Energy Storage Systems For Electric Aircraft

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Abstract- *High power output and high energy density are quite important requirements for advanced energy storage systems in electric planes and electric vehicles. In this paper, We are going to review the present batteries technologies used in powering the electric aircraft used for small to medium range airplanes and some future technologies which could be implemented in the coming few years. Currently, the problem with current battery technologies is the relatively small energy density of the batteries which are adequate for electric cars but not for aviation use. We will also look at the use of super or ultra capacitors in combination with batteries to make a much more efficient and effective power system. Battery-Supercapacitor hybrid (BSH) alone itself will provide unique assets such as high performance, cheapness, safety, and environmental friendliness.*

Keywords- Batteries, supercapacitors, electric aircraft, electric power system, energy storage.

I. INTRODUCTION

The aviation sector is on the brink of crisis. Its future is in limbo because the world is moving towards decarbonization. Planes are currently only responsible for 2-3% of the world's CO_2 emissions but this is expected to rise to 25% by 2050. Most major polluters have clear technology pathways to a cleaner future, however, the aviation industry has no clear way forward for replacing kerosene. The technology required to transition to cleaner ways of flying has not kept pace. Transition to net carbon-zero, biofuel development, and sustainable aircraft development are expensive. With regulations in countries like France makes the shift to electric is the only top priority as the governments are creating structures for green flying to be cheaper flying by charging hefty carbon taxes. But before adopting electric airplanes there are many hurdles to overcome before it can successfully adapt to renewable energy(Electric). One of the biggest hurdles to overcome is the energy density of our storage methods. This energy storage dilemma is slowing down our adoption. For the aviation of electric planes, we need a technology which can provide us with high energy output. We have a lot more to improve in the battery management system of electric planes for its commercial uses. Lithium-ion, NMC(Nickel Manganese Cobalt Oxide[$LiNiMnCoO_2$]) chemistry, and other high energy density chemistries batteries have a high density which is quite safe when used properly and can be used in electric planes. The drawback of all these batteries is that they have limited charging and discharging ability and still not enough energy density. Increasing speed of charging only results in hazardous emission of gas, fire, and degradation of battery potential with its constituents. So if we go deep into it we get that it charges slowly and takes time to transfer power. A battery can store a large amount of energy but its discharge rate is low. On the other hand, we have supercapacitors with high power density and low energy storage, but their discharge rate is high. Also, the lifespan of supercapacitors is high; approximately it ranges from some 100,000 to millions of cycles. It has a wide effective operating temperature. There are some limitations to supercapacitors also, the discharge rate of supercapacitors is high so they aren't suitable for storage of energy for a long period.

Basically, to overcome the low energy storage capacity of the supercapacitor and the low discharge rate of the battery, we are going to integrate the supercapacitor and battery. The best way to increase efficiency is to merge the various types of energy storage sources with high energy density and better charging rate capability. Along with hybridization of supercapacitor and battery, there is graphene battery which will fill up the gap between battery and supercapacitor. It is an alternative energy storage object which resembles the property of supercapacitor and battery. Recently some companies are interested in graphene batteries.GAC (a Chinese company) is interested in graphene and is planning on using them.

II. OVERVIEW OF SOME PROMISING BATTERY AND SUPERCAPACITORS TECHNOLOGIES

2.1) Present Battery Technologies:

a)Lithium Nickel Manganese Cobalt Oxide Batteries

At present, the batteries which are used for electric airplanes are the same batteries used in electric vehicles. Most of the electric aircraft made at present are using NMC(Lithium Nickel Manganese Cobalt Oxide[$LiNiMnCoO_2$]) chemistry; these systems can be tailored to serve as Energy Cells or Power Cells. For example,18650 NMC cells for moderate load condition feature a capacity of about 2,800mAh and may deliver up to 4A to 5A; NMC within the same cell optimized for specific power features a capacity of about 2,000mAh but delivers a continuous discharge current of 20A. Nickel-based systems have a higher energy density, lower cost, and longer cycle life than cobalt-based cells but the disadvantage is that they have a slightly lower voltage[1]. It has a nominal voltage of 3.7V with specific energy(capacity) of 150-220 Wh/kg with a cycle life of 1000-2000 depending on the depth of discharge and operating temperature. These batteries are replacements of the LCO(Lithium Cobalt Oxide[$LiCoO_2$]) chemistry batteries as they have similar energy density and power but improved safety increased in cycles and increase in the performance of the batteries. This makes the batteries extensively used in the current electric vehicles powertrain and present-day electric aircraft like Eviation Alice and Pipistrel Velis Electro using the NMC Li-polymer batteries and 18650 NMC Li-ion batteries respectively.

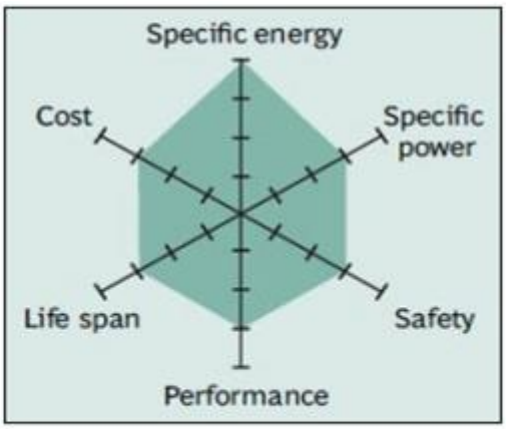

Fig. 1. Snapshot of the properties of NMC Battery
Source: Boston Consulting Group

b)Silicon-Anode Batteries and Lilium Jet:

Lilium Jet is an all-electric aircraft. It is capable of vertical takeoff and landing(eVTOL). It is a seven-seater electric aircraft with a cruise speed of 280 km per hour and a physical range of 250+km. On 28th July 2021 Lilium partnered with Custom Cells to supply high-performance Silicon anode batteries for the 7 seater Lilium jet.[2]

Silicon may be a promising material because of its attractive theoretical specific Capacity(>3500mAh for Li-ion system) And low discharge potential (370mV vs. Li/Li+)[3].
Following Table 1 shows the comparison of varied anode materials:[4]

Silicon has attracted substantial attention as an alternative battery choice for Li-ion batteries and also the abundance of the element silicon is greater than that of lithium.

Table 1:Comparison of various anode materials

Anode Materials	C	Li	Si	Sn	Sb
Lithiated phase	LiC6	Li	Li4.4Si	Li4.4Sn	Li3Sb
Theoretical specific capacity (mAh/g)	372	3862	4200	994	660
Theoretical volume capacity (mAh per cm cube)	837	2047	9786	7246	4422
Volume change(%)	12	100	320	260	200
Potential vs. Li	0.05	0	0.4	0.6	0.9

Source:https://www.sigmaaldrich.com/IN/en/technical-documents/technical-article/materials-science-and-engineering/batteries-supercapacitors-and-fuel-cells/recent-developments-in-silicon-anode-materials

2.2)Future Battery Technologies:

a)Solid-state battery:

Lithium in Lithium-ion batteries forms dendrites in liquid battery systems which lead to compromisation of life of the battery and may even cause the risk of fire first thus compromising the safety of the battery, replacing the liquid electrolyte with solid-state electrolyte is nothing but solid-state batteries. Solid-state batteries are inherently safer. The battery's energy density is also higher than Lithium-ion batteries. Lithium-ion batteries have a risk of battery damage such as swelling due to changes in temperature or leakage caused by external forces because it uses liquid electrolyte solution and cobalt oxide used in batteries have a tendency to undergo thermal runway and the organic electrolytes in many lithium-ion batteries are highly flammable when gets heated.
So the Solid-state battery replaces the liquid electrolyte and separator with a solid electrolyte. This solid electrolyte is impenetrable to Li metal dendrites.

Solid-state batteries Using a Lithium metal anode can achieve 480Wh/kg using a low-density solid-state electrolyte such as polymer are a sulphide.[5]

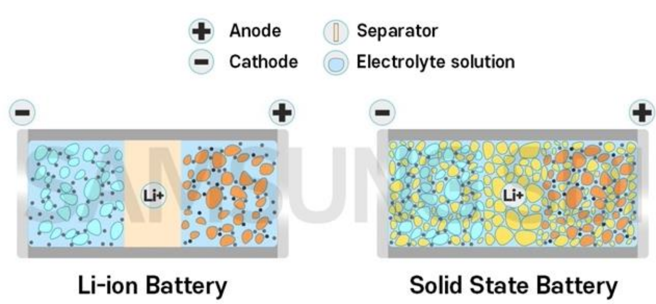

Fig. 2. Structure of Li-ion battery(left) and solid-state battery(right)
Source:https://www.samsungsdi.com/column/technology/detail/56462.html?listType=gallery

b)Lithium-Air Battery:

Lithium-air batteries by far have higher theoretical energy density than any lithium-ion batteries, which have the highest specific energy density of conventional battery systems at present being used. The theoretical specific energy density of the lithium-air battery(excluding oxygen) is as high as 11,430 Wh kg^{-1}, comparable to the energy density of fossil fuels[6]. They are attracting more and more attention from electric vehicles (EVs) and the aviation industry for making the aircraft reach 500 mi(804.67 km). In practice, Li-air batteries with selected energy of roughly 6.12 MJ/kg at the cellular level are demonstrated and proved. This is almost 5 times greater than that of a commercial Li-ion battery and is sufficient to run 2 tonnes EVs for about 500 km (310 miles) using 60 kg of batteries with a single charge. However, the sensible power and life-cycle of Li-air batteries need quite a significant amount of improvements before they can find an appropriate position within the market[7]. During discharge, electrons flow from an external circuit to do electrical work and Li-ion migrates to the cathode. During charging the lithium metal plates onto the anode, releasing O_2 at the cathode. Both non-aqueous(with Li_2O_2 or LiO_2 as the discharge products) and aqueous (LiOH as the discharge product) Li-O_2 batteries have also been considered. The aqueous battery requires a protective layer on the negative electrode to stop Li metal from reacting with water as that would be very dangerous[8].

2.3) Supercapacitor and BSH technology:

Battery technologies are widely used now but it comes with several drawbacks like weight, volume, large internal resistance, etc. On the other hand, due to the advancement of material and other technologies, supercapacitors are the most promising energy storage device as they have low weight, high power density, greater transit response, low volume, and minimum internal resistance. A supercapacitor virtually has infinite charge cycles, it can be charged and discharged a huge number of times; it can be from 100,000 to 1 million times. The lifespan of a supercapacitor is also high. A supercapacitor can last for 10-18 years, while a Lead-Acid battery can last around 3-5 years only. The supercapacitor has super-fast charging time; it needs a very short period for getting a full charge. Therefore, for the applications where the charge time is required to be very less, supercapacitors are only over the same capacity as several batteries. Supercapacitors are safer than batteries in terms of the above risk factors. However, charging a supercapacitor using a higher voltage than its rating is potentially harmful to the supercapacitors. Charging more than one capacitor at a time is a complex job.

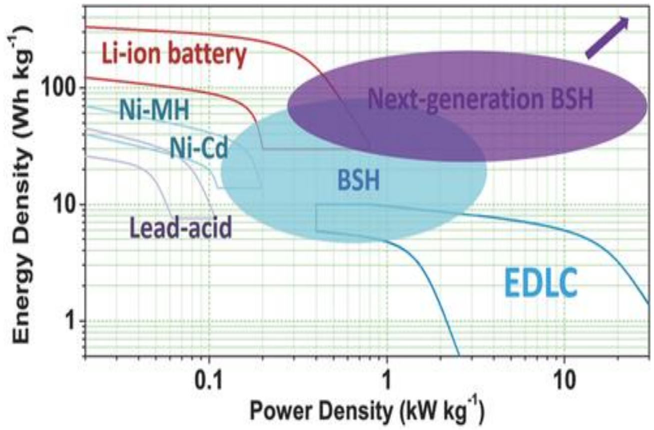

Fig. 3. Graph showing the different Energy Storing mechanisms in Energy density vs Power Density Graph

Source: https://onlinelibrary.wiley.com/cms/asset/56c016d6-bb

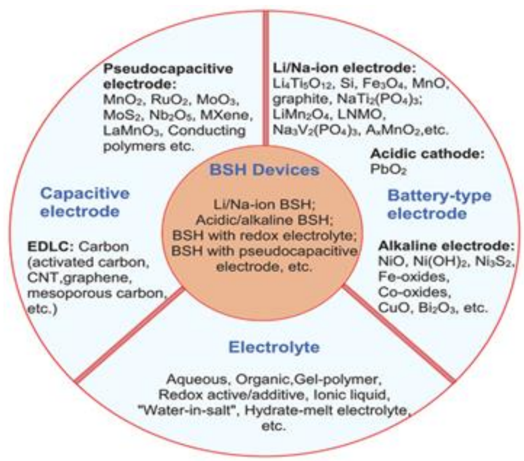

Fig. 4. General energy storage mechanism and device structure of BSHs.

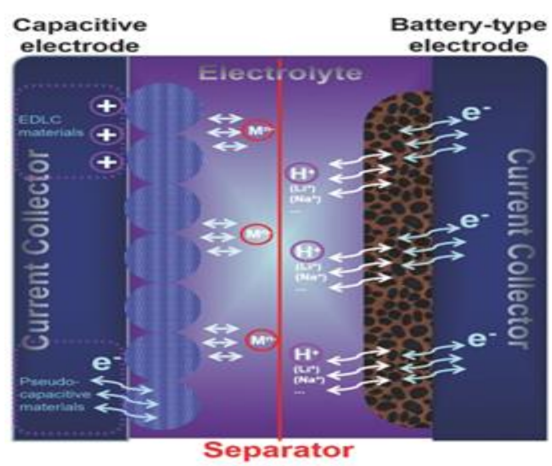

Fig. 5. Various types of BSHs and their electrode and electrolyte materials.

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Table 2: Comparison of Supercapacitor and Li-ion battery[9]

Metric	Supercapacitor	Li-ion Battery
Maximum Charge Voltage (V)	2.2 - 3.3	2.5 - 4.2
Usage Cycles (Charge/discharge)	100,000 - 1,000,000	500 - 10,000
Specific energy (Wh/kg)	4 - 9	100 - 265
Specific Power (W/kg)	4000-9000	300 - 1500
Typical self discharging time	Several weeks	month+
Charge temperature (in celsius)	-40 - 65	0 - 45
Discharge temperature (in celsius)	-40 - 65	-20 - 60

Difference between supercapacitor and battery

(1) Batteries shine at storing energy, while supercapacitors rate better for power. This means that supercapacitors are better at discharging their stored energy quickly, on the other hand, batteries save more energy within the same amount of material. Batteries keep near-constant voltage output until they die, while supercapacitors' voltage output decreases gradually as they discharge[10].

(2) Supercapacitors have a longer lifespan by a number of charge cycles. The supercapacitor with the shortest lifespan is still an order of magnitude ahead of the longest-living standard battery. On the other hand, because supercapacitors charge and discharge a lot sooner than batteries, their working life is inclined to be only 150-200 percent that of a battery (by completing cycles more quickly) [10].

Solid-State Hybrid Ultracapacitor Battery:

Benefits:

1. It is safe and highly robust compared to normal batteries.
2. It is unique, durable.
3. Devices can be recharged as many times as possible as per our needs [11].

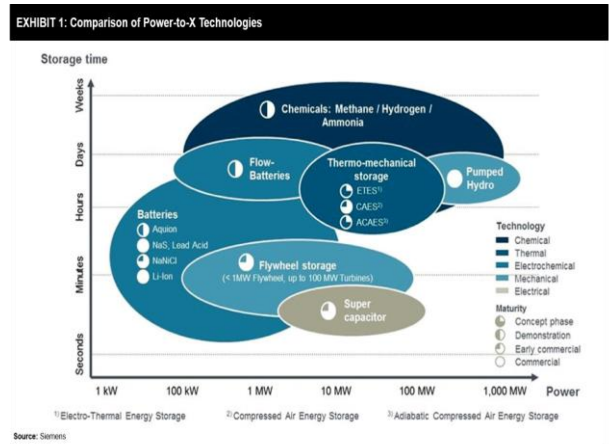

Fig. 6. Storage time against the power delivered for electrical energy storage technologies

Source:https://www.futurebridge.com/industry/perspectives-energy/green-ammonia-for-energy-storage/

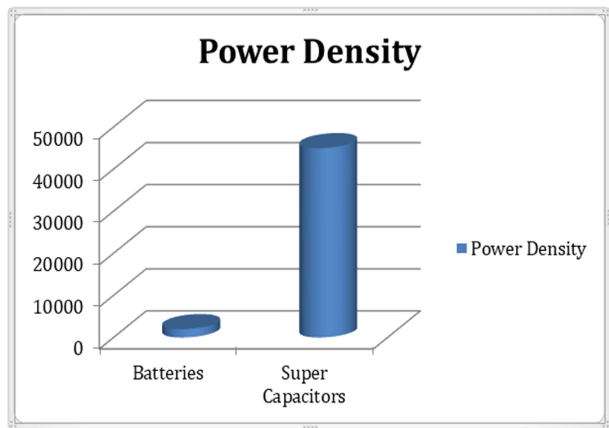

Fig. 7. Graph showing difference between the Power Density of Li-ion batteries and Supercapacitors

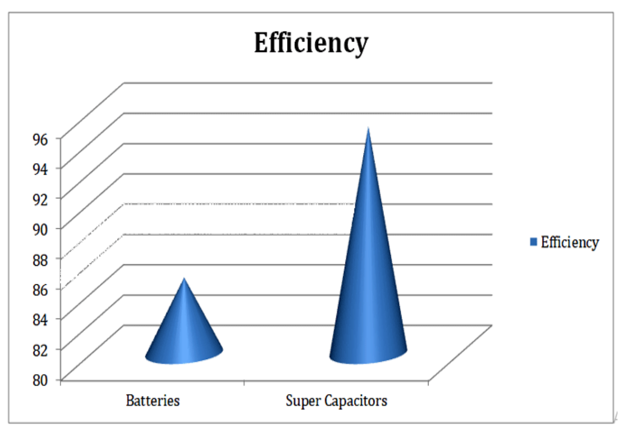

Fig. 8. Graph showing difference between the Efficiency of Li-ion batteries and Supercapacitors

2.4) Lithium-Graphene battery:

Graphene battery is one of the alternatives which can augment the battery life. Graphene batteries are low weight as compared to the other batteries (example:- Li-ion battery). It can store energy up to 1000Wh weight per kg. Graphene is quite stable, safer, and balanced. Electrical conductivity and high heat conductance are various of its characteristics, they also have a broad effective temperature range. Due to its high conductivity, it offers fast charging Thin and lightweight with very good energy storage capacity makes it a good choice for use in long-term distance planes. Graphene can be used in lithium-ion batteries to increase its performance. This hybridization results in the enhancement of the properties of the battery. Pure graphene can not be directly used as an electrode, but graphene composite materials are important and can be used instead of pure graphene.

Table 3: Cathode materials containing graphene composite for LIBs

Composites	LiFePO4/ graphene	LiMnPO4/graphene
Capacity	160 mAh /g at a rate of 5C	150 mA h/g at a rate of 5C,
Synthesis techniques	Coprecipitation	solvothermal
Some points	Low cost, low toxic	High efficiency, low toxic
Reference	[12]	[13]

Hybrid lithium transition metal oxides /graphene composite(Table 3) is used to increase the cathode performance of Li-ion batteries. This hybrid graphene composite is used as a cathode electrode in lithium-ion batteries [13]. Hybrid batteries enhance the battery performance which increases the electrical conductivity and also increases the lifespan of the battery. Low weight, fast charging rate, greater energy storage capacity, reduction in the internal resistance of batteries, and enhancing the output power.

III. CONCLUSION

With the increase in demand for technology, we need to broaden our minds and think of alternative and effective ideas. The above review paper is aimed at using newer battery technologies and battery-supercapacitor hybrids and also hybrid of many other energy sources as an alternative for only batteries in the Electric plane power system. Electric planes could be the future of aviation. In theory, they will be much quieter, cheaper, and cleaner than the planes we have today. Electric planes with a 1000 km range on a single charge could be used for half of all commercial aircraft flights today, cutting global aviation's carbon emissions by about 15%. The battery-supercapacitor hybrid can increase the efficiency of the Electric plane power system. Due to the high energy density of batteries and high power density of supercapacitors, they are suitable for the treatment of low-frequency power and high-frequency power respectively. It is very efficient and highly reliable. Also, this hybridization reduces the aging of batteries and increases the period of maintenance. The introduction of graphene to improve the properties of batteries. Graphene-based technology will play an important role in the future(Li-ion hybrid batteries' excellent performance will play a vital role). This hybridization of energy sources decreases the cost and time and also enhances the efficiency of planes that can be used on commercial platforms in the next generation.

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