



Recording frequency optimization for massive battery data storage in battery management systems



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HIGHLIGHTS

- Flexible recording frequency approach is applied for low frequency signals.
- The most dynamic period is analyzed with DWT and FFT for high frequency signals.
- The mean absolute derivation method verifies the most dynamic period by DWT.
- Recording at 1 Hz is not enough for voltage and current during the dynamic period.
- The optimal recording frequency will not influence the SOC estimation accuracy.

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ABSTRACT

Massive data storage is an advanced function in a fully functional battery management system (BMS). Reducing the recording signal length undoubtedly saves the precious memory space for BMS. And it also reduces the network and computation loads. However, it leads to a side effect that the trend of signal distortion is enhanced. The optimal recording frequency in practice should be as low as possible on the condition that little signal distortion happens. This paper presents a novel method which uses a multi-frequency recording technology that cooperates two approaches according to the signal dynamics. A flexible recording frequency method is applied for stationary signals which only records signals when their values are changed. While for dynamic signals, the most dynamic period is found using discrete wavelet transformation (DWT) and further analyzed by fast Fourier transformation (FFT). By comparing two recording signal indicators for four different recording frequencies, we conclude that recording at 1 Hz is not qualified for the cell voltage and current during the dynamic period in our system due to the high dynamic performance of the vehicle. In the demonstrated vehicle, only by increasing the recording frequency to at least 2 Hz, can the accuracy of the recorded cell voltage achieve the level the same as the measurement accuracy in engineering. And we also verify that when the recording frequency is reduced to the optimal frequency compared to the high frequency recorded original signals, the accuracy of the SOC estimation is not influenced.

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1. Introduction

With the rapid progress in lithium ion battery chemistry, large scale electric energy storage becomes possible nowadays. Large

battery packs such as battery energy storage stations or electric vehicles (EVs) consist numerous battery cells [1,2]. However, cells always have inevitable variations which may come from manufacturing process or the operation environment [2–5]. A battery management system (BMS) is therefore required to manage and monitor all cells as well as the overall states of the battery pack. A fully functional BMS should fulfil the following requirements:

(1) Sensing and monitoring: all kinds of BMSs at least monitor the total current, the total voltage, voltages and temperatures of

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individual cells, as well as temperatures of the specified nodes in air [6]; (2) Power management: good power management will not only improve the life of battery packs or reducing the charging cost [7,8] but also precisely detect battery cell parameters by specific methods [9,10]; (3) State estimation: state of charge (SOC), state of health (SOH) and state of function (SOF) are calculated and are extensively investigated in literature [6,11,12]; (4) Thermal management: good thermal management guarantees preference temperature to make battery packs work well and temperature uniformity between cells is a more critical issue for better thermal management [13]; (5) Communication: as the modular topology is commonly applied in the BMSs, CAN (Controller area network) bus, the most typical communication link in the automotive environments, is commonly used in BMSs [14]. Daisy chained network is also a current focus in engineering for the BMS network. The future networks could be Flexray [15], and wireless commutation also draws much attention; (6) Cell balancing: BMS needs to equalize the cells in order to maximize the battery's capacity and life [16,17]; (7) Fault detection: battery system faults can be generally categorized into two types: system related faults and battery related faults which are intensively studied [18,19].

Massive data storage is an extended and advanced function in BMS. A fully functional BMS may record history data including the signals of total voltage, total current, cell voltages, cell temperatures and states such as pack and cell SOC as well as cell balancing currents and so on. These data are recorded in a block of the BMS master controller which is specialized for data recording or a data logger controller linked to the master controller through the network. A secure digital memory card (SD card) or other memory storage devices are commonly used to store the data in the data logger, and it can be read on a PC for further research or for the maintenance of the battery pack [18]. With the progress in wireless communication, data transferred and saved into the server through wireless networks, e.g. 3G or 4G, is the newly developed technology for massive data storage. Though not all types of the BMSs have the function of massive data storage, it is very important for the BMS to record battery data during the operation in order to thoroughly analyze the battery performance off line:

- (1) As one of the most important part in big data digging for energy storage systems, the recorded data provide real working conditions of the battery packs. Data in EVs contain the information of the vehicle power demands and the driving habits as well as the charging habits of the EV users. Micro grid power demands can be revealed by analyzing data in battery energy storage stations.
- (2) Precise working conditions of battery packs from the stored data support the further development of EVs and other energy storage systems with improved data-driven algorithms [12,20,21], and as well as academic study of battery pack ageing [22].
- (3) When battery system failures occur in some instances, the stored data can be used to investigate the origins of the faults and help to reduce similar failures in the future. For example, if we would have more comprehensive data during the battery fire accident in Boeing 787 (ANA 787 on January 16, 2013), causes of the fire might have been directly revealed instead of inferring conclusions from the post-mortem battery pack [23].

A data logger needs to record hundreds to thousands of signals according to the size of the battery packs. For example, in a small pack with 96 cells in series, at least 400 signals are typically required to be recorded including the total voltage and current, cell voltages, cell temperatures, balancing currents, cell SOC and some control state signals et al. [18]. For large packs, e.g. a battery energy

station with 20 battery strings in parallel and each string with 240 cells in series [1], the order of magnitude of the recording signals will be a ten thousand.

Data from a demonstrated EV in our experiments show 434 signals were recorded with 1 Hz recording frequency, and 2 signals were recorded with 4 Hz (the total current and voltage). The recording time was 26 days and recording a signal at a time takes an average of 8 bytes. To calculate the memory space the data takes, we use the following equation.

$$M = nTfm \quad (1)$$

where M is the total memory space the data take, n is the number of signals, T is the total recording time, f is the recording frequency and m is the memory space it takes to record a signal at a time. Data of 26 days occupied 7.4 Giga Bytes (GB), i.e. completely full memory space of an 8 GB Secure Digital Memory Card (SD card). It was not a coincidence that the SD card was full, because the earlier data were covered by the incoming data.

Because the number of signals is predetermined by the design of the battery pack system, it is an effective way to reduce the recording frequency in order to increase the total recording time for the limited memory space in BMS. On the one hand, reducing the recording frequency will increase the capability of the recording time. As a result, some data logger set the recording period to 1 min or even longer [1]. But on the other hand, dynamic working condition in EVs requires fast recording of the current and voltage so as to ensure that no distortion happens to the recording signals. Typically, the recording frequency is set to 1 Hz [24] or even 10 Hz for this purpose.

In conclusion, reducing the recording frequency increases the total recording time but also increases the tendency of signal distortion according to the Shannon's sampling theorem. Conversely, increasing the recording frequency decreases the tendency of signal distortion but also decreases the total recording time. Therefore, the optimal recording frequency in practice should be as low as possible on the condition that no signal distortion happens. The benefits of reducing recording signal length without signal distortion are to save the memory space for memory stick devices and to reduce the network load. Besides, the additional benefits are:

- (1) For off-line data processing, less data means faster and easier data processing.
- (2) More importantly, the battery data are required to be stored in the memory space of the BMS microcontrollers for on-line calculation with some slightly more sophisticated functions. For example, cell voltage interpolating, charging curve fitting or on-line data-driven battery parameter estimation [12,25], they all need to recall the saved battery data from the Flash to the RAM (Random-Access Memory) and then calculated by the core of the microcontrollers. Obviously, the precious resources of RAM (currently less than 8 MB in most applications) as well as the computation capability limit the size of the recorded data. By optimizing the recording frequency, RAM as well as the computation capability will be greatly saved and more efficiently used.
- (3) With the increasing popular wireless networks (e.g. 3G or 4G), cloud storage and computing are becoming feasible for vehicle application [26]. As the wireless flow is expensive at present, reducing recording signal length will undoubtedly save the cost of the cloud storage system.

This paper presents a novel method which uses a multi-frequency recording technology according to the signal dynamics. For stationary signals, a flexible recording frequency method is applied which only records signals when their values are changed. For dynamic signals, firstly, the most dynamic period is revealed

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