Applied Energy 197 (2017) 52–62

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Signal synchronization for massive data storage in modular battery management system with controller area network

Xiangdong Kong [a], Yuejiu Zheng [a,b,*], Minggao Ouyang [b], Xiangjun Li [c], Languang Lu [b], Jianqiu Li [b], Zhendong Zhang [a]

[a] *College of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai 200093, PR China*
[b] *State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, PR China*
[c] *Electrical Engineering and New Material Department, China Electric Power Research Institute, Beijing 100192, PR China*

HIGHLIGHTS

- The asynchronous mechanism of data storage in BMS is analyzed.
- An on-line synchronization method is proposed to decrease time latency as much as possible.
- An off-line sync method is proposed based on frequency division equivalent circuit model (FDECM).
- Mean absolute derivative (MAD) value is used to evaluate the dynamic property of “resistances difference”.
- Optimal compensation time can be found by one-dimensional search method because of the unimodal MAD values.

ARTICLE INFO

Article history:
Received 10 November 2016
Received in revised form 23 March 2017
Accepted 1 April 2017

Keywords:
Battery management system
Battery pack model
Data storage
Signal synchronization
Controller area network

ABSTRACT

One of the key battery performances which can be described as the resistance characteristic is the cell voltage response with dynamic currents, and it requires synchronous cell voltages and current. But due to inevitable network latency in modular battery management system (BMS) with controller area network (CAN), cell voltages and current are usually asynchronous. We firstly analyze the sampling and the storage process of battery signals to study the asynchronous mechanism in BMS. We develop an on-line synchronization method using a “global clock” from the master controller to decrease the time delay as much as possible. And we further propose a model based sync method based on the frequency division equivalent circuit model (FDECM) for the battery pack. The low frequency cell difference model is used to identify cell “resistances difference”, and then the optimal time compensation for cell voltages is obtained when the minimum mean absolute derivative (MAD) value of identified resistance differences is reached according to the low frequency characteristic of cell “resistances difference”. The proposed methods are verified by simulation and experiment. The current and cell voltages in the data logger of BMS can be synchronized when the optimal compensation time is applied respectively for each cell. The data after synchronization can meet the requirements of further data analysis and processing, which is of great significance to enhance and improve the control strategy of BMS.

1. Introduction

Due to the double pressure of energy crisis and environmental deterioration, humans have been exploring the cleaner energy sources and efficient and secure energy storage devices [1]. After entering the 21st century, lithium-ion batteries, fuel cells, super capacitors and other energy storage device technology have made great progress [2–4]. Coupled with the rapid development of Internet technology and unmanned technology, electric vehicles (EVs) have become increasingly popular and ushered in another golden development period [5–7]. As the only power source in the EVs, the battery pack with a large capacity consists of a considerable number of series-parallel connected cells [8,9]. To keep cells working safely and effectively, the battery pack must be equipped with a battery management system (BMS). The BMS manages and monitors all cells as well as the overall states of battery pack [10,11]. There are mainly three BMS topologies in practical use, namely, centralized, distributed, and modular BMS.

---

[*] Corresponding author at: College of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai 200093, PR China.

E-mail address: yuejiu.zheng@gmail.com (Y. Zheng).

http://dx.doi.org/10.1016/j.apenergy.2017.04.002
0306-2619/

The centralized BMS takes all management functions into one controller. In the case of a small battery pack, the centralized BMS has a relatively low cost [12]. But for EVs with hundreds of cells, massive sensor harnesses are quite complicated and unreliable. Besides, the load of controller is extremely heavy. Moreover, the centralized BMS has a poor extendibility which means the centralized BMS needs to be redesigned when the number of cells increases or decreases [13]. Therefore, the centralized BMS is seldom seen in the battery packs for EVs.

Each cell equips a small controller in the distributed BMS. The small controller is integrated in the cell to constitute the "smart battery" [14]. So the cell has a certain degree of self-management function. This topology has a clear advantage in reducing the complexity of sensor harness. It also helps to achieve higher precision and better anti-jamming. But the distributed BMS has a relatively high cost on hardware. And because the power supply for each small controller is from the corresponding cell, energy consumption differences may result in gradually increased cell variation [15]. In addition, network latency between cells and master controller is a big problem due to the large number of cells [16].

In electric vehicles, the battery system consists of a battery management system (BMS) and a battery pack, as shown in Fig. 1. A battery pack is usually composed of several battery modules, each of which is made up of several battery cells. A typical modular BMS topology usually contains a master controller, several slave controllers, and an independent electric meter [17], as shown in Fig. 1. As the computing center of BMS, the master controller not only need to communicate with the VCU (Vehicle Control Unit) through the external CAN bus, but also need to manage subordinate equipment, such as slave controller, electric meter and data logger, through the internal CAN bus. Each slave controller manages all battery cells in a battery module and detects their individual voltage. The electric meter is used for the high-precision measurement of total voltage and current of battery pack.

A comparison of different BMS topologies is listed in Table 1. The modular BMS has less computation load compared to the centralized BMS and less network load compared to the distributed BMS. In addition, each slave controller is shared by dozens of cells, so the average cost is lower than that of the distributed BMS. As a result, the modular BMS is becoming the dominant type in EVs and battery energy storage systems compared to the centralized and distributed BMSs.

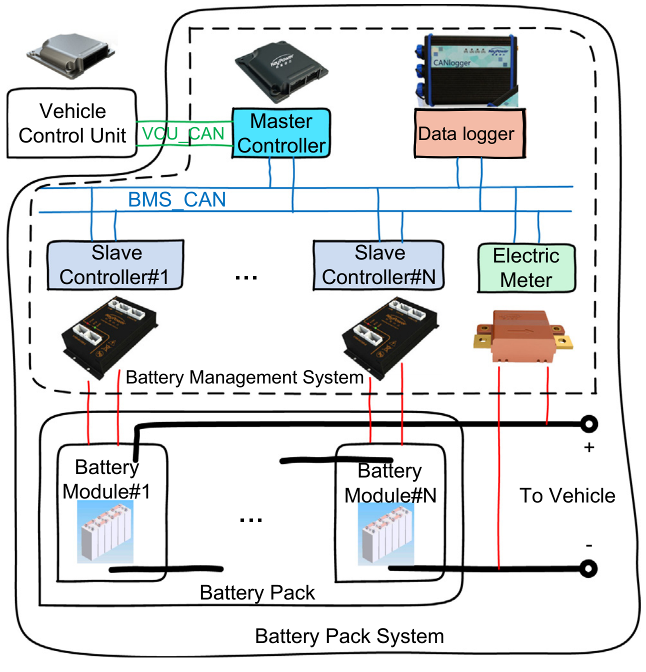

Fig. 1. Battery pack system and modular BMS topology.

Table 1
Comparison of different BMS topologies.

	Centralized BMS	Distributed BMS	Modular BMS
CPU load	High	Low	Middle
Network load	Low	High	Middle
Expandability	Bad	Good	Good

Many chips support either controller area network (CAN) or daisy-chained network in the modular BMS. The daisy-chained network still has its drawbacks considering the fault tolerance and real-time performance. Therefore, currently, CAN is the first choice in the modular BMS [18,19].

A fully functional modular BMS uses a data logger to record the signals of total voltage, total current, cell voltages, cell temperatures and states (e.g. the SOC of pack and cells). The data logger is a listen-only node on the CAN bus. It records specified signals on a secure digital memory card (SD card), and the data can be further read on a personal computer (PC) [20,21]. An alternative approach is to implement wireless network such as 4G for data transmission and storage on the cloud for further use [22]. The data stored will be used for parameter identification, state estimation, fault diagnosis and other research calculations in the BMS. These works are important for the safety of battery pack and the efficient management of BMS [23]. The off-line analyzing of recorded data also has a great importance for the future development of EVs and other battery energy storage systems. However, the data recorded in the data logger are not as good as the experimental data because of the relatively lower accuracy and lower sampling frequency.

A lot of research has been done on the data processing of energy storage systems [24]. With the increase in the number of batteries and the application of cloud technology in the battery energy management system, there have been more problems associated with the data itself [25]. While efforts are spared to improve the accuracy and to increase the sampling frequency, network latency has seldom been discussed [26,27]. The network latency will lead to unsynchronized data in the data logger. The asynchronous cell voltages and the current could lead to ridiculous results. For example, battery equalization is based on cell consistency, and voltage consistency is the most important parameter to observe cell consistency. If the cell voltages are not synchronized, the differences between cell voltages at "the same time" are not reliable to indicate the voltage consistency. More critically, if the recorded data were used for battery modeling and parameter identification, the estimated parameters would be ineffective. An extreme scenario is that one may observe a cell voltage rise "when" the cell is discharged, while in fact the cell voltage rise might be caused by charging in the previous step. In such cases, any model identification would lead to a wrong result. Further analysis based on these parameters, such as state estimation and fault diagnosis, is not reliable. Therefore, synchronization for massive data storage is necessary.

We propose a sync method for cell voltages and the current based on equivalent circuit models (ECMs) for battery packs. According to the literature, ECMs for Lithium batteries are summarized as follows: Rint model, Thevenin model, PNGV model, hysteresis model, RC model, ESC model, etc. [28–31]. In Ref. [32], a systematic comparative study of twelve equivalent circuit models is conducted, and the comparison results indicate that the first