Research Article

Multi-Chemistry Battery Management System for Electric Vehicles

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Abstract

Electric vehicle technology is increasing its market share through its sound development. Battery management systems (BMS) also play an essential role in this technology regarding efficiency, safety, and meeting the end user's expectations. In this study, a simulation study of a multi-chemistry BMS capable of real-time switching has been carried out so that the system can operate more efficiently. The proposed system aims to increase efficiency and performance using two batteries with different characteristics. The primary battery chemistry used is lithium titanate oxide (LTO) batteries, which can provide higher instantaneous power in times of high power demand. The second battery chemistry is lithium iron phosphate (LFP) batteries, which have higher endurance due to their high energy density. Each battery has six modules and provides a total voltage of 450 volts. The WLTP Class 3 driving cycle was used as the vehicle's speed reference in the simulation, considering its power/weight ratio. The battery control signal required for switching between batteries is produced according to the instantaneous power requirement of the vehicle. For this, the acceleration value is calculated, and the transition from one battery to the other is determined accordingly. If the acceleration is above the threshold value of 0.75, the LTO battery is connected. In the other case, the LFP battery is connected. Contactors are used to provide switching between batteries but not IGBTs. Consequently, contactors can be used as switching elements with a transition window of 3 seconds. This technic is less costly than designing such a system with fast-switching circuit elements like IGBT. In addition, the multi-battery mechanism consisting of LTO and LFP chemistries showed better performance than a battery pack with only LFP chemistry with the same specs. In other words, multi-chemistry BMS provides a significant performance and efficiency increase.

Keywords: *Battery, Battery Management System, Electrical Vehicles, Lithium-Ion Batteries*

1. Introduction

Humanity has struggled to find a solution to the transportation problem throughout history. Primitive solutions to the transportation problem in previous years have improved over time. These developments are transportation made possible by land, air, and sea. Steam engines powered the first self-propelled vehicles used for transportation purposes in history. In time, fossil fuel technology replaced steam technology; however, electric vehicles have already been running on the streets (Morimoto 2009). A key component of electric vehicle technology is the development of electric motors and batteries. This electric motor, made by M. Faraday in 1822, emerged with the movement ability of magnetic field and electromagnetism.

Along with the increasing knowledge and developing material technology on this subject, electric motor studies, pioneered by M. Faraday, continued to develop thanks to the work of many scientists in this field (Guillemin and Thompson 1891; Heller 1896). Electric motors have led to developments such as using this technology in rail systems for the first time (Arai 1995; Dunckley 1993; Guarnieri 2012; Saslow 2002). In 1835, Dutch inventor Sibrandus Stratingh made the first self-propelled electric vehicle using Faraday's principles of electromagnetism (Hist. Univ. Groningen 2021). In parallel with these advances, electric vehicle technology has continued to develop. However, the abundance of oil reserves and the discovery of new oil resources have caused internal combustion engines to be more popular. For a long time, authorities and consumers put electric vehicles on ice because internal combustion technology was affordable. Hence, during this time, transportation requirements were primarily met with internal combustion engines. Therefore, electric vehicles did not see sufficient demand at the beginning of the 20th century and remained partially behind in terms of technical development. This situation did not adversely affect the development of electric vehicle technology in the following years, and the studies continued. The first fully electric vehicle, the General Motors EV1, was mass-produced and launched in 1996 (Glover and Kimberley 1996; Johnson 1999; Wired wheels 1996).

Today, electric vehicles have loomed large worldwide. Resulting, a tough electric vehicle market is formed all over the world. This increasing demand brings another technical problem—electrical energy storage. The solution to this problem is storing the electrical energy as chemical energy. Because battery packs are the energy storage units of an electric vehicle, a battery management system - BMS, can be defined as hardware responsible for detecting possible technical problems with the measurements it takes, monitoring, controlling, and balancing the battery (Sandeep Dhameja 2002; Stuart et al. 2002). BMS can also serve as a system by estimating the battery status, preventing it from being overcharged/discharged, optimizing performance, and reporting the results

(Andrea 2010; H.J. Bergveld, Kruijt, and Notten 2002). The purpose of BMS is to ensure that the energy in the battery is used with maximum efficiency. In addition, it is to ensure that both the user and the system work safely. In order to ensure this and to make the necessary intervention if there is a problem, the charge/discharge cycles should be monitored and controlled, which will give the most accurate information (H.J. Bergveld, Kruijt, and Notten 2002; Hendrik J. Bergveld, Pop, and Notten 2008; Pop et al. 2008).

The primary functions of a BMS should have begun to take shape in the 1900s, with the studies carried out specifically for lead-acid batteries (Kruger and Barrick 1966). A BMS should monitor critical parameters such as the state of charge, current, voltage, temperature, cell age, and electrolyte density (Bruen et al. 2016; Buccolini et al. 2016; Cheng 2016; Garche and Jossen 2000; Popp et al. 2021; Xing et al. 2011).

However, from today's technical perspective, BMS can be defined as an integrated hardware and software body that enables the battery to operate within a specified safe/optimal operating envelope. To do that, measuring or calculating some parameters such as current, voltage, temperature, state of charge (SoC), state of health (SoH), state of energy (SoE), and remaining useful life (RUL) is necessary. BMS is also responsible for logging, processing, and sending data via a wireless connection to a cloud server or sharing it with other connected devices and vehicles (Dikmen 2022; Dikmen and Karadağ 2022) Our study presents a BMS simulation that uses the superior features of different battery chemistries together and demonstrates the efficiency of the proposed switching mechanism with optimal timing to take advantage of these features.

2. Materials and Methods

The simulation study was conducted in the MATLAB/SIMULINK 2021a environment. There are five main blocks in the simulation model.

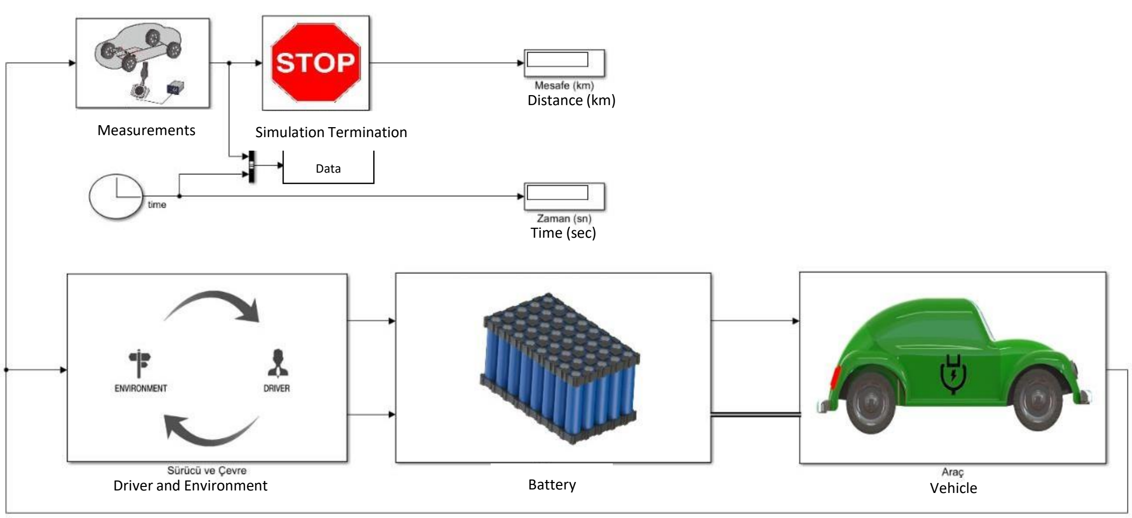

Figure 1 General View of Blocks

The vehicle block contains the dynamic model of a vehicle, the engine, reduction gear, shaft, drivetrain, and engine cooling system. The vehicle model is presented in Figure 2.

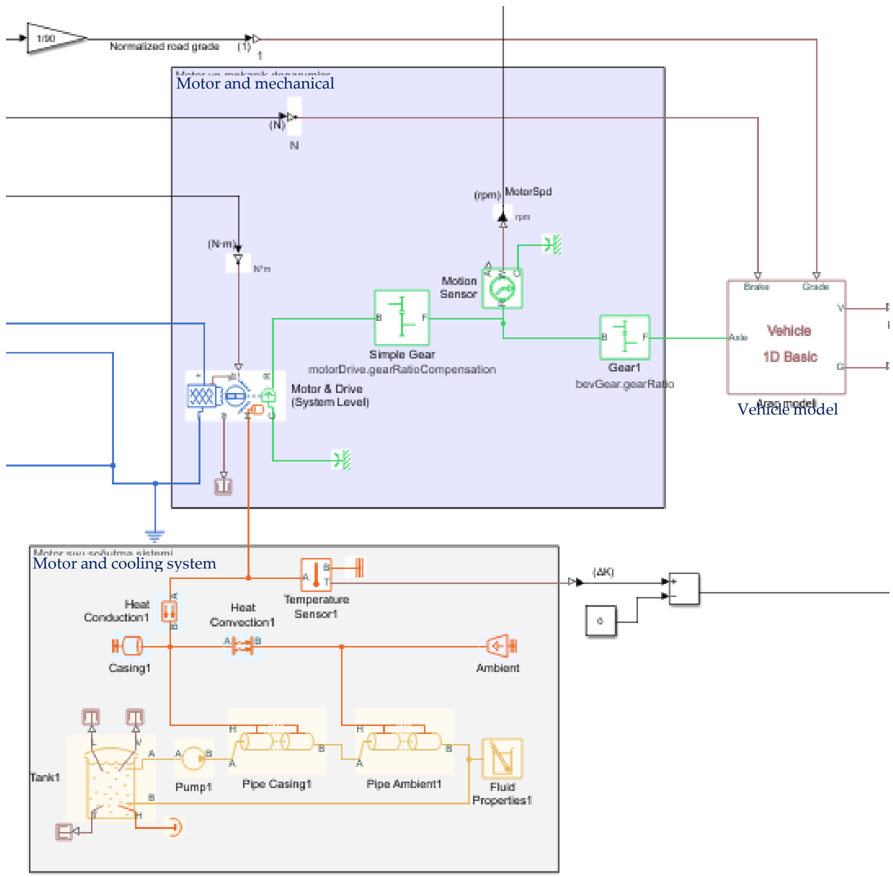

Figure 2 Modelled Vehicle

The cooling system of the electric motor on the vehicle is a liquid-type cooling system. The cooling fluid of choice is a mixture of ethylene glycol and water. This way, when the engine is warmed up, it is cooled efficiently and again, ensuring it operates in the optimal temperature range. The performance efficiency of the cooling system in question is presented in Figure 3. The system provides an efficient result despite the high initial temperature value.

There are groups of 18 series cells in two batteries. These groups, in turn, form modules consisting of pairwise parallels among themselves. There are six modules in each battery. Thus, batteries formed with approximately 450 Volts. Each module performs a thermal exchange both within itself and with each other. Thermal control in the battery block takes into account this thermal exchange. In this way, the batteries can operate within a suitable temperature range.

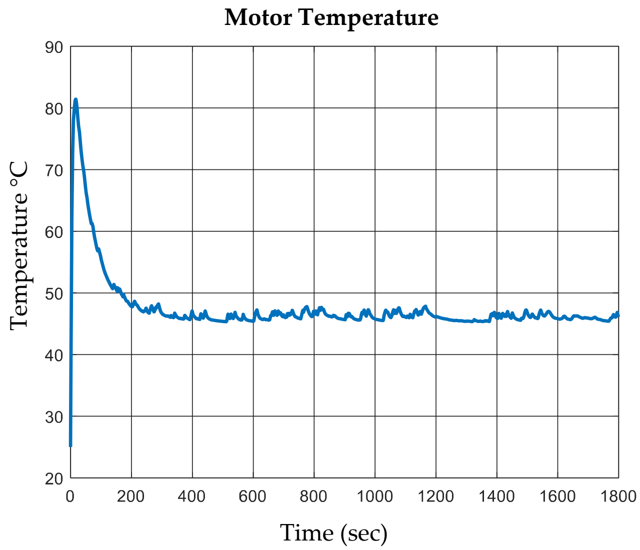

Figure 3 Performance Efficiency of Motor Cooling System

In the driver and environment block, there is the block that provides the production of the driving cycle and the vehicle control block that provides the modeling of the driver.

3. Results

To calculate the consumption values of the vehicle, the model was run with the WLTP driving cycle. Considering the power/weight ratio, the WLTP driving cycle Class 3 is used. WLTP Class 3 drive cycle is presented in Figure 4.

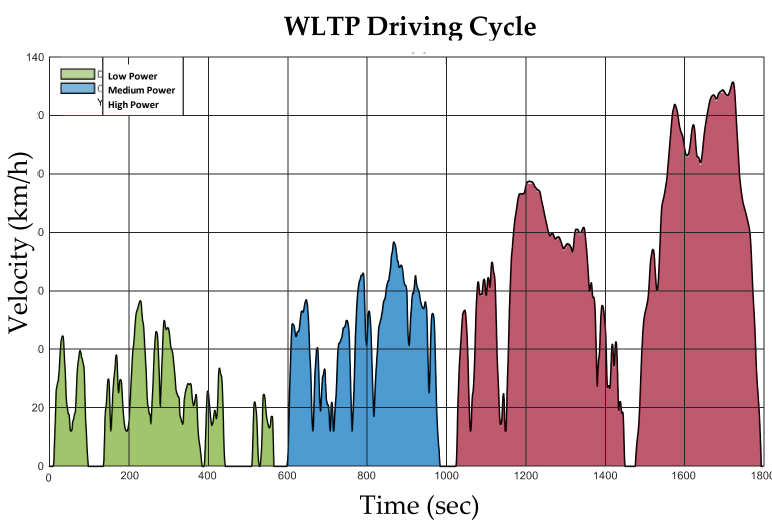

Figure 4 WLTP Class 3 Drive Cycle

In the battery block, along with two batteries, contactor switches enable electrical connection between the system and the batteries. One of the most important considerations at this point is the order in which the switching occurs.

Essentially, IGBT is needed to perform high-speed switching under high power. However, with the developed switching method, it has been observed by the simulation study that normal contactors are also suitable for use.

The basic approach adopted by the applied method is as follows; It is to delay the disengagement of the LFP battery for 3 seconds after the LTO battery is activated. Similarly, while the LFP battery is powering the system, the deactivation of the LTO battery delays 3 seconds. The effect of this method on the system is presented in Figure 5. The weight of the modeled vehicle is 1600kg, and its engine power is 150kW. Accordingly, the power/weight ratio of the car is 93.75.

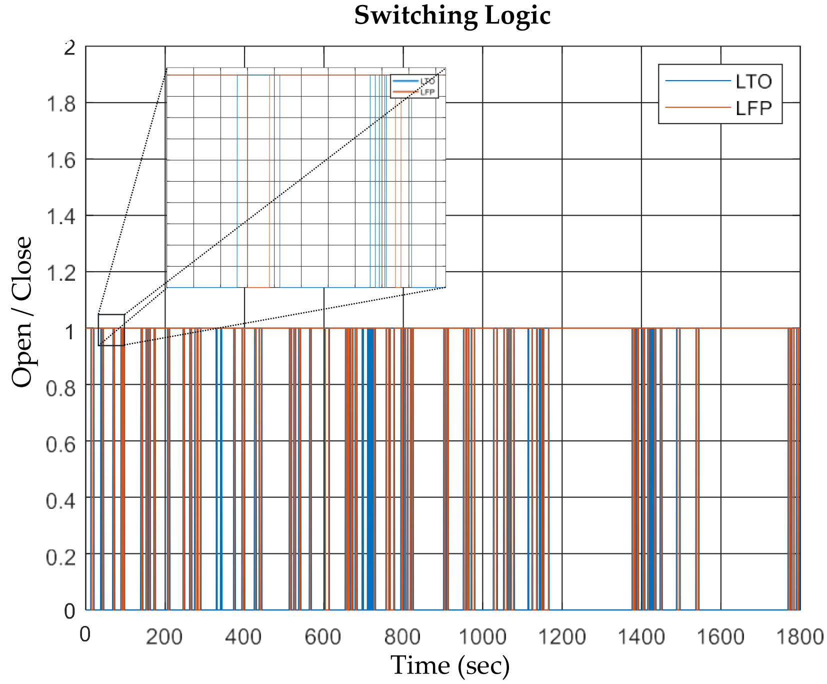

Figure 5 The Effect of the Proposed Method

These sections are low, medium, and high-power sections. Relatively low speed and acceleration are taken as references in the low power section. Similarly, high speed and acceleration reference is applied in the high-power section.

The driving cycle's reference speed values are used to calculate the required acceleration. This calculation result produces a battery control signal that enables switching between batteries. If the calculated acceleration value is above the determined threshold value, the LTO battery is activated. In other cases, the LFP battery is activated. The determined reference value was determined as 0.75 m/s^2 for this simulation.

Figure 6 presents the battery control signal generated by the simulation run with the WLTP drive cycle. Here, the signal required for the activation of the LTO battery is shown when the vehicle's acceleration is in the range of ±0.75m/s2. The enlarged part in the figure shows the battery control signal in 390-450 seconds. As a result, the LTO battery receives any regenerative energy the vehicle produces during deceleration and provides the high energy the car needs during rapid acceleration.

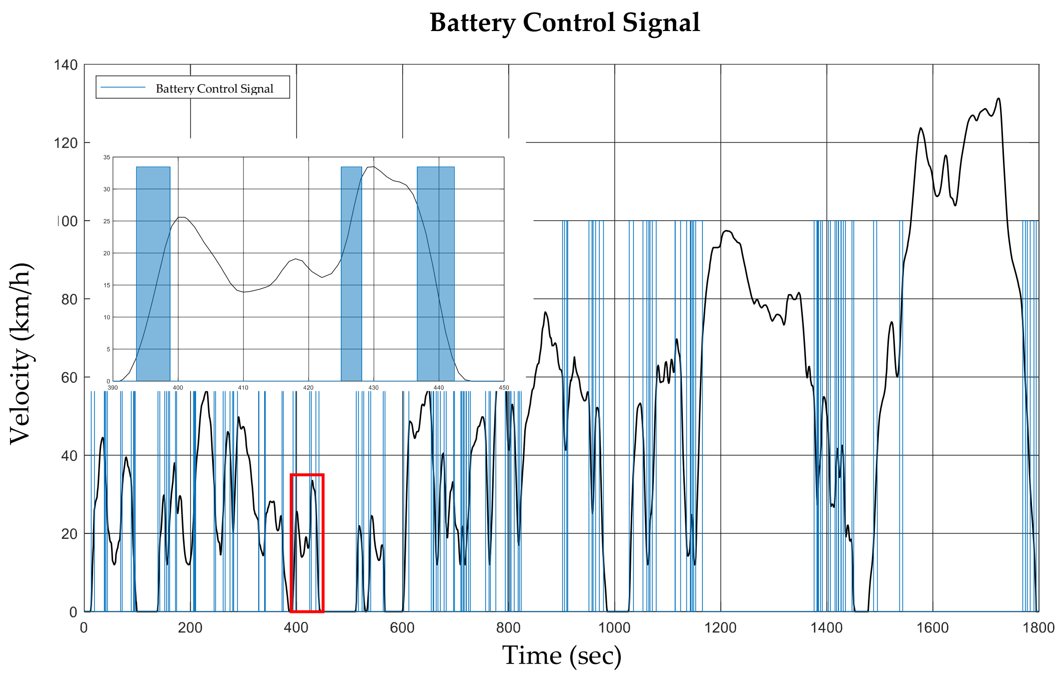

Figure 6 Battery Control Signal Generated by the Simulation

The data calculated in the vehicle, the battery, and the driver models are classified with relevant tags in the measurements block. Resulting, values such as the distance traveled, the total power consumed from the battery, etc., are calculated. The data obtained are placed in appropriate categories. Consequently, the time data taken from the simulation clock is added to all these data and saved in a file.

4. Discussion and Conclusion

The general approach used in multi-chemistry battery management systems is to use the LTO battery for support purposes, while the LFP battery continuously provides energy to the system. In this study, we are focused on advancements in such BMS algorithms and developing a new method. In this method, only one battery pack is connected to the system by switching the battery packs in real-time. In doing so, switching from one battery pack to the next is done within a three-second transition period, eliminating the need for a snubber to overcome transients. In addition, the study shows that cheaper contactors can be used instead of expensive IGBTs as switching elements in the system. As a result of the study, it has been observed that the multi-battery mechanism consisting of LTO and LFP chemistries significantly increases efficiency compared to the only LFP battery pack with the same features. According to this study, although the efficiency increase varies depending on parameters like the capacity ratio of batteries, it has been observed that it can be between 10% and 22% in a multi-chemistry BMS using the developed algorithm.

5. Acknowledge

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