eVTOL and its BTMS

At the general debate of the seventy-fifth session of the United Nations General Assembly on September 22, 2020, the People 's Republic of China clearly put forward the '3060' dual carbon goal to the world, which specifically refers to that China will strive to achieve a peak carbon emission by 2030 and strive to achieve carbon neutrality by 2060. Carbon dioxide emissions begin to decline after reaching a peak in a certain year, that is, peak carbon emission. And the term 'carbon neutrality' is used to describe the process of offsetting the additional carbon dioxide generated by human activities. This is achieved through several different methods, including conversion, carbon sequestration and carbon capture, with the aim of achieving net-zero carbon dioxide emission. Furthermore, over 100 countries have committed to achieving carbon neutrality by 2050 in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP 26), with the objective of averting the adverse impacts of climate change [1].

The transport sector plays a key role in this process and faces considerable challenges. In 2017, the transportation sector accounted for 16% of global carbon emissions. According to data from the International Energy Agency (IEA), this proportion had risen to 25.7% by 2019 [1, 2]. In recent years, the transportation industry has begun to accelerate its transition to net-zero emissions through electrification. One of the most notable examples is that almost all well-known automobile companies have announced their own electric vehicle (EV) plans, and electric vehicles are gradually replacing the market position of fuel-powered vehicles. According to the IEA, global sales of electric vehicles were 13.9 million in 2023, accounting for about 20 per cent of global vehicle sales. And the global electric vehicle fleet is expected to increase from 39.8 million vehicles in 2023 to 226 million vehicles in 2030 [3]. However, at the same time, the growth in private car ownership has brought about the problem of traffic congestion. People waste time due to traffic congestion, which leads to loss of productivity and impacts on economic development. The transport sector itself is also an important part of the economy, so the pursuit of more efficient transport is imperative.

Driven by the dual forces of electrification and high efficiency in the transportation industry, the concept of flying cars has emerged, or we can also call them electric vertical take-off and landing aircrafts (eVTOLs). The rapid development of eVTOL aircrafts marks a transformative era in urban air mobility, presenting novel solutions to address the congestion and environmental challenges prevalent in modern cities. In terms of environmental sustainability, eVTOL 's greenhouse gas emissions during 100 km point-to-point trips are not only 35 % lower than internal combustion engine vehicles (ICEVs), but also 28 % lower than battery electric vehicles (BEVs). Meanwhile for a 100 km trip, a ride in an eVTOL will save around 83% of travel time over a car [4]. According to the IEA, eVTOL may account for more than 15 % of urban short-distance travel by 2050.

Batteries serve as the main source of energy within eVTOL aircraft, with current designs utilizing high energy density lithium-ion technology. Lithium-ion batteries are selected because of their high energy density, long cycle life, and proven reliability, which is crucial for extending flight time and stability. Ongoing research into battery technologies, including solid-state batteries and battery management systems, holds promise for further improvements in energy density, safety, and lifespan. Such advancements are critical for extending the operational range and capabilities of eVTOL aircraft, making them more viable for a variety of urban applications [5].

Thermal management is a critical challenge of battery systems for eVTOL aircraft. As eVTOL batteries undergo high discharge rates during flight maneuvers, they generate significant heat that must be effectively dissipated to maintain safe and reliable operation. If the temperature increase caused by heat generation is not properly managed, it can result in thermal runaway or even an explosion. Low temperatures, on the other hand, reduce the conductivity of the electrolyte and affect battery capacity [6-8]. Also the non-uniformity of temperature distribution within the battery pack reduces its usable capacity and cycle life [9]. We need a well-designed Battery Thermal Management System (BTMS) to ensure the safety and performance of lithium-ion batteries, thus improving the overall safety and reliability of eVTOL. Conventional thermal management strategies used in electric vehicles may not be sufficient for eVTOL applications due to the unique operational requirements.

Depending on the heat transfer medium used, we can broadly classify BTMS into three categories: air-cooled systems, liquid-cooled systems and cooling systems based on phase change materials (PCM). Air-cooled BTMS are relatively simple to design, reliable and economical. However, its direct use of air, which has a poor heat transfer capacity, to convert to a medium result in a low heat transfer efficiency. The heavier and more complex design of liquid-cooled BTMS is more efficient than air-cooled, helping to significantly reduce cell module temperatures. PCM-based BTMS has attracted more and more attention in recent years, which achieves effective thermal management by using latent heat in phase change processes such as solid-liquid, liquid-gas, and solid-gas. The PCM-based BTMS eliminates the effects of noise and vibration during operation, while ensuring uniform battery temperature distribution. However, it tends to be limited by the temperature range of the phase change material, and the design is complex and costly [8-10].

Since the eVTOL industry is still in its infancy, research on its BTMS has not been reported sporadically until the recent two years. Wu et al. [8] proposed a design method for eVTOL battery thermal management, which analyses the thermal characteristics of the battery under flight discharge conditions through numerical calculations and experimental studies, and evaluates the effects of different ambient temperatures, intake mass flow rates and fin arrangements on the performance of the BTMS. Zhao et al. [11, 12]proposed a BTMS based on wavy channel liquid cooling technology for eVTOL aircraft, while optimizing it based on cruise altitude, hovering time and battery pack size.

BTMS addresses a significant gap in eVTOL technology—managing the risk of overheating and thermal runaway, which are critical for safety and performance. By integrating advanced thermal management systems, we ensure optimal battery operation, enhancing reliability and longevity. The research in this field not only helps to promote the commercial operation of eVTOL, but also contributes to sustainable development by minimizing the environmental impact associated with battery degradation. These efforts are critical to maintaining high performance standards and passenger safety, making them an important part of a joint effort to advance urban air traffic.

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