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Systematic Modelling and Design of a Battery Pack for Formula Electric Vehicles

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Abstract

This manuscript presents a systematic approach for the design and development of a 403 V, 7 kWh battery pack for a Formula SAE student racing electric car. The pack is made up of 6 individual segments which are connected in series. Each segment has a maximum energy of 1.17 kWh and is made up of 16 arrays connected in series. Each array holds 8 Lithium-ion batteries which are connected in parallel. The overall design of the battery pack is in full compliance with the Formula SAE rules. The manuscript presents the calculation procedure and battery sizing for the power demand of a typical Formula SAE student racing electric car using vehicle dynamics equations. The entire electric traction system is modelled in Matlab/Simulink. The paper also explains the development process of the 7 kWh battery pack and highlights important design considerations, such as busbar sizing. Finally, this work presents the battery management system (BMS) architecture that will be used to monitor the health and status of the battery pack. A master-slave architecture is used, and each battery segment is provided with its own slave BMS to be controlled by a centralized master unit.

Introduction

There is no doubt that the breakthroughs in battery technology and electric traction have paved the road for the electrification of the transportation sector. From an environmental point of view, transportation electrification will have a tremendous positive impact on air quality. A typical energy storage system for an electric vehicle (EV) is the battery which acts as the main energy source [1]. Some of the commonly used batteries for EVs are Lead-Acid, Nickel-Cadmium, and Lithium-ion [2]. Lead-Acid batteries are one of the oldest rechargeable batteries. Their technology is mature, and they have been used extensively in a variety of applications, including EVs. However, Lead-Acid batteries have a low specific energy density (30 Wh/kg) [3], which is a major limitation in terms of providing all electric range for EVs. Therefore, an EV with Lead-Acid batteries can only travel short distances and requires frequent charging. Nickel-Cadmium batteries have been the main competitor for Lead-Acid batteries, especially in EV applications. Nickel-Cadmium based batteries have double the specific energy density (55 Wh/kg) that of Lead-Acid batteries [3]. One main drawback for Nickel-Cadmium based batteries is the higher cost in comparison to Lead-Acid batteries. Moreover, Cadmium is not considered environmentally friendly [3]. Lithium-ion batteries were introduced in the early 1990s. They offer higher energy density than Cadmium based batteries. Currently, the energy density of typical Lithium-ion batteries varies from 100 to 265 Wh/kg [3]. Despite being more expensive than other available batteries in the market, their lightweight advantage has made them extremely popular for EV applications. Furthermore, the Lithium-ion battery cell has a nominal cell voltage of nearly 3.6 V, which is higher than other presently available battery chemistries. Today, major EV manufacturers such as Tesla, Nissan, and Hyundai are using Lithium-ion battery cells. In an EV, the battery pack is built by connecting series and parallel combinations of battery cells. The selection of cells is influenced by many parameters most importantly: nominal cell voltage (V), cell capacity (Ah), volumetric energy density (Wh/m^3), gravimetric energy density (Wh/kg) and the cost of cells. There are very few literature presenting a systematic method to model and build a battery pack. A brief design procedure for the battery pack is presented in [4] but lacks tangible results and modelling aspect. A 266 volts battery design is being presented in [5] which is made of Lithium-Cobalt-Oxide pouch cells and the authors present some insights and design recommendations.

This manuscript presents a systematic method to design a battery pack for a Formula SAE student racing electric car. The manuscript first introduces a general battery pack design method that applies to any EV. The design process is summarized using a flow chart diagram. The method is based on the physical equations of the forces acting on the vehicle that determine the vehicle dynamics. In the second part of this manuscript, the physical realization of a 7 kWh, 403 V battery pack is discussed, which includes battery cell selection, series-parallel combination and busbar design considerations. Furthermore, the manuscript also discusses the electrical structure of the battery pack. The third part of this manuscript discusses the construction and assembly of the battery pack.

Summary/Conclusions

This manuscript presented a comprehensive method to design a 7 kWh, 403 V battery pack for a Formula SAE student racing electric car. The method is based on physical equations representing the total resistances acting on the vehicle and considering the power converter, electric motor and transmission system losses. The size of the battery pack is then determined based on the average energy demand for a predefined drive cycle. The second part of the manuscripts focuses on the development and realization of the battery pack based on the proposed method. First, the Samsung 25R-18650 Lithium-ion cells are selected based on the energy density and cost. Then the series and parallel combination of the battery cells is determined based on the desired voltage and energy requirements. The manuscript also investigates the use of Copper and Aluminum for the busbar design. Aluminum is eventually selected as the mass of one Aluminum busbar is 2.2 times lower than a copper busbar. Finally, a thorough explanation for the construction of the battery segments and the battery casing is given. The design of the battery pack is in full compliance with the Formula SAE rules for designing student electric racing car. The design procedure mentioned in the manuscript can be easily extended to any electric vehicle.

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