High Capacity Batteries for Powering Electric Vehicles

Introduction

With fossil fuels becoming more extinct and rising in price, the current commuter vehicle market is making the shift over towards vehicles powered by electricity. These new vehicles require a battery that are high capacity, lightweight, and small enough to fit inside the vehicle. The current industry solution to this is to use Lithium-Ion cells arranged together in various series and parallel configurations to create a battery module. This technical paper reviews the difference between the two major types of rechargeable batteries on the market, the internal composition, specifications, and hardware required with a Lithium-Ion battery module, and commercially available Lithium-Ion modules.

Lithium-Ion vs. Lead-Acid Batteries

Electric motors used to propel vehicles demand more power than typical car battery used in vehicles that are powered by an internal combustion engine. The battery in a traditional vehicle is mainly used in a short burst to start the internal combustion engine, followed by only needing to power to the onboard electronics while the motor runs on gasoline. This task is normally accomplished using a Lead-Acid battery, an older type of rechargeable battery, which features a structure of lead plates submerged within a water and sulfuric acid electrolyte [1]. Current electric vehicles use Lithium-Ion batteries as they are made for larger sustained loads. In comparison Lead-Acid batteries are cheaper but come with many disadvantages. Lead-Acid cells have a lower energy density containing 30-50 Wh/kg compared to the 90-190 Wh/kg, depending on composition, of Lithium-Ion cells. Lead-Acid cells take eight to 16 hours to while Lithium-Ion cells have a charge time between less than an hour to four hours. Lastly, Lead-Acid cells also have a higher toxicity due to containing lead and sulfuric acid to hold a charge [2]. The reduced weight for the same amount of power and faster charge times were essential to the creation of modern electric vehicles. The lighter weight means less power is wasted just to move the battery and the faster charge times are essential for consumer adoption of electric vehicles.

Technology inside Lithium-Ion Battery Modules

Internals of Lithium-Ion Battery Modules

Individual Lithium-Ion battery cells have a low volumetric energy density, as they “only reach a practical limit of about 900 Wh/L at the cell level [3].” For example, the EM3 LIR18650 Lithium-Ion cell has a nominal capacity of 3,000 mAh and a nominal voltage of 3.78 V [4]. The output of a single cell is inadequate to drive the electric motor, so multiple cells of the same voltage and capacity are arranged different series and parallel configurations to create a battery module to produce the desired output voltage for a determined range. Series cells are used to boost the voltage output while parallel cells are used to boost capacity. Essentially a battery module is a determined number of Lithium-Ion cells put into a case with a determined configuration to create larger single 'battery' that can produce enough power for a desired range for the electric vehicle.

The battery modules are not left out in the open and must have a case designed to contain and protect them. These cases are commonly made from aluminum and stainless steel with thickness optimized for weight savings. The cases are standardized for three different locations of the overall input and output terminals known as Type A, B and C. Type A places both the positive and negative terminals on the same face of the case for ease of wiring. Type B places the positive and negative terminals on opposing faces for improved heat dissipation and current distribution. Type C uses the outer case as the negative terminal and features only one terminal for the positive connection [5]. The type of case chosen depends on the location where the module is needed to be installed. The most common case type for electric vehicles is Type A. This is done to place the terminals of the module parallel and facing away from the road surface [5].

Parameters and Performance Measurements

Lithium-Ion battery modules are measured by the output voltage and the amount of power in kilowatts they can produce over an hour of constant use, known as a kilowatt-hour or kWh. The configuration of the cells inside the module are denoted by (X)p(Y)s. The number of cells in parallel is denoted by the number (X) followed by a p and the number of cells in series (Y) are denoted by a s after the number. For example, a single Tesla Model S battery module arranges 444 cells into a 74p6s configuration to produce 22.8 V with 5.3 kWh of capacity [6].

Additional Required Hardware

The main additional hardware for a Lithium-Ion battery is a charging circuit that can safely provide power back to the battery. Lithium-Ion batteries need to have the different amount of current applied to them depending on the voltage across the cell's terminals. Recharging the cell from a low voltage, the battery requires a constant-current charge that decreases the magnitude as the cells regain voltage. This amount of current applied decreases nonlinearly as the charge is increased, until the voltage across the cell reaches close to the voltage rating. Once this point is reached the charger needs to supply a constant-voltage charge with a low current that comes to a stop as the cell reaches the applied voltage.

This curve of current can be modeled for the battery and taken to be the charge curve of the cell. This curve needs to be updated with time as degradation of the cell will change the curve [7]. It is important to have a charging circuit with a controller chip that can read the state of the Lithium-Ion battery and charge it with the correct current as not to overcharge the battery. Overcharging the cell is undesirable as it would create extra heat and reduce the lifespan of the battery.

Commercially Available Batteries

The growing need for Lithium-Ion battery modules to power electric vehicles means that more companies are creating larger and lighter modules. However, these companies are not listing their modules for easy commercial sale and ask consumers to inquire with them for prices. A calculated average price of Lithium-Ion battery modules, based on the reducing price of the technology from 2010, found that in 2018 on average price was $176/kWh [8]. The ideal battery for an electric vehicle would be the largest kWh rating that can be found within budget, while still being small and light enough to fit inside the vehicle. If the battery can be recharged as the vehicle is in motion, the range can be extended above the rated kWh or can allow for a smaller capacity battery to be used.

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