Real-Time Safety Monitoring of Charging Pile Based on 5G and Cloud Computing

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Abstract. How to ensure the safety of charging pile including the protection of people, electric vehicles and batteries, has become the focus of social attention. This paper proposes a real-time safety monitoring scheme for the charging process based on 5G low latency and massively parallel cloud processing. The scheme is a second line of big data safety to ensure the safety of charging process. By accessing massive Internet of Things data in real time, it calculates in real time in the cloud to predict accidents, and gives early warning to the control system of the charging pile and the on-site management personnel of the charging station in time, so that they can timely intervene and control in advance, so as to avoid and reduce the occurrence of accidents.

1. Introduction
With the increasingly widespread use of electric vehicles, the charging and safety of electric vehicle batteries has become a great challenge. The existing safety measures can not effectively deal with the challenges of safety’s problems[1-3].

Electric vehicles are high-speed moving instruments with a large number of high-energy batteries. The use of vehicles is often exposed to harsh environment, such as high temperature in summer, cold in winter, heavy rain in flood season, typhoon, and even various physical damage such as bumping and puncture, which leads to many safety hazards of electric vehicles[4]. The characteristics of charging pile equipment are high voltage and high current. Once the equipment has any insulation problems, the control system function fails or incomplete, it will directly lead to very dangerous accidents. The users of electric vehicles and charging piles generally has very limited or do not have knowledge of electrical safety, and lack of effective inspection methods and tools for hidden dangers of equipment, which increases the risk of charging process of electric vehicles.

At present, the safety control of charging pile in the process of work has only defense line, which is the collaborative interaction between charging pile and electric vehicle battery management system[5-7]. Because there is a just one line of safety, many severe accidents repeatedly occur. Without a unified IoT big data center as the second defense line, we can not fully explore the accidents’s patterns and hidden dangers behind the accidents, and there is no way to establish safety models to realize comprehensive and automatic real-time safety monitoring. Therefore, we need the second defense line...
of big data, which is to collect and calculate the data of the Internet of things sensors in real time, and recognize the hidden dangers systematically and automatically to do timely control. The safety models of big data can be adjusted flexibly in the cloud, which can integrate the influence of multiple factors to realize smart early warning and early active maintenance, so as to avoid the small hidden risks eventually develop into severe accidents[8-10].

This paper will elaborate on how to build the second big data line. The second big data line is a safe charging platform. It can collect 5G low latency data, store massive amount of data, explores data by visual analyzing, struture charging safety models, build battery health assessment model, and flexible and scalable massive parallel processing system. The second big data defense line can integrate and consolidate online and offline information such as battery management system, charging pile, charging station, consumers, electric vehicles and battery manufacturers to realize information closed-loop, so as to promote the benign development of safety ecosystem and greatly reduce the probability of dangerous accidents.

2. Model algorithm
Active temperature management degree evaluation model is the core problem of battery charging safety. This paper implements a practical model.

The characteristic of active temperature management is that the number of monitoring points will change dispersedly with time and temperature. In the battery status information message sent by battery management system, there are temperature and monitoring point numbers of high temperature point and low temperature point. The system inputs three features into the algorithm model. The first characteristic quantity is the total number of high and low temperature monitoring points, that is, the total number of all monitoring points that used to be high or low temperature points in the charging process. The other two characteristic quantities are variation ratio of low temperature point and variation ratio of high temperature point. These two values can be calculated by the dispersion degree of high temperature point and low temperature point, using variation ratio features. The formula is as follows:

\[ V_r = 1 - \frac{f_m}{\sum f_i} \]  

\( f_m \) - Frequency of modal class, \( \sum f_i \) - total frequency of variable values. The higher the ratio \( V_r \) is, the more dispersed the high and low temperature points are. That is to say, the battery management system is actively rotating charging cells to ensure even temperature.

We use Kmeans algorithm to do clustering with three features, the variation ratio of low-temperature point, the variation ratio of high-temperature point, and the total number of high-temperature and low-temperature monitoring points. The formula is as follows:

i. Randomly select k clustering centroids as \( \mu_1, \mu_2, \ldots, \mu_k \in \mathbb{R}^n \)

ii. Repeat the following process until convergence

For each sample \( i \), calculate the class it should belong to

\[ c^{(i)} := \arg \min_j \| x^{(i)} - \mu_j \|^2 \]  

For each sample \( j \), recalculate the centroid of the class

\[ \mu_j := \frac{\sum_{i=1}^{m} 1(c^{(i)}=j)x^{(i)}}{\sum_{i=1}^{m} 1(c^{(i)}=j)} \]  

For important metrics such as temperature, volt, current, the change trend within specific history observation window are key features. We adopt the following formulas:

\[ Current\_window = \sum_{n=0}^{60\times60\times4} |c_n| \]  

\( |c_n| \) is the number of high or low temperature points.
\[ \text{Volt\_window} = \sum_{n=0}^{60 \times 60 \times 4} |v_n| \]  \hspace{1cm} (5)

Observation window is 1 hour, 4 records per second, a total is 14400 (=3600*4) records, n=0 is the latest one. C means battery current during past window, V means battery voltage. If both Current\_window=0 and Volt\_window>0, issue an alert.

\[ \text{Temprise\_window} = \max_{n=1}^{\text{max}} (t_0 - t_n) \]  \hspace{1cm} (6)

Observation window is 2 seconds, 4 records per second, T means battery detected temperature in the past time window, N =0 is the latest one. If Temprise\_window >=2, issue an alarm.

3. Introduction of System Scheme

3.1. System Technical Architecture

Each connected charging point corresponds to a special cloud service resource including data receiving process, real-time computing process, data storage process, etc. (Refer to Figure 1)

Main components include that, firstly, edge end: charging station, charging pile, charging plug, consumer app, station management end. Secondly, cloud: big data storage, big data monitoring center, processes service group (each station corresponds to a group which includes monitoring service, receiving service, computing service, storage service, alarm & report service).

The main data flow: firstly, the charging pile at the edge end flows to the processes service group in the cloud. Secondly, cloud data storing and models calculating. Thirdly, the alarm & report are delivered to the consumer app, big data monitoring center, charging station management console and charging pile control system.

Resource scheduling service: we start and stop the cloud service process group according to the configuration file parameters (Table 1). When need to add more charging stations, the processes service group in the cloud can be increased accordingly. By modifying the configuration file, we can implement the linear expansion of the system.
Table 1. Cloud computing resource configuration parameter

| Cloud Service | Station | Pile | Plug | Plug No.   | Station No. |
|---------------|---------|------|------|-----------|-------------|
| serverA       | stationA| pile1| plug1| 0001000101| CC010101    |
| serverA       | stationA| pile1| plug2| 0001000102| CC010101    |
| serverA       | stationA| pile2| plug1| 0001000201| CC010101    |
| serverA       | stationA| pile2| plug2| 0001000202| CC010101    |
| serverA       | stationA| pile3| plug1| 0001000301| CC010101    |
| serverA       | stationA| pile3| plug2| 0001000302| CC010101    |
| serverB       | stationB| pile1| plug1| 0002000101| CC010102    |
| serverB       | stationB| pile1| plug2| 0002000102| CC010102    |
| serverB       | stationB| pile2| plug1| 0002000201| CC010102    |
| serverB       | stationB| pile2| plug2| 0002000202| CC010102    |
| serverB       | stationB| pile3| plug1| 0002000301| CC010102    |
| serverB       | stationB| pile3| plug2| 0002000302| CC010102    |

3.2. Real-time data acquisition and history data storage

During the charging process, the system can collect can27930 messages generated by the charging pile and battery management system in real time. A charging plug can generate more than 64 messages per second, it is more than 230000 messages per hour. The collector on the charging point converts the CAN message into the Ethernet socket message, and then sends the data to the big data center in the cloud in real time through the 5G terminal of the charging point.

The receiving process service of big data center can receive all charging plug's message data in real time and forward it to real-time computing process service and historical data storage process service. The real-time computing process service and the historical data storage process service will process data flow in real time.

The historical data storage process service is responsible for storing data into files. According to the parameter "maximum line number of data file", the new file name is the charging plug number plus date and time stamp.

The historical data file will be imported into the database regularly or near real-time. Through the configurable conversion program, we can transform the original message into business readable data table and field for in-depth analysis, mining and management backtracking.

3.3. Real-time computing and early warning

The system first merges the received multi frame messages (including BRM, BCP, BCS, etc.), and then parses the required service field information from the original message data, including:

1) The maximum allowable charging current, maximum allowable charging voltage and maximum allowable temperature of the battery in BCP message;
2) Battery type, rated capacity, rated total voltage, vehicle identification code, etc. of BRM message;
3) Battery charging voltage demand and current demand of BCL message;
4) The battery charging voltage measurement value, current measurement value, as-is SOC of BCS message, etc;
5) The voltage output value and current output value of charge point of CCS message;
6) The BSM message includes the highest power battery temperature, the highest temperature detection point number, the lowest power battery temperature, the lowest temperature detection point number, etc.
Then the system will cache the real-time data flow with a certain observation window, including: battery detection temperature in the past certain duration, the supply voltage and current of charging pile in the past certain duration, the battery management system detection voltage, current, SOC, etc. in the past certain duration. The specific cache observation window length can be configured according to the needs of the model.

The system calculates multiple models according to the message data received in real time and the cache window data, and model configuration parameters (Refer to Table 2). The go-live models includes:

1) Heating too fast: in the past two seconds window, the temperature rises more than two degrees;
2) Insulation leakage: the supply voltage and current of the charging pile are inconsistent with the voltage and current detected by the battery management system;
3) Invalid charging: the battery management system detects that the current is 0, but the supply voltage is not 0, lasting for more than 30 minutes.

Table 2. Model parameter configuration

| Parameter name                          | Value     | Description                                |
|-----------------------------------------|-----------|--------------------------------------------|
| Calc interval of temp rising rapidly    | 1         | Calculate every second                     |
| Observation window of temp rising rapidly | 2         | In last 2 seconds                          |
| Threshold of temp rising                | 2         | Temp rising maximum is 2                   |
| Calc interval of invalid charging       | 3         | Calculate every third second               |
| Observation window of invalid charging  | 1800      | In last 30 minutes                         |
| Calc interval of insulation leakage     | 2         | Calculate every second second              |
| Observation window of insulation leakage| 3         | In last 3 seconds                          |
| Instantaneous voltage threshold         | 1000      | Calculate every second                     |
| Instantaneous current threshold         | 100       | Calculate every second                     |

If the calculation result exceeds the safety threshold or matches the failure mode, the system will generate real-time warning information and send it to the alarm process. The alarm process will send the alarm information to the station manager, big data monitoring center, consumer app and charging pile control system according to the type and severity of the alarm.

3.4. Flexible charging of charging pile control system
According to the type of alarm information, the charging point control system can either carry out flexible charging or stop charging immediately. Flexible charging policies can reduce SOC target, voltage, and current, and intermittent charging and so on.

3.5. Charging report and battery health information
At the end of the charging process, the system will generate the charging report and battery health information, and the report process will forward it to the big data monitoring center and consumer app. The charging report includes the summary information of this charging, temperature curve, voltage, current, SOC curve and battery health information.

4. Operation analysis
Based on Jilin Grid Charging Safety Big Data System, we have collected some data and done some exploration analysis with sample data provided by the charging pile manufacturer. Found the following six patterns and safety risks (some of which have been modeled and putted into system).

4.1. Invalid charging
The blue voltage line remains unchanged at 343 volts for the last 3 hours during the charging process, the red current line is 0 amperes, and the yellow line’s state of charge remains 95% unchanged. This
condition lasts for up to 3 hours. Both charging pile system and battery management system have not perceived condition and interrupted charging process (the duration window parameter can be configured according to the variant actual situations).

4.2. Insulation Leakage
The blue line is supply current of the charging pile, and the yellow line is detected current of battery management system. At the initial time of the charging process, there is a difference between the two lines and they do not coincide. The red line is the difference between the current supplied by charging pile and the current detected by battery management system. In the initial period of time, the difference is not 0, which represents the part of current’s difference. In this condition, leakage may be caused by insulation problems.

4.3. Temperature rising too fast
During the charging process, the two highlighted points show that, high temperature increase from 25 to 27 degrees in a one-second interval. In actual situation, it is necessary to determine the temperature rise tolerance threshold (including observation window and temperature rise threshold) according to weather conditions.
4.4. Active temperature management

By integrating the three feature, variation ratio of low temperature points, variation ratio of high temperature points, the total number of high and low temperature testing points, Kmeans clustering model was adopted to obtain four classifications. The 3D scatter diagram was used to visualize the following figure. It can be seen that the points with high dispersion degree of high and low temperature testing points are blue, followed by green, then yellow and finally red. According to scatter diagram of high and low temperature distribution of each charge, it can be verified that these four clusters accurately reflect the degree of active temperature management, and are completely positively correlated with car vendors, that is, electric vehicles of the same vendor have the same characteristics of temperature management mode.

![Figure 5. Active temperature management’s clusters](image)

4.5. Instantaneous over-voltage and over-current

During the charging process, instantaneous over-voltage and over-current occurs, testing values as high as thousands. It occurs frequently in the initial stage (red circle), and then occasionally in the next stage of the charging process (green circle). Maybe the electrostatic effect produce an instantaneous over-current, may also be data error. It is necessary to detect whether the anti-static function and data transmission function of the charging pile and the electric vehicle are properly functioning.

![Figure 6. Instantaneous over-voltage and over-current](image)

4.6. Battery SOC does not increase and current flows backwards

When the battery SOC reaches 90%, no longer increases (green circle), and accompanied by a small continuous or occasional current outflow (red circle), it is necessary for a professional Third-Party organization to testing whether the lines of battery are in poor contact or have been damaged, whether the battery cell is aging severe or even charging drum.
5. Conclusion
In this paper, the construction scheme of the second big data defense line for charging safety is described in practical details, and it has been put into trial operation in production.

The key technologies of this solution include real-time collection of massive and high frequency Internet of Things data, configurable parsing of CAN27930 message, flexible and scalable massive parallel processing architecture, interactive visual exploration and analysis of massive historical data, and foundings of safety models and battery health assessment model hints.

In the future, with the construction of more charging stations and energy storage stations, massive amounts of data can be collected to the cloud by 5G capture cards at the edge end. We can use these data for deeper exploration and analysis, so as to discover and deploy more safety models and establish a solid second line of defense for charging safety. With date riching and completing in big data center, a battery health rating system can be established to support the echelon utilization of power battery recovery and reuse when building battery energy storage stations in the future.

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