**Early Faulty Battery Detection in Electric Vehicle Based on Self-Discharge Rate Analysis**

PROPOSAL

1. ***Research Question***

Our research question is to find out an early self-discharging detection method based on long term battery data analysis. There will always exist defects in the manufacturing process, even though at an extremely small percentage, that would result in the product performing poorly and in rare cases causing safety issues. Therefore, continuous monitoring of the battery usage and early detection of battery faults become a must, so we are interested in an early self-discharging detection that can be used to detect self-discharging before it can cause any problem.

1. ***Background Research***

In electric vehicles and energy storage systems, the battery cells are connected in series within the electric power storage unit, so called battery pack. Each cell must ensure good consistency, otherwise there will be different battery cell decay rates and temperature differences among battery cells, which will lead to battery pack performance degradation and life shortening. The self-discharge of the battery refers to the phenomenon that the energy stored in the battery decreases after the battery is charged and placed in the open-circuit state for a period of time, which affects the holding ability of the stored electricity of the battery under certain conditions. When the self-discharge of the battery is too large or the self-discharge consistency among the cells in the battery pack is poor, it will affect the driving range of electric vehicles and the energy storage systems. Serious battery self-discharge may lead to thermal runaway of the battery cell and increase the potential safety hazards, which may lead to safety problems of electric vehicles and energy storage systems. Therefore, the self-discharge rate is an important reference factor in battery safety management. Pei and Chen, among others, have summarized the two main methods for measuring the self-discharge rate, namely the static method and the dynamic method [1]. Xu and Gong, among others, have also discussed the self-discharge behavior of lithium-ion batteries, including the optimization of traditional measurement techniques and the development of novel measurement techniques [2]. Furthermore, a precise prediction method not only forecasts the depth of discharge (DoD) and the state of capacity fade in batteries to prevent over-discharging, but it also regulates the use of electric vehicles (EVs) by extending the mileage range and enhancing the relative efficiency of the battery [3].

1. ***Sampling and Experimental Design***

*Variables*: Average battery cell voltage

*Type of Study*: Observational study. Because we put identical treatments on each cell, we observe the change in average battery cell voltage to detect early faulty battery.

Data Collection:

Scope of Inference:

These data cannot be used to establish causal links since data is collected in an observational study. The findings can be generalized to the cells’ population because we use large sample (215 sets of cells) in this study.

1. ***Exploratory Data Analysis:***

This paper aims to detect battery cells with abnormal self-discharge rates as early as possible. In the very early stage, the abnormality is too little to tell. However, based on long-term running data, even though the abnormality is small in its absolute value, it could exhibit a more observable trend of value changes over time. In order to analyze the cell self-discharging situation, the research takes an electric vehicle that has experienced abnormal cell self-discharge as an example, and selects its total current, the maximum cell voltage, the minimum cell voltage, the maximum cell number, the minimum cell number, the maximum temperature, the minimum temperature, and the voltage data of all cells during its operation from June 2021 to July 2021.

As for detect digressive cells, clustering is performed according to the average and the medium cell voltages at each chunk to identify outliers. When a cell is identified as an outlier more than 7 times, it is considered to be an abnormal outlier cell. Afterwards, one will calculate the slope of the average voltage of the abnormal cell at two adjacent chunks. When more than 6 slopes are negative and a linear fitting is performed on the average voltages of all chunks, and the slope of the fitting line is also negative, then the cell is confirmed to be a digressive cell.

Each self-discharging cell needs to be confirmed by testing it on-site. Once the on-site testing result returns, one can confirm the effectiveness of the algorithm, or if necessary, adjust certain thresholds due to false positive results. As far as the research has been conducted, about one-month long data from 5 different vehicles was evaluated, and one anomaly with no false positive were found, presented in Fig 1. It can be seen that the voltage difference between the abnormal (orange) cell and other cells is small before June 26, but getting bigger and bigger, until July 14, when it was found that the battery voltage was too low, triggered an alarm and stopped the vehicle operation. We would analyze more cases of vehicles in the future.

图形用户界面

低可信度描述已自动生成

1. ***Group Task Assignment and Timeline***

In this project, Steven is responsible for introduction, Jonathan is responsible for data collection, Shubo is responsible for methods and data analysis, Ted is responsible for conclusion and Yulin is responsible for future suggestion. The proposal and data collection would be completed by May 17th, the methods and algorithm derivation would be done by May 20th, the data processing and analysis would be done before May 22nd, the conclusion and future study would be finished before May 24th. Finally, the project would be completed and double checked before May 26th.

1. ***Data***

In this research, we used a single battery package which contains 216 cells and was experiencing abnormal self-discharge. We measured every cell’s average terminal voltage in each day from 2021 June 17th to July 20th under a constant temperature of 26 Celsius. [Below listed parts of the data we used]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Cell 55** | **Cell 56** | **Cell 57** | **Cell 58** | **Cell 59** | **Cell 60** |
| **June 17th** | 3.2992871 | 3.299437 | 3.2995063 | 3.2992514 | 3.29932 | 3.2987431 |
| **June 18th** | 3.298186 | 3.2986977 | 3.2994621 | 3.2977093 | 3.2989785 | 3.2974771 |
| **June 19th** | 3.3061069 | 3.3068634 | 3.3076677 | 3.3072757 | 3.3070842 | 3.3057057 |
| **June 20th** | 3.3332204 | 3.3336327 | 3.3342424 | 3.334361 | 3.3338804 | 3.332676 |
| **June 21th** | 3.3299356 | 3.3300939 | 3.330671 | 3.3307773 | 3.330381 | 3.329312 |
| **June 22th** | 3.2908968 | 3.2912275 | 3.2915158 | 3.2905955 | 3.2912981 | 3.2902628 |
| **June 23th** | 3.2566748 | 3.2566278 | 3.2574021 | 3.2549087 | 3.2573516 | 3.2553108 |
| **June 24th** | 3.2494813 | 3.2496029 | 3.2501317 | 3.2478055 | 3.2500922 | 3.2481194 |
| **June 25th** | 3.2726297 | 3.2726917 | 3.2732334 | 3.2714971 | 3.2731446 | 3.2713624 |
| **June 26th** | 3.3014955 | 3.3014926 | 3.301939 | 3.3013812 | 3.3017602 | 3.3007135 |
| **June 27th** | 3.2973764 | 3.297413 | 3.2974203 | 3.297274 | 3.2974132 | 3.2967587 |
| **June 28th** | 3.2609719 | 3.2609366 | 3.2615172 | 3.2599236 | 3.2614072 | 3.2597653 |
| **June 29th** | 3.2890734 | 3.288983 | 3.2896593 | 3.2888943 | 3.2895219 | 3.2880195 |
| **June 30th** | 3.3248557 | 3.3249414 | 3.3249537 | 3.3249508 | 3.3249027 | 3.3244058 |
| **July 1st** | 3.2908121 | 3.2906272 | 3.2915959 | 3.2905274 | 3.2913673 | 3.2899369 |
| **July 1st** | 3.3028886 | 3.3030248 | 3.3033643 | 3.3031843 | 3.3032015 | 3.3022908 |
| **July 2nd** | 3.3252933 | 3.325322 | 3.3254972 | 3.3254458 | 3.3253851 | 3.324655 |
| **July 3rd** | 3.3121608 | 3.3122035 | 3.3123844 | 3.3124036 | 3.3122928 | 3.3116331 |
| **July 4th** | 3.3175749 | 3.3176923 | 3.3180783 | 3.3180249 | 3.3178435 | 3.3170087 |
| **July 5th** | 3.3225745 | 3.3226981 | 3.323306 | 3.3232935 | 3.3230397 | 3.3220314 |
| **July 6th** | 3.297837 | 3.2978817 | 3.2980702 | 3.2978935 | 3.2979652 | 3.2972774 |
| **July 7th** | 3.3274339 | 3.3286093 | 3.3306076 | 3.3305704 | 3.3296316 | 3.3278054 |
| **July 8th** | 3.3085743 | 3.3088214 | 3.3097078 | 3.3095518 | 3.3092746 | 3.3081914 |
| **July 9th** | 3.3093018 | 3.3097887 | 3.3109704 | 3.3107998 | 3.3103495 | 3.3091013 |
| **July 10th** | 3.3244803 | 3.3248148 | 3.3257853 | 3.3256202 | 3.3253279 | 3.3241789 |
| **July 11th** | 3.3358582 | 3.335805 | 3.3358578 | 3.335911 | 3.3359102 | 3.3351412 |
| **July 12th** | 3.3308052 | 3.3308672 | 3.3307513 | 3.3306787 | 3.3308257 | 3.3301361 |
| **July 13th** | 3.3365692 | 3.3365274 | 3.3366896 | 3.3367449 | 3.3366302 | 3.3359044 |
| **July 14th** | 3.3324847 | 3.332486 | 3.3325732 | 3.3325463 | 3.3325163 | 3.3318505 |
| **July 15th** | 3.333 | 3.333 | 3.333 | 3.333 | 3.333 | 3.3323199 |
| **July 16th** | 3.333 | 3.333 | 3.333 | 3.333 | 3.333 | 3.3320721 |
| **July 17th** | 3.3329887 | 3.3329982 | 3.3329648 | 3.3329997 | 3.3329446 | 3.332 |
| **July 18th** | 3.3322362 | 3.3324199 | 3.3321473 | 3.3325085 | 3.3321428 | 3.332 |
| **July 19th** | 3.3320001 | 3.3320012 | 3.332 | 3.3320055 | 3.332 | 3.3319928 |

***7. Reference***

[1] Pei Pucheng, Chen Jiayao, Wu Ziyao, Self-discharge mechanism and measurement methods for lithiumion batteries[J]. Tsinghua University (Science and Technology), 2019, 59(1):53-65.545

[2] Xu Tao, Gong Lu, Fang Lei, Wang Chenxu. Research progress in self-discharge of Li-ion battery[J].

[3] Lee, S., Kim, J., Lee, J.,et al.:‘State-of-charge and capacity estimation of lithium–ion battery using a new open-circuit voltage versus state-of-charge’,J. PowerSour., 2008,185, (2), pp. 1367–1373