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Fault and defect diagnosis of battery for electric vehicles based on big data analysis methods

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HIGHLIGHTS

- A battery fault diagnosis technique by means of big data technology is proposed.
- Outlier detection algorithms are utilized for fault diagnosis verification.
- Quantitative battery fault analysis in the form of probability is proposed.
- A multi-dimensional influences in the time dimension is quantified.

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ABSTRACT

This paper presents a novel fault diagnosis method for battery systems in electric vehicles based on big data statistical methods. According to machine learning algorithm and 3σ multi-level screening strategy (3σ-MSS), the abnormal changes of cell terminal voltages in a battery pack can be detected and calculated in the form of probability. Applying the neural network algorithm, this paper combines fault and defect diagnosis results with big data statistical regulation to construct a more complete battery system fault diagnosis model. Through analyzing the abnormalities hidden beneath the surface, researchers can see the design flaws in battery systems and provide feedback on the upstream of designing. Furthermore, the local outlier factor (LOF) algorithm and clustering outlier diagnosis algorithm are applied to verifying the calculation results. To further validate the effectiveness of the diagnosis method, a corresponding analysis between statistical diagnosis results and actual vehicle is given. To test the big data diagnosis model, the diagnosis results based on the actual vehicle operating data for the whole year is shown.

1. Introduction

Electric vehicles (EVs) have been widely recognized as an integral part of efficient and green transportation. Battery systems are a key component of EVs that largely defines their performance and cost-effectiveness [1–3]. With the eye-catching development of advanced lithium-ion batteries, they have been established as the dominant energy storage device for EV applications, thanks to their intrinsic advantages including high energy density, no memory effect and long lifespan relative to other battery chemistries [4–8]. However, the increasing risks of battery system failure occurred in recent years make consumers worried, so accelerating the researches on fault diagnosis and safety management of electric vehicle battery system become particularly important [9,10]. Voltage fault, including over-voltage and under-voltage, is a common fault type of battery systems. The voltage fault may imply more severe internal faults including mechanical fatigue, separator failure, internal short-circuit and so on. Therefore, potential voltage abnormality diagnosis is capable of locating and analyzing the catastrophic faults in advance.

1.1. Review of battery diagnosis approachs and big data statistical diagnosis methods

Nowadays, scholars all over the world are studying the fault diagnosis of battery systems for improving the safety of EVs. For example, Chen et al. proposed a model-based fault diagnosis approach by investigating the external short circuit fault characteristics of lithium-ion batteries [9]. Dey et al. proposed a two-state model for thermal fault diagnosis, which is able to describe the

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dynamics of the surface and core temperature of lithium-ion battery cells [10]. Mingant et al. proposed a State-of-Health (SOH) diagnostic technique for Li-ion batteries based on the analysis of free voltage and current signals [11]. Liu et al. proposed a sensor fault detection and isolation method for lithium-ion batteries in electric vehicles using adaptive extended Kalman filter [12]. Piao et al. proposed an outlier detection algorithm for evaluation of battery system safety [13]. Adnan et al. proposed a data-driven approach for embedding diagnosis and prognostics of battery health using the support vector machine (SVM) [14]. Sidhu et al. proposed an adaptive nonlinear model-based fault diagnosis method, where nonlinear models represent signature faults and the extended Kalman filter is utilized for estimation [15]. Zhang et al. proposed an online and real-time capacity fault diagnosis for parallel-connected lithium-ion battery groups [16]. Yan et al. introduced Lebesgue-Sampling-based fault diagnosis and prognosis (LS-FDP) framework for lithium-ion batteries, and a novel diagnostic philosophy of "execution only when necessary" is developed for computational cost reduction [17]. However, battery systems is an extremely complicated and non-linear system, and the processes and causes of battery system faults during actual vehicular operations are more complex [18,19]. Although there are many advanced fault diagnosis algorithms presented in these studies, most of them are based on the static battery experiments for validation, which cannot be effectively applied to real EV applications.

Big data statistical methods have been applied to fault diagnosis field, and scholars are trying to utilize the advanced big data techniques to advance electric vehicle related research [20,21]. For instance, Arias et al. proposed an electric vehicle charging demand forecasting model based on big data technologies [22]. Barré et al. proposed a statistical analysis for the recorded data parameters of electrical battery ageing [23]. Louie et al. proposed probabilistic models, and analyzed the statistical characteristics of aggregated electric vehicle charging station loads [24]. Li et al. proposed an approach for battery State-of-Charge (SOC) estimation based on dynamic data-driven and model-based recursive analysis [25]. Hu et al. proposed a battery capacity estimation method based on particle swarm optimization and k-nearest neighbor regression [26]. Outlier analysis is also a method of fault diagnosis [13,27,28]. However, most conventional statistical studies of electric vehicles cannot be utilized to locate the faulty battery cells. Furthermore, when the cell voltages still remain within the permitted limits, the presented methods are unable to detect or predict the fault occurrence. In addition, the sample capacity of conventional battery fault diagnosis applications is quite small, which cannot comprehensively and accurately reflect some deep-seated characteristics.

1.2. Contribution of the paper

The conventional approaches for battery fault diagnosis lack the capability of detecting and locating the faults in real EV applications, and also fail to detect the abnormal changes without obvious failure. In this study, a new method for detecting potential abnormal changes of cell voltages is presented to bridge these drawbacks.

To detect the potential voltage abnormalities of battery cells, the 3σ multi-level screening strategy is proposed and utilized for fault diagnosis model establishment. For more comprehensive statistical results, massive operating data collected from Beijing Electric Vehicles Monitoring and Service Center are extracted and calculated in the diagnosis model. In order to construct a high-performance and accurate diagnosis algorithm, the BP neural network and the 3σ-MSS are both used to fit big data processing results. Through replacing the 3σ-MSS core algorithm by two types of methods: the local outlier factor (LOF) algorithm and the clustering outlier diagnosis algorithm, the big data statistical model can be evaluated and verified. Through analyzing these abnormal voltage data hidden beneath the surface, researchers can see the design flaws in the target battery system and provide positive feedback for battery system design.

Furthermore, two battery fault diagnosis models in the time dimension are constructed to demonstrate how the varying conditions influence the battery performance and fault frequency. Since it is well acknowledged that the performance of battery systems is strongly influenced by the ambient conditions as indicated in Ref. [29], this model is also an effective tool to quantitatively assess the fault severity influenced by environmental factors.

1.3. Organization of the paper

The big data source and the 3σ-MSS mathematical model for fault diagnosis are described in Section 2. Section 3 defines two types of faults, and then shows analysis results and their corresponding verifications. Mutual verifications by two outlier detection algorithms are illustrated in Section 4. The changes and characteristics of cell faults in the time dimension are described in Section 5, with key conclusions summarized in Section 6.

2. Statistical diagnosis model of electric vehicle battery

2.1. Big data source of electric vehicles

The data was collected from Beijing Electric Vehicles Monitoring and Service Center, which serves as a national big data platform for electric vehicles in China, as shown in Fig. 1. This data platform can provide the real-time and off-line data of electric vehicles used for public transportation. In the platform, there are a large quantity of electric vehicle data, covering the aspects of vehicle position and speed and battery system states.

The real-time running data of electric vehicles mainly include traction battery system, motor drive system, vehicle control system, and some other parts. The data of the traction battery system mainly includes: the total voltage and current of the battery system, SoC state, cell voltages, the temperatures of battery pack characteristic points. Motor drive system data includes: voltage, current, speed, torque, temperature, etc. The vehicle control system data mainly include: vehicle speed, gear position, accelerator pedal value, brake pedal value, insulation condition, and some fault conditions etc. Other parts of the data mainly include: air condi-

Fig. 1. Beijing electric vehicles monitoring and service center.

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