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Literature Review on Efficiency Enhancement of Lithium-ion Batteries by Thermal dissipation

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Abstract

As the market for renewable resources increases, the bandwidth of applications using Li-ion batteries as the primary source of energy also increases. Li-ion batteries are at a risk of undergoing thermal runaway under uncontrolled situations. Overcharging, over-discharging, high internal temperatures, etc. are all factors towards the gradual degradation of Li-ion batteryperformance. Therefore, it is important to have an efficient battery management system to ensure the smooth functioning of the battery. Thermal management systems is an important aspect of the battery management systemto keep battery temperatures under critical levels. Although, there are various methods of coolingdown the battery such as air or liquid cooling, these methods are remedial in nature and not precautionary. Plenty of research is being done in order to remove heat from the primary sourceitself.

Key words: Li-ion battery, Digital temperature sensor, hall Effect Current Sensor

1.Introduction

As the reserves of fossil fuels and other perishable energy sources are diminishing, the demandfor renewable energy is increasing.

The energy industry now moving towards electric alternatives of limited resources. Photovoltaic cells (solar cells) have a great potential for off-grid power generation which have become a standard for motive power,

commercial vehicles, water heaters and many other applications. Not only have they evolved drasticallyand proven to be a reliable source to clean energy but also the manufacturing cost of solar cells is reducing day by day, making it more affordable to the masses. Incandescent light bulbs have slowly replaced by LED. One can hardly disagree when one says that the Li-ion batteries have been a game changer in the renewable energy sector [2]. Li-ionbatteries are extensively used in Hybrid Electric Vehicles (HEVs), Electric vehicles (EVs), etc. due to its high power to weight ratio. Unlike traditional fuel cars, EVs have no harmful byproductslike carbon monoxide, carbon dioxide, nitrous oxide, etc. Electric vehicle registered a 40% year – on –year increase. The share of EVs in the market is only going to increase in the coming years. Figure1.1 shows increase in new electric bus registration by country/region 2015-2019

Fig.1Lithium-ion (Li-ion) batteries are a type of rechargeable batteries which play an extremely important role in the field of renewable energy.

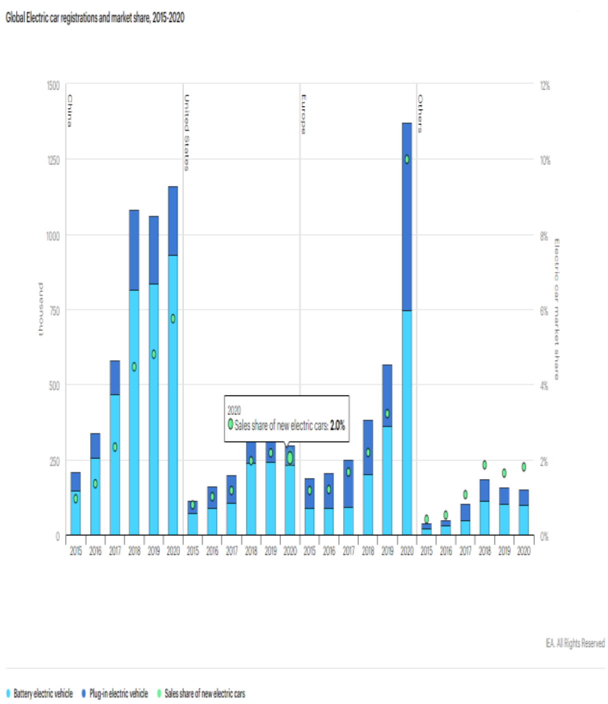

Fig. 1 ***Electric car registrations increased in major markets in 2020 despite the Covid pandemic***

In 2016, Samsung recalled all of its Galaxy Note 7 after it was discovered that the phone faced heating issues which resulted in a number of fires and explosions at the user end [16]. The fires were caused due to the excessive heating of the phone's battery during charging and the inability to properly regulate its temperature. The release of the Galaxy Note 7 and its subsequent recall cost the company approximately $17 billion. In 2018, Toyota recalled more than 1 million of its plug-in Prius models as well as other C-HR SUV models over issues related to electrical/battery systems [17]. Previously, a hybrid Prius exploded in one the user's home after getting a battery replacement in California resulting in the user losing his house and all other belongings.

2. Literature Review:

The idea of building a thermal management system for batteries is not new. There has beena lot of research in the field of thermal management. A variety of methods are tried and tested to establish the efficiency of the cooling system. Some of the methods used for cooling are air

cooling, liquid cooling, cooling using Phase Change materials, cooling using heat pipes, etc. These methods deal with cooling the battery externally to prevent it from reaching hazardous temperatures. Although these various methods exist and are effective in lowering the temperature of the battery pack, they are preventive measures, not precautionary. A precautionary approach is preferred as appropriate measures are taken before the occurrence of an unpleasant incident as it always battery to avoid an accident than heal from it later. The main challenge for today's researchers is to build a system which prevents the battery from internally reaching critical temperatures during operation. This thesis adopts a precautionary approach than a preventive one as it focusses on preventing internal heat generation rather than cooling it externally. In the following paragraphs, a brief survey of the advancements in thermal management systems (both internal and external) are given.

Soltani et al. [7] proposed a thermal model for Li-ion capacitors which are valid up to 500A currents and can function in a wide temperature range. Li-ion capacitors aim to integrate the advantages of both Li-ion batteries as well as electric double-layered capacitors and erase their drawbacks. The working ambient temperatures for Li-ion capacitors are -20°C to +60°C. These

capacitors are extremely versatile and can be used for high energy applications as it has an energy density of 14Wh/Kg. It is perfect for power shaving and regenerative applications, although it is unfortunate, they don't capture the regenerative braking market as much. The researchers designed a first order and second order electrical equivalent model for the Li-ion capacitor. Through experiments they observed that the second order model was accurate up to 98% for smaller currents. They also designed a 1D thermal model with an error less than 5%. These results were first simulated and then later verified through experiments.

Karimi et al. [2] performed a comparative study between natural convection air cooling and forced convection cooling using dielectric silicone oil. Flat Li-ion batteries with ducts attachedto the two opposite ends of the multi-cell pack was taken into consideration for the experiment. While studying natural convection air cooling, they observed that the maximum battery pack temperature did not exceed 39°C. But since it is natural convection, the air flow rate is very low

resulting it extremely small heat removal.

Greco et al. [5] suggested the use of heat pipes for thermal management of Li-ion batteries. A heat pipe is a pipe having two sections; one for the heat side and the other is the condensation side. The pipe has a liquid medium which absorbs heat from the hot surface of the battery. As thetemperature of the liquid medium rises, it evaporates and moves to the cooler section of the pipe and condenses. Once the condensation is completed, the liquid travels back to the heat side throughcapillary action. Heat pipes have a high contact surface and the maximum temperature of the battery pack was observed to be 27.6°C while it was 51.5°C when forced convection was used.

The reduction in liquid level at the heat side and the effect of gravity on the movement of the liquidinside the pipe was ignored. The proposed model is not efficient in an application where the size of the heat pipes would be critical.

Qian et al. [3] proposed a liquid cooling method using mini channel cold plates where themini channels would be placed between 2 batteries in a multi-cell battery pack. A number of parameters such as number of channels, inlet mass flow rate, flow direction, width of channels, etc. were taken into consideration. The effects due to the changes in the different parameters werestudied and 3D thermal model was designed. The model showed good cooling at a discharge rateof 5C. The cold plate touches the surface of the battery and the heat transfers to the liquid mediumthrough the mini channels. Only 2 mini channels can keep the maximum battery temperature under40°C for more than half the discharge time. Through experimentation, it was observed that a 5

channel cold plate was sufficient for thermal management and increasing the mini channels morethan 5 achieved no significant reduction in battery temperature.

Zhao et al. [6] discuss the effects of changing physical characteristics of the battery in orderto reduce internal heat generation and systematic thermal management models to directly tackle with external heat dissipation. For external heat removal a number of methods such as air cooling, liquid cooling using dielectric materials and PCMs, heat pipes, etc. were tested. The experiments concluded that forced air convection was the best method for cooling the battery due to low safetyissues. IN case if indirect contact of the liquid medium with the battery pack, the thermal resistance increases, and hence additional measures need to be undertaken to deal with the same. The authors discussed electrode modification as a way of reducing internal heat generation as electrodes are responsible for maximum heat generation in a battery. Reducing the electrode thickness results inlower heat generation but it also means lower energy density of the battery. Electrode modification increases manufacturing costs significantly. Hence, it is not a practical approach.

2.EV batteries

The fact that batteries are the heart of Electric Vehicles is irrefutable. The Battery Management System plays a pivotal role in the smooth and efficient functioning of the battery andultimately the car. Yet, the batteries used in all commercial EVs are not the same. Different manufacturers use batteries of different construction and specifications. The battery energy capacity, battery type, cooling system used for thermal management, etc. all decide the mileage, charging time and longevity of its use. The construction of the battery cell is a key factor in determining the subsequent

battery management system. Batteries of construction types such as cylindrical, prismatic, pouch are used for commercial EVs [13].

The table (1) illustrates some EVs and HEVs and their respective battery specifications.

Car Model	Battery Type	Battery Capacity	Miles covered	Charge time
Toyota Prius (PHEV)	Li-ion	4.4KWh	11	3hr-115V-15A 1.5hr-230V-15A
Chevy Volt (PHEV)	Li-Mn	16KWh	40	10hr-115V-15A 4hr-230V-15A
Smart Fortwo ED	Li-ion 18650 cells	16.5KWh	85	8hr-115V-15A 3.5hr-230V-15A
BMW i3	LMO/NMC (prismatic)	42KWh	175	4hr-11KW-AC 30min-5KW-DC
Tesla S	Li-ion 18650 cells (3.4Ah)	90KWh	265	12KW supercharger; 80% in 30mins
Tesla 3	Li-ion 18650 cells (3.4Ah)	75KWh	310	11.5KW-AC 30mins - DC

3.Thermal Behavior of Li-ion batteries

The experiment setup was designed in the simplest possible way to understand the thermal performance of the battery under constant and alternating loads. The goal of this experiment is topractically observe the maximum value of the battery temperature under different values of constant current delivered by the battery to the load and also estimate the behavior of the hybrid battery-supercapacitor architecture. The components used for the construction of the experiment are:

Table 2 Components used for the test setup

Commercial Label	Components
Panasonic NCR18650B	Li-ion battery
DS18B20	Digital Temperature Sensor
ACS712 20A	Hall-effect Current Sensor
DROK load tester	Electronic Load

The electronics load tester is capable to sinking currents up to 5A. The hall-effect current sensor is essentially a digital ammeter which reads the current flowing from the battery to the load. The digital temperature sensors are physically connected to the body of the battery with the aid of

thermal conducting tapes which do not interfere with the temperature sensing capabilities of the sensor.

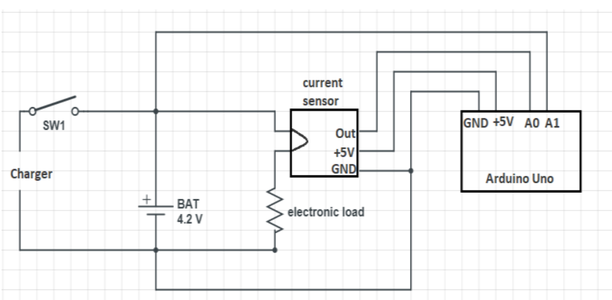

Fig.2 Circuit diagram of the test setup

The Vdd of the temperature sensors and the Vdd of the current sensor and connected together to the +5V pin and the GND pins are collectively connected to the GND (ground) pin of the ArduinoUno. Since the DS18B20 is a one wire sensor, all four DQ pins can be connected to the same A5 pin of the Arduino Uno. The body of the battery along with the connected temperature sensors was enclosed in a clear plastic box to prevent the changes in ambient temperatures affect the battery temperature or record accurate readings on the sensor.

4.Conclusion

This paper reviewed different methods of thermal management of Li-ion batteries, addressed the conditions under which thermal runaway occurs and designed a precautionary strategy to avoid battery temperature escalations reach critical levels. The battery-supercapacitor hybrid architecture has a well-documented history of efficient performance especially in hybrid energy storage system applications. While current thermal management technologies employ physical methods of battery cooling, the method detailed in this thesis makes use of the hybrid architecture to regulate the current being delivered by the battery as a means of controlling its internal heat generation.

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