Research on Integrated Safety Assessment in the Process of Electric Vehicle Charging

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Abstract. With the increasing number of electric vehicles, the problem of charging reliability and safety has become the focus of foreign scholars and industry. By analyzing the charging safety characteristics of power battery, charge and discharge equipment and power supply equipment of electric vehicles, the safety mechanism of integrated electric vehicles is established in this paper. Based on the research of integrated safety warning and control, the integrated online warning module and intelligent protection module of electric vehicle charging are constructed. Based on the failure statistics of the integrated safety early warning system and combined with the integrated safety assessment index system of EV charging process, the regional EV charging safety can be assessed, so as to promote the healthy development of EV charging.

1. Introduction
In recent years, the electric vehicle industry has developed rapidly. As an important means of reducing carbon emissions, China's electric vehicle production and sales are growing rapidly, and the market is developing rapidly. From the perspective of the growth of electric vehicles, the future of electric vehicles will usher in explosive growth. As electric vehicles are becoming more and more accepted by consumers, how to improve the charging safety of electric vehicle users has become the focus of urgent work.

At present, domestic and foreign researches on Integrated Safety Assessment of EV charging process are mainly carried out. The existing method is to improve the detection accuracy and improve the control method to make the results more convincing[1]-[2][3]. Kai [4] et al. according to the electric safety protection of electric vehicle charging equipment, a new method based on synthetic weight is proposed, which quantifies the abstract ability of electrical safety and a real charging equipment is tested in order to verify the validity of the evaluation index. In the literature[5]-[6][7], an evaluation system of the electrical performance including some safety items is established, but fails to give an effective assessment indicator as well. Yan [8] et al. proposed a supervisory control system of charging station which contains five subsystems, supervising charging pile, battery charger, smoke sense, quick replace, and data switching exchange. Chen [9] analyzed the power battery pack, motor drive system, vehicle controller, and high-voltage lines of the electric vehicle to find out the factors that affect the electric vehicle fire, then the analytic hierarchy process and expert weighting method were used to evaluate and analyze the dangerous parts of electric vehicles easy to release fire, and several prevention and control countermeasures were proposed for the important factors causing electric vehicle fire. However, these literatures only describe the improvement of performance, still lacking a specific index that can be measured.
In this paper, the safety mechanism of integrated electric vehicles is established by analyzing the charging safety characteristics of power battery, charge and discharge equipment and power supply equipment of electric vehicles. Based on the analysis on comprehensive warning and control of EV charging safety, the integrated online warning module and intelligent protection module of EV charging are constructed. Based on the failure statistics of the integrated safety early warning system and combined with the integrated safety assessment index system of EV charging process, the regional EV charging safety can be assessed, so as to promote the healthy development of EV charging.

2. Research on Integrated Safety Early Warning and Intelligent Protection Control of Electric Vehicle Charging Process

2.1. Analysis of the mechanism of integrated safety in the charging process of electric vehicles

The faults in the charging process of electric vehicles mainly come from power battery failure (EV), charging infrastructure failure (charging pile) and power supply facility failure (distribution network). The failure phenomena of power battery mainly include the reduction of battery capacity, excessive charging voltage, failure to charge the battery pack, low discharge voltage, large self-discharge, local high temperature, poor unit voltage consistency, battery arc breakdown, battery damage and so on. The failure phenomena of charging equipment mainly include charging gun failure, failure of charger program identification, abnormal report of BMS, internal communication failure of charger, failure of voltage and current, failure of communication terminal with BMS, failure of electronic lock and so on. There are many factors that affect the safety of power system. From the perspective of main components, distribution network faults can be divided into generator faults, transformer faults and transmission line faults.

In view of the possible failure types of the above-mentioned vehicle-pile-grid, the corresponding safety decision-making mechanism and control method are given as shown in Figure 1.

![Figure 1. Analysis of safety mechanism and safety decision-making mechanism of vehicle-pile-grid integration](image)

(1) normal working condition

Electric vehicle power batteries can obtain electric energy from the regional power grid through charging stations to meet charging needs. Under normal working conditions, the security decision mechanism performs normal monitoring operations.

(2) battery failure

When the battery fails, it will directly affect the performance of the pile (the power electronic protection device of the burned pile) or affect the performance of the grid (generate voltage shock, voltage over-limit, reduce power quality, etc.), or indirectly affect the performance of the grid. According to the different types of influence, respectively remove the vehicle-pile connector or the vehicle-pile-grid connector.

(3) fault of charging pile
When the charging pile fails, it will affect the vehicle (over voltage, over current, over charge, spontaneous combustion, etc.) or affect the grid. According to the different types of influence, respectively remove the vehicle-pile connector or the vehicle-pile-grid connector.

(4) regional power grid fault
The probability of regional power grid fault is relatively small. When the fault occurs, it will directly affect the pile and the vehicle, or indirectly affect the vehicle by the pile. According to the different types of influence, respectively remove the vehicle-pile connector or the vehicle-pile-grid connector.

2.2. Research on integrated safety early warning and intelligent protection control
According to the analysis of the safety decision-making mechanism for the integration of vehicle-piles-grid, the integrated charging system of electric vehicles should include fault warning functions and protection control functions, based on which the integrated online warning module and intelligent protection control module can be constructed.

2.2.1. Integrated online warning module
The integrated online warning of EV charging process includes the short-term warning and the medium and long-term warning. Figure 2 shows the short-term fault handling module.

According to the short-term fault treatment indexes of vehicle-pile-grid, the classification fault tree of vehicle-pile-grid is used to judge the specific fault types respectively. After determining the fault information, the tag attached to the data of the EV interconnection platform is used to track the source of the fault data and locate the fault. After the fault location is determined, the fault object is determined and controlled by intelligent protection control strategy of EV interconnection platform. The output of the short-term fault processing module includes vehicle fault processing, pile fault processing, grid fault processing and orderly charging processing.

Figure 3 shows the medium and long term fault warning and processing module.
According to the medium and long-term early warning and control indexes of vehicle-pile-grid, AHP is used to determine the weight of secondary indexes of vehicle-pile-grid, and the three indexes with the largest weight are defined as the basis of integrated early warning evaluation. Secondly, the comprehensive fuzzy analytic hierarchy process is used to evaluate and analyze the influence of current main charging anomaly information on vehicle-pile-grid in the coming period of time, so as to determine the influence degree on vehicle battery, charging pile and power grid. Finally, the evaluation results are analyzed and located.

2.2.2. Intelligent protection control module

The integrated safety warning and intelligent protection control in the charging process of electric vehicles mainly includes the short-term integrated fault logic judgment module of vehicle-pile-grid and the mid-long-term warning module of vehicle-pile-grid. The short-term integrated fault logic judgment module for vehicle-pile-grid is shown in figure 4.

The short-term integrated fault logic judgment module for vehicles, piles, and grid includes input quantity definition, core fault integrated judgment logic analysis definition, output quantity definition, and fault information record. The input includes the fault code information of vehicle-pile-grid, the status data of vehicle-pile-grid and the operation data of vehicle-pile-grid. The logic analysis of integrated judgment of core fault includes logic judgment of vehicle-pile-grid fault, topological relation analysis of vehicle-pile-grid fault and fault location after judgment. The output includes fault warning.
output and fault handling. Fault information record is mainly used to archive the fault information that has occurred.

The mid-long-term integrated warning module of vehicle-pile-grid is shown in figure 5.

![Figure 5. The mid-long-term integrated warning module of vehicle-pile-grid](image)

The mid-long-term integrated early warning module for vehicle-pile-grid includes the definition of input quantity, the definition of medium and long term integrated early warning module and the definition of output quantity. The input amount includes the code information of single medium and long term warning result of vehicle-pile-grid, the code information of short-term fault records of vehicle-pile-grid, and the abnormal data of vehicle-pile-grid. The core medium and long term integrated early warning module includes the selection of key safety indicators of operation status, the assessment and analysis of integrated safety status of vehicles-piles-grid, and the early warning processing after assessment. The output includes warning information, warning output and warning processing.

3. Construction and application of integrated safety evaluation index system for electric vehicle charging process

In summary, based on the integrated safety early warning module of the electric vehicle charging process and the intelligent protection control module, the fault information of the electric vehicle charging process in the area can be counted, and combined with the fault tree to construct a safety evaluation index system, thereby the safety evaluation of the charging process of electric vehicles in the region is realized. The integrated safety evaluation index system for the charging process of electric vehicles is shown in Figure 6.

![Figure 6. An integrated safety evaluation system for EV charging process](image)

In order to make the safety evaluation index system practically applicable, the analytic hierarchy process can be used to obtain the weight of each evaluation index. As a comprehensive judgment
analysis method based on the combination of qualitative and quantitative analysis, the AHP is combined with expert experience to compare the influence of different factors on the same goal, determine the weight of each index, and reduce subjectivity and arbitrariness. The specific method is to construct the judgment matrix according to the T.L.Saaty scale theory, introduce the judgment matrix scale to compare the importance of each factor, and check the consistency. From this, the evaluation index system and weight composition are shown in Table 1.

| Evaluation goal | First level indicator | Weight | Secondary indicators | Weight |
|-----------------|-----------------------|--------|----------------------|--------|
| Integrated safety evaluation index system for electric vehicle charging process | Power battery safety indicator | 0.4905 | SOC reduction | 0.0941 |
| | | | Overcharge and over discharge | 0.2471 |
| | | | Over temperature | 0.1578 |
| | | | Self-ignition | 0.5100 |
| | | | Mechanical failure | 0.1571 |
| | | | Electrical fault | 0.4721 |
| | | | Software failure | 0.2516 |
| | | | Communication failure | 0.1192 |
| | Charging facility safety indicator | 0.3119 | Distribution network warning | 0.2500 |
| | Power supply facility safety indicators | 0.1976 | Distribution network failure | 0.7500 |

Throughout the evaluation, the weights of evaluation index were determined by AHP, that is, the key step of calculating weights in fuzzy comprehensive evaluation was finished. Each specific indicator in the indicator system has shown that different links in the charging process have different importance. The safety evaluation system and fuzzy comprehensive evaluation method can be used to evaluate the safety of the electric vehicle charging process in the area.

4. Conclusions
This paper analyzes the charging safety characteristics of electric vehicle power batteries, charging and discharging infrastructure, power supply equipment and formulates the integrated safety mechanism of electric vehicles. Through integrated safety early warning and control research, an integrated online early warning module and intelligent protection module were built for electric vehicle charging. Based on the fault statistics of the integrated safety early warning system, combined with the integrated safety evaluation index system of the electric vehicle charging process, it can realize the safety assessment of electric vehicle charging in the region and promote the safety of electric vehicle charging.

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