Research on the Working Characteristics of Energy Storage Device for Battery Electric Vehicles under Complex Driving Conditions Based on Big Data

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Abstract. In this work, the actual working characteristics of on-board energy storage devices under complex driving conditions based on big data of new energy vehicle operation are explored. Studies were conducted on the distribution characteristics of vehicle speed and acceleration. Additionally, further examination was carried out on the corresponding current, voltage, temperature characteristics, power, and SOC variation characteristics of energy storage devices. The results show that for conditions of driving speed in the range of 0~70km/h and acceleration fluctuating between -1m/s^2 and 1m/s^2, the working current of the vehicle energy storage device is generally between -80A and 100A, and can reach above 110A at some points. The braking energy recovery rate is about 37.38%. The total voltage shows a fluctuating downward trend over time. Near the same time point, the voltage fluctuation amplitude can reach over 10V. The temperature of energy storage device does not fluctuations with operating time, only a 1℃ jump occurred at a few time points. The total power fluctuates within the range of -30KW to 40KW. As the running time increases, the SOC value of the vehicle shows a gradient decreasing trend. Despite the complex driving conditions of the vehicle, the decrease in SOC value over time exhibits a good linear characteristic. Under normal driving behavior, the Energy storage device is frequently in a cyclic charging and discharging process, with current, voltage, and temperature values remaining within a relatively stable and acceptable range, which ensures that the energy storage device is not subjected to irreversible structural damage.

Keywords: Big data, Driving behavior, New energy vehicle, Power battery

1. Introduction

With the increasing greenhouse effect, energy conservation and emission reduction have become an important issue advocated by countries all over the world. In order to reduce carbon emissions and achieve carbon neutrality as soon as possible, various new low emission or even zero emission production technologies and equipment have gradually been invented and widely applied. New energy vehicles are typical representative of them [1,2]. Based on the

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difference in power supply method, new energy vehicles can be divided into four categories: pure electric vehicles, plug-in hybrid vehicles, extended range hybrid vehicles, and fuel cell electric vehicles[3].

Among them, pure electric vehicles completely overturn the traditional energy supply mode of cars, providing energy for vehicle operation through power batteries. Due to the fact that fossil fuels are no longer required during operation, zero emissions have been fully achieved, making it an effective way for humans to address the greenhouse effect issue[4]. In order to achieve carbon neutrality as soon as possible and improve the global environmental quality level, the Chinese government has vigorously promoted the production and use of new energy vehicles in recent years. The current number of new energy vehicles in China has reached 18 million, ranking first in the world. Due to the use of a large number of electronic control components and sensors, the BMS and other intelligent system of electric vehicles can monitor the operating parameters of key components in real time. Therefore, in addition to possessing superior environmental performance, new energy vehicles also have significant advantages in electrification and intelligence compared to traditional fuel vehicles[5]. In order to ensure the safe operation of vehicles, a comprehensive new energy vehicle big data monitoring system has been established in China. Based on the operation big data of new energy vehicles, real-time monitoring of key operating parameters of various components during vehicle operation can be carried out. Studying these data and combining it with artificial intelligence models for analysis and prediction have become an important research direction at present[6,7]. New energy vehicles mainly use power batteries to provide energy for vehicle operation. The currently widely used power batteries in the world are mainly lithium-ion batteries. However, due to the fact that the electrochemical structure of lithium batteries is easily affected by the environment and usage performance, the driving behavior, charging and discharging behavior of users have a significant impact on their performance. A large number of experimental results have shown that both overcharging and over discharging can cause structural irreversible damage to batteries [8-11]. Many domestic and foreign research institutions have conducted extensive research about the impact of charging and discharging behaviors on battery aging characteristics [12-19]. The user's driving behavior not only directly determines the discharge characteristics of the battery. Due to the energy recovery of the battery during the braking process, an electric current can be formed to charge the power battery. Therefore, driving behavior can also affect the charging characteristics of power battery. However, there are currently few reports on the impact of user driving behavior on new energy vehicles, especially power batteries.

In order to explore the impact of driving behavior on new energy vehicles, especially on on-board energy storage devices, in this work, complex driving conditions based on big data of new energy vehicle operation are selected and the working characteristics of on-board energy storage devices are studied. This work will reveal the working characteristics of new energy vehicle energy storage devices under complex driving behaviors, explore the impact of user driving behavior on vehicle aging characteristics, and lay a foundation for further optimization and development of new energy vehicle technology.

2.Research objects and methods

The research object studied in this work is a battery electric vehicle. The corresponding big data all come from Guangzhou New Energy Intelligent vehicle big data platform, mainly includes operating data such as vehicle speed, voltage, current, SOC value, operating mileage, temperature, time, etc are extracted and integrated. The collection frequency of new energy vehicle operation data in this work is 10s/frame. To deal with the abnormal features of the raw data caused by external issues such as poor network connectivity, external vibrations, and sensor failures, data preprocessing was carried out before the study, mainly including completing missing values, removing outliers, deduplicating data. The data segments with missing charging data exceeding 60 seconds are deleted. If less than 60 seconds, interpolation method is used to fill in. The methods and principles for handling numerical errors are same as that of the missing data. For duplicate data, sort according to the time field of the data, select the first item to be saved in the duplicate data, and then delete the remaining duplicate data.

3.Result and discussion

3.1 Driving behavior

Figure 1 shows the distribution characteristics of vehicle speed over time under continuous operation. The total duration of this driving process is 3 hours, 19 minutes, and 55 seconds. During the driving process, the vehicle speed frequently fluctuates within the range of 0-70km/h, The driving state is complex and variable, with multiple brake behaviors reducing the speed to 0km/h. Enlarge the local speed distribution of the vehicle for the first 13 minutes of driving as shown in Figure 1(b). As can be seen, in the driving process, the car can maintain a speed level of 50km/h within a range of 3-5 minutes. In most states, the speed of the vehicle shows a clear peak valley distribution over time, that is, the vehicle frequently experiences sudden acceleration and deceleration.

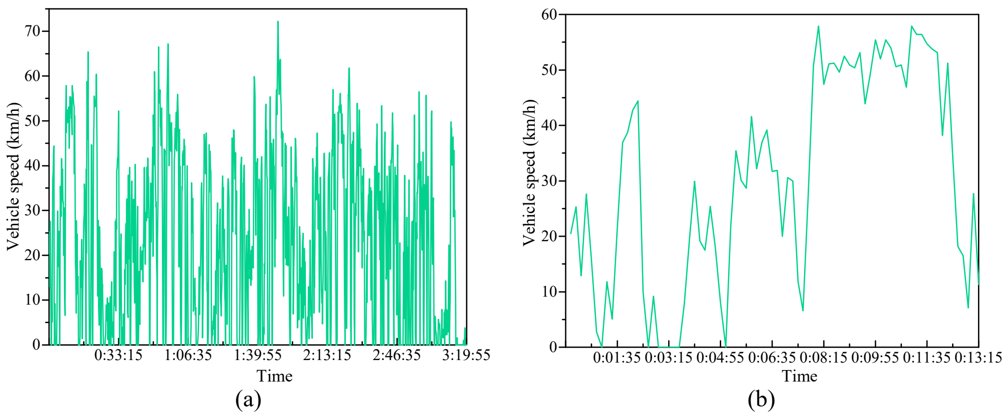
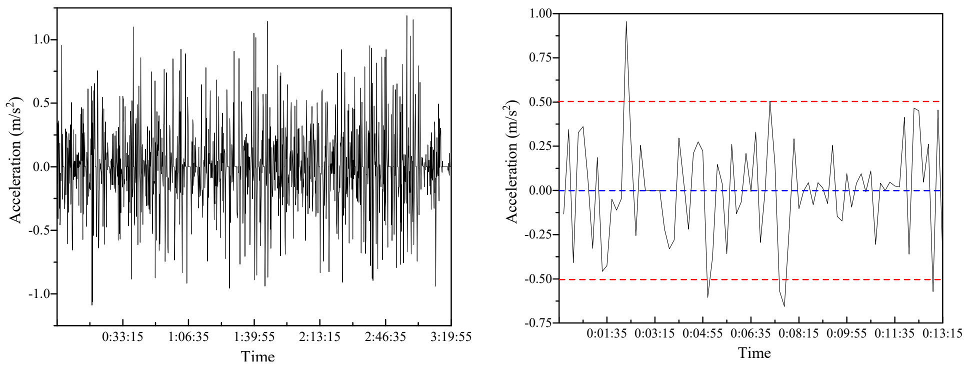


Figure 1. Vehicle speed distribution characteristics under continuous driving conditions.

The distribution characteristics of acceleration over time during vehicle operation are shown in Figure 2. The positive values indicate acceleration, while negative values indicate deceleration.

Because the data acquisition frequency in this work is 10s/frame, the calculated acceleration here is the average acceleration within 10s. As can be seen, during the driving process, the vehicle's acceleration always fluctuates within the acceleration range of -1m/s^2 to 1m/s^2, and the acceleration values during the acceleration and deceleration processes exhibit good symmetry. The amplification analysis of some acceleration distribution intervals is shown in Figure 2(b). From the figure, it can be seen that in the first ten minutes of vehicle startup, the acceleration in most states is within the acceleration range of -0.5m/s^2 to 0.5m/s^2, and only at a few time points can achieve an acceleration of more than 0.75m/s^2. After running for more than 15 minutes, the frequency of acceleration reaching 0.75m/s^2 or higher during acceleration and deceleration increases significantly. In the last 15 minutes of the vehicle operation, the overall acceleration of the vehicle decreased again to within 0.5m/s^2, with only a few points experiencing a rapid deceleration of -0.8m/s^2.



(a) (b)

Figure 2. Acceleration distribution characteristics under continuous driving conditions

3.2 Current and voltage characteristics of energy storage device

Figure 3 shows the total working current distribution characteristics of the energy storage device over time during vehicle operation. The positive current value indicates that the battery is supplying power to the outside, while negative value indicates that the motor is braking and charging the battery. As shown in the figure, the total working current of the battery fluctuates within the range of -80~100A during the operation. At certain time points the working current can reach over 110A. Taking 50A as the boundary, it can be seen that the amplitude and frequency of discharge current exceeding 50A during vehicle operation are significantly higher than those during charging. In the driving process, the main working current is generally below 50A. Enlarge the data for the first 13 minutes of the driving process as shown in Figure 3(b). As shown in the figure, the battery working current of the vehicle is generally within 50A within the first 5 minutes of driving. After that,the fluctuation range of the working current significantly increases, and a working current of over 80A begins to appear. In order to quantitatively analyze the recovery of braking energy during vehicle operation, the ampere hour integration method was used to calculate the charging and discharging amount during the vehicle operation. During the driving process, a total of 40.72Ah of electricity is discharged by the energy storage device and 15.22Ah of electricity is recovered. Without considering charging efficiency and other losses, the braking energy recovery rate is 37.38%.

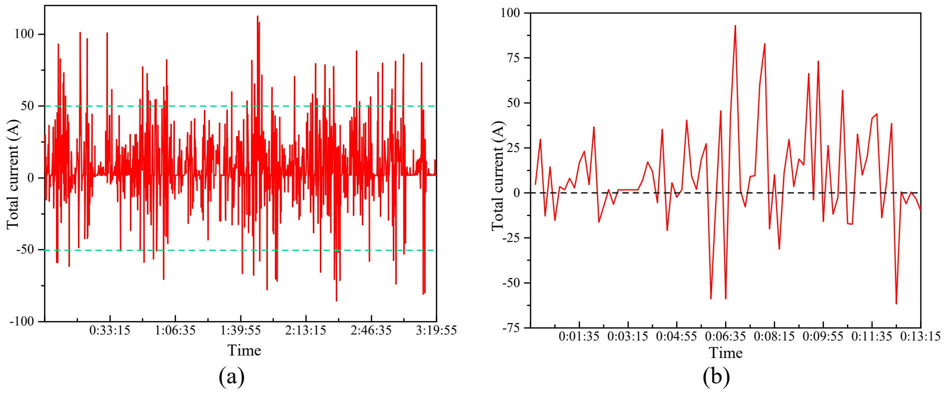


Figure 3. Current distribution characteristics under continuous driving conditions

Figure 4 presents the distribution characteristics of the total voltage of the energy storage device, the highest and lowest voltage values of the battery cell over time during the driving process of the vehicle. As shown in the figure, the total voltage of the energy storage device fluctuates frequently due to the influence of working current and battery internal resistance. The voltage fluctuation amplitude can reach over 10V near the same time point. Meanwhile, as time goes on, the overall voltage of the energy storage device gradually decreases, dropping from 335V to around 320V. The lowest and highest values of individual voltage also exhibit a pattern of fluctuation and gradual decrease with running time. The lowest single cell voltage decreased from 3.70V to around 3.54V, and the highest single cell voltage decreased from 3.72V to around 3.56V. During vehicle operation, the individual battery maintains good consistency and the peak voltage difference is maintained at around 0.15V.

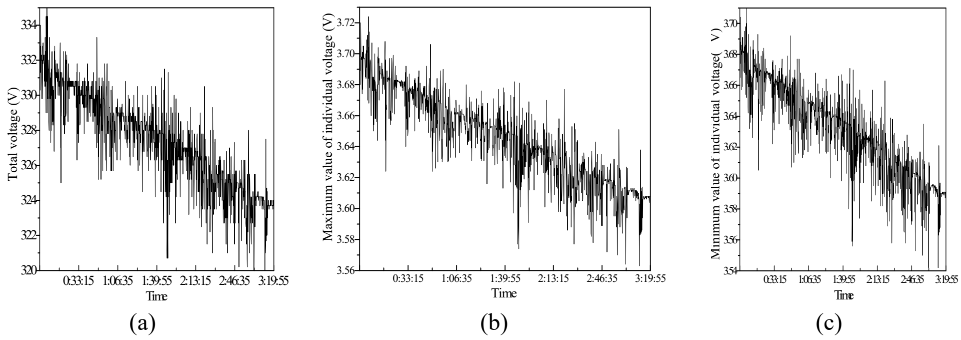


Figure 4. Distribution characteristics of the total voltage, the highest and the lowest value of individual voltage under continuous driving conditions

Figure 5 shows the distribution characteristics of the highest and lowest temperature values of the energy storage device over time during the driving process. As shown in the figure, the temperature of the energy storage device did not show significant fluctuations with time, but remained basically unchanged at 23 degrees. Only after running for about 2 hours, the energy storage device temperature decreased by 1℃. The variation characteristics of the lowest temperature over time are basically consistent with that of the maximum one, with jumps occurring at values of 19℃ and 20℃, indicating that the temperature of the energy storage device can be controlled at a stable temperature level under the function of the thermal management system.

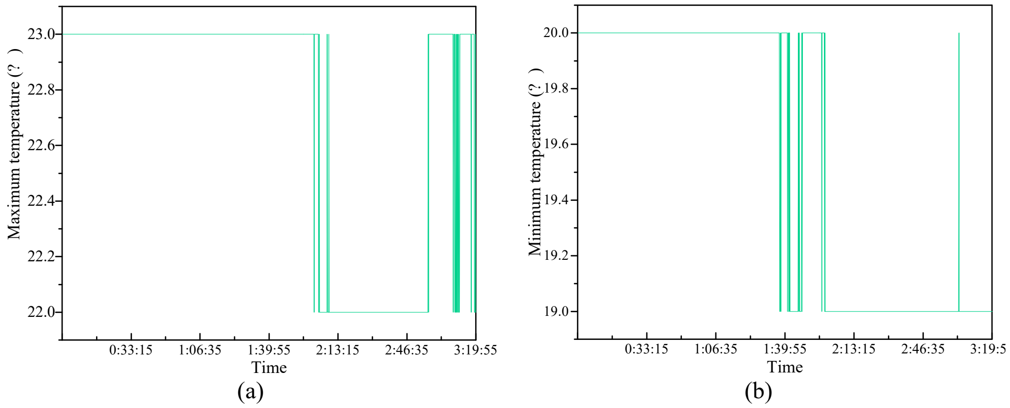


Figure 5. Highest and lowest temperatures of energy storage device distribution characteristics under continuous driving conditions

3.3 Power and SOC attenuation characteristics

Figure 6 presents the distribution characteristics of the total power of the energy storage device over time during the driving process. The positive power value represents the power output from the energy storage device during operation, while the negative value represents the power recovered by the braking system to charge the energy storage device. As shown in the figure, the total power of the energy storage device fluctuates within the range of -30KW to 40KW during the driving process. The amplitude and frequency of the output power exceeding 20KW are significantly higher than the conceptual frequency of the braking system towards the battery. There is a clear consistency between the power distribution characteristics and the current distribution characteristics. The main part of the power is between -10KW and 15KW.

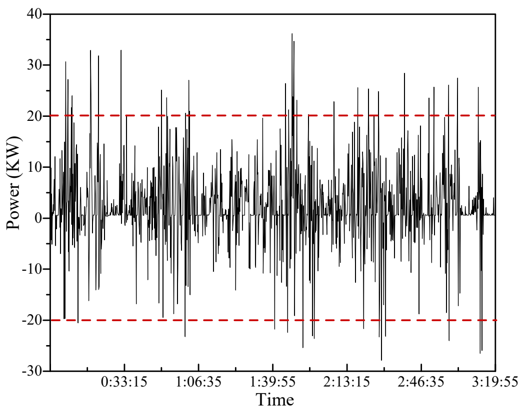


Figure 6. Power distribution characteristics over time under continuous driving conditions

Figure 7 presents the distribution characteristics of SOC values over time during the vehicle's current driving process. As can be seen, with the increase of running time, the SOC value of the vehicle shows a gradient decreasing trend, from 48% to about 25%. Although the state changes during vehicle operation are complex, the decrease in SOC value over time exhibits a good linear characteristic. It indicates that the brake recovery device has a good effect on maintaining the stability of the energy storage device. Enlarge the SOC variation characteristic curve of the vehicle in the first half hour as shown in Figure 7(b). For the vehicle studied in this work, the SOC value decreases by 1% each time under the data acquisition frequency of 10s/frame. Due to the influence of vehicle working characteristics, the time span of unit SOC decrease varies, generally between 8-15 minutes during this driving process. In addition, due to the influence of vehicle braking charging, there is a frequent phenomenon of SOC value first decreasing and then immediately recovering during driving process.

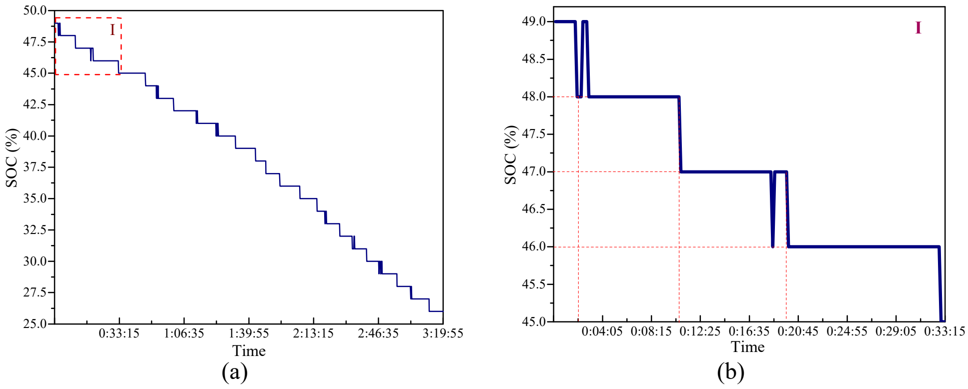


Figure 7. SOC value distribution characteristics under continuous driving conditions

4. Conclusion

In this work, the actual working characteristics of on-board energy storage devices under complex driving conditions are explored based on big data of new energy vehicle operation . The distribution characteristics of vehicle speed, acceleration are studied, and the corresponding current, voltage, temperature, power, and SOC variation characteristics of energy storage devices are studied on this basis. The main conclusions are as follows:

(1) In the approximately 3-hour driving process, over a hundred times of acceleration and deceleration behaviors can be observed. The vehicle speed fluctuates frequently in the range of 0-70km/h, with acceleration fluctuating between -1m/s^2 and 1m/s^2. The total working current of the energy storage device is generally between -80A and 100A, and can reach over 110A at some time points. In the driving process, the braking energy recovery rate is approximately 37.38%.

(2) The total voltage of the energy storage device fluctuates and decreases over time during vehicle operation. Near the same time point, the voltage fluctuation amplitude can reach over 10V. The temperature of the energy storage device did not show significant fluctuations over time, only a 1℃ jump occurred at a few points.

(3) During vehicle operation, the total power of the energy storage device fluctuates within the range of -30KW to 40KW, with the main part locating between -10KW and 15KW. Although the state changes during vehicle operation are complex, the decrease in SOC value over time exhibits a good linear characteristic. Due to the influence of vehicle braking charging, there is a frequent phenomenon of SOC value decreasing first and then immediately recovering.

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