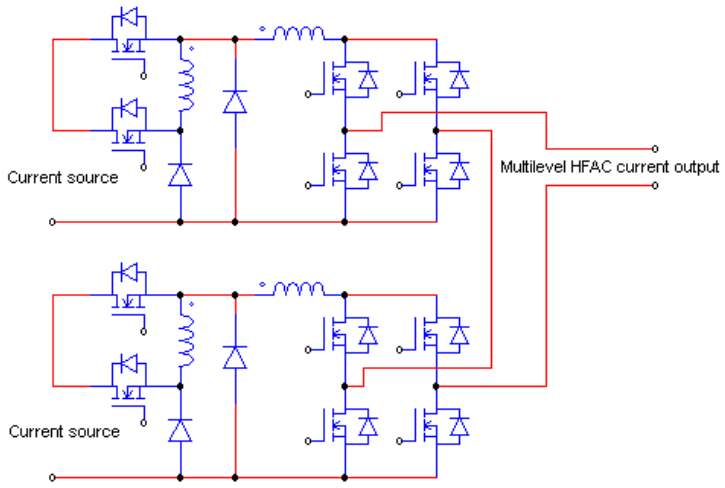

Fig. 5 HFAC 9-level switched inductor based CSI derived from switch cap based from [14] using duality principle

IV. Conclusion

This competition paper focuses on simple ideas to improve the existing electrical system of an aircraft and supports the global initiative for more / all electric aircrafts in future. The paper discusses the possibility of HFAC power distribution systems inside the aircraft to utilize several benefits it offers. Incorporating super-capacitors into the system offers several advantages during starting and regenerative braking. Multilevel switched capacitor and switched inductor based HFAC VSI and CSI respectively offer good features that improve the overall design of the power distribution system in an aircraft.

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