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Fault Diagnosis Model of New Energy Vehicle Charging Equipment Based on Fuzzy Fault Tree Theory

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Abstract: This paper probes into the new energy automobile charging equipment fault diagnosis problem. Fuzzy fault tree theory is introduced as a solution, fuzzy mathematics is used to improve the accuracy of fault diagnosis, the fault diagnosis model of charging equipment is established, and the fault diagnosis system based on Internet of things technology is designed, including equipment layer, communication layer, server and client. The system aims to realize the real-time monitoring and processing of the fault of new energy vehicle charging facilities, improve the user experience and improve the safety index.

Keywords: Fuzzy fault tree; Internet of things; Charging equipment; New energy vehicles.

1. Introduction

Under the situation of global environmental problems and energy crisis becoming more and more serious, electric vehicles, as a kind of green energy transportation tools, have attracted the attention of governments and automobile enterprises all over the world[1]. However, the development of electric vehicles is not mature at the present stage, and the endurance problem is an important resistance to the development of electric vehicles. As an important device to supplement energy for electric vehicles, the stable and reliable operation of charging equipment is particularly important. However, the circuit of electric vehicle charging equipment is complex, and the reasons for failure are complex. In the case of continuous upgrading of electric vehicle charging technology and continuous improvement of automation, its structure is increasingly complex, which brings great trouble to the fault diagnosis and safety warning of electric vehicle charging equipment[2]. Charging pile is an important device for electric vehicle to supplement energy, and it is also an important guarantee for endurance. Therefore, it is of great significance to identify charging pile failure and make safety warning for ensuring users 'charging experience and charging safety.

At present, there have been a series of studies on the fault analysis and detection system of electric vehicle charging pile, but there are still some problems: (1) More research focuses on fault diagnosis. On the one hand, there is relatively little research on intelligent charging pile system combining resource scheduling, safety warning and other functions. (2) The fault analysis of charging piles mostly relies on the theoretical research of complex algorithms, which lacks applicability for practical applications[3].

In this paper, the fuzzy fault tree theory is used to analyze the fault of electric vehicle charging equipment, and a set of new energy vehicle charging equipment fault diagnosis system is designed based on the Internet of things technology. The system can find the root cause of the fault, help the staff to deal with it quickly, and improve the processing efficiency.

2. Fuzzy Fault Tree Theory

2.1. Defects of traditional fault tree theory

Fault tree analysis (FTA) is a graphical deduction method that divides the causes of system faults into branches[4].

The fault tree is composed of "events" and "gates". The events are represented by failure probabilities, and the gates are used to describe the relations between events[5]. In fault tree analysis, the least desired fault state of the system is taken as the top event, which is the goal of the analysis, and all the factors that can cause the fault are found out as the middle event. Then all the factors that cause the middle event are found out, and in this way all the causes of the system failure are traced back to the bottom event[6]. The logical relationship between the system failure and the intermediate events and the bottom events is connected by logic gates to form a tree diagram to represent the relationship between the system and the causes.

However, the existing theories and methods need to regard the occurrence probability of the top event and the bottom event of the fault tree as a precise value, which has many shortcomings in practical applications: (1) The causes of the failure of the system components are not only caused by objective uncertain factors, but also by human subjective reasons, such as human error, design experience and other fuzzy uncertain factors[7]. (2) In practical engineering, the failure mechanism of the system is not clear in many cases. In complex human-machine systems, due to the imprecision of system modeling caused by human factors, correlated failures, and common cause failures, pure probability methods are difficult to work, and the relationship between events is often uncertain. (3) In some high-reliability systems, the failure frequency is very low, and a large amount of data can not be obtained;

2.2. Fuzzy fault tree theory

Fuzzy fault tree is a method that combines fault tree analysis method with fuzzy mathematics theory. It extends the traditional fault tree analysis to deal with uncertain problems, so that the application scope of fault tree analysis is wider[8]. When applying the fuzzy fault tree theory to analyze, we need to calculate the fuzzy probabilities, which are obtained based on the previous data and analysis experience. On this basis, fuzzy mathematics is used to calculate fuzzy probabilities instead of the original precise-valued probabilities.

The fault probability of components needed in fault diagnosis can generally be calculated by historical fault data. However, due to the continuous change of the use environment of the equipment and the replacement of components from time to time, the failure probability of each component becomes uncertain. The fuzzy fault tree theory is to solve this kind of problem, it uses fuzzy logic to express the uncertain component failure probability with fuzzy numbers, so that the probability becomes fuzzy probability. At the same time, the theory also takes into account the "human" this factor can not be ignored, and the judgment of the experienced personnel on the fault is also integrated into the results through calculation, which is more practical. In addition, for those concepts such as the degree of failure that cannot be quantified by precise values, fuzzy fault tree theory can also be flexibly expressed by fuzzy numbers, which has a high degree of flexibility[9].

It is defined as the set of fault symptoms of the equipment, and is the total number of fault symptom types:Um

$$U = \{U_1, U_2, \cdots, U_m\} \tag{1}$$

Is defined as the fault cause set and is the total number of fault cause types:Vn

$$V = \{V_1, V_2, \cdots, V_n\} \tag{2}$$

According to the influence degree of each bottom event contained in the fault symptom set on the equipment, the fuzzy vector of fault symptom can be defined as follows.

$$u = \{u_1, u_2, \cdots, u_m\} \tag{3}$$

It is defined that the fault cause causes the equipment failure, and the membership degree of each fault cause is, at this time, the fuzzy vector of the fault cause is defined as:$V_i V_i v_i$

$$v = \{v_1, v_2, \cdots, v_n\} \tag{4}$$

The fuzzy decision equation is listed as follows.

$$v = u^{\circ} R \tag{5}$$

Where is the fuzzy relation matrix:R

$$R = (r_{ij})_{m \cdot n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{i1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{6}$$

And has.$0 \leq r_{ij} \leq 1,\ 1 \leq i \leq m, 1 \leq j \leq n$

The established fuzzy relation matrix of dimensions is essentially a mapping. $m \times nR$The fuzzy relation matrix can map the fuzzy fault symptom set to the fuzzy fault cause set, so that the bottom events of different fault states are integrated to make decisions, and it has high adaptability. The column represents the fault cause, the row represents the fault symptom, and the matrix element represents the membership degree of the first symptom to each cause.$r_{ij} i V_i j U_j$

The fuzzy synthesis operator "" is needed in the fuzzy diagnosis, which means that the fuzzy relation matrix R and the fault cause fuzzy vector are operated in a certain operation mode, and finally the fuzzy relation equation is solved to obtain the fault result. $^{\circ}\ v$Through this fuzzy combination operation, we can effectively deal with the uncertainty and fuzziness, and get more comprehensive and accurate fault diagnosis results.

3. Fault Diagnosis Model for New Energy Vehicle Charging Equipment

Due to the practical needs of fault diagnosis and the particularity of information fusion technology, it is feasible to use information fusion technology in fault diagnosis. At present, fault localization methods mainly include Bayesian network fault localization, fuzzy information fusion localization, evidence theory fusion fault localization, etc. In this paper, fuzzy fault tree is mainly used to calculate legal fault information.

According to the analysis, the fault components of charging equipment include the total fault tree of charging pile, the fault tree of charging module, the fault tree of main circuit, the fault tree of charging gun, the fault tree of control circuit, the fault tree of user terminal equipment and the fault tree of charging pile over temperature. These causes are classified as intermediate events and bottom events, and the middle events are caused by the bottom events.

Taking the risk of "charging equipment failure" as the top event, we first look for the direct causes that can lead to the risk, and summarize several intermediate events as the direct causes according to the working principle of charging equipment. These intermediate events are "charging module failure", "main circuit failure", "charging gun failure", "control circuit failure", "user terminal failure", "charging pile overtemperature failure"[10]. As these intermediate events can be further subdivided, each intermediate event can be corresponding to one or more events, until subdivided to the bottom event, these bottom events constitute the basic component leading to system failure.

The first-level intermediate event "charging module fault" can be subdivided into "AC input fault", "communication fault", "output short circuit fault", "output overvoltage fault" and "output overcurrent fault"[11], in which "AC input fault" can be subdivided into "AC power outage" and "AC input missing item". "Communication fault" can be further subdivided into "communication protocol problem", "hardware problem", "insulation detection module communication interruption", "AC module communication interruption", "meter communication interruption"[12]. The first-level intermediate event "main circuit fault" can be subdivided into "output fuse fault", "reactor anomaly", "transformer secondary coil anomaly", "power switch anomaly" and "unipolar switch anomaly". The occurrence of any one of these bottom events can lead to the occurrence of its corresponding intermediate events. The partition results are shown in Table 1 and Table 2. The logic structure diagram of the fault tree is shown in Figure. 1.

Table 1. Intermediate event system code and interpretation

Event codes	Event name
T	**Failure of charging equipment**
E_1	**Failure of charging module**
E_2	**Main circuit failure**
E_3	**Charging gun failure**
E_4	**Control circuit failure**
E_5	**User terminal fault**
E_6	**Overtemperature fault of charging pile**
E_7	**Ac input fault**
E_8	**Communication failure**
E_9	**Output short circuit fault**
E_{10}	**Output overvoltage fault**
E_{11}	**Output overcurrent fault**
...	...
E_{26}	**Overheated charging pile**
E_{27}	**Charging pile module fan overheating**

Table 2. Underlying event system code and interpretation

Event codes	Event name
x_1	**Ac power outage**
x_2	**Ac input is missing**
x_3	**Communication protocol issues**
x_4	**Hardware issues**
x_5	**Communication breakdown of insulation detection module**
x_6	**Ac module communication interruption**
x_7	**The meter communication is interrupted**
x_8	**The filter is broken down in the middle**
x_9	**Rectifier drive circuit failure**
x_{10}	**Faulty output fuse**
x_{11}	**Abnormal reactor**
x_{12}	**Abnormal secondary coil of transformer**
x_{13}	**Abnormal power switch**
x_{14}	**Abnormal monopole switch**
...	...
x_{42}	**Module fan malfunction**
x_{43}	**Poor/damaged switch contact**
x_{44}	**Faulty temperature sensor**

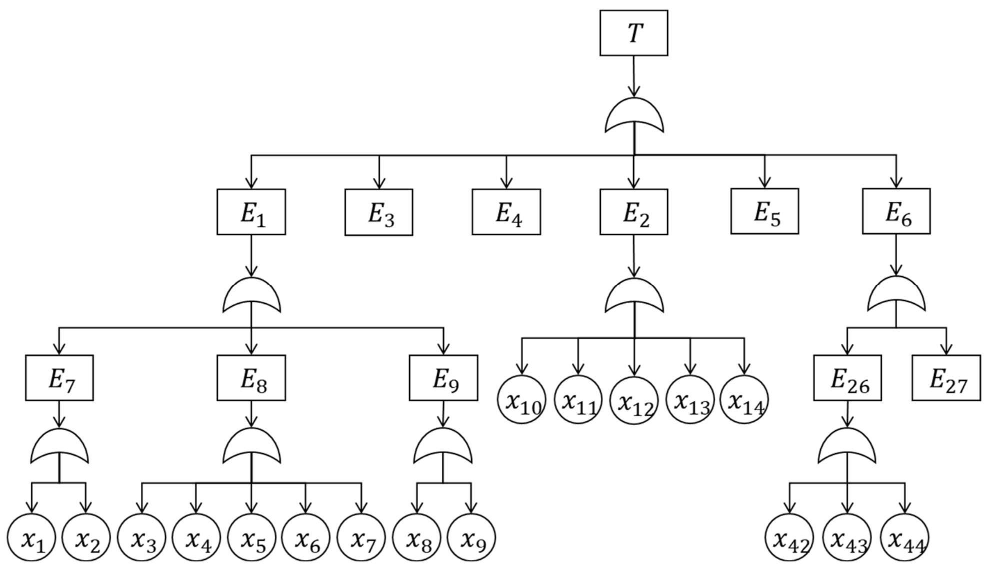

Figure 1. Logic structure diagram of fault tree for new energy vehicle charging equipment

4. Fault Diagnosis System for Electric Vehicle Charging Equipment

The architecture of the whole system is shown in Figure 2, which consists of four layers, namely the perception layer, the network layer, the data layer and the application layer from bottom to top[13]. Figure 2. Fault diagnosis system structure diagram of charging equipmentThe perception layer includes sensors and device acquisition terminals, and its main task is to obtain the status information of charging devices. The network layer relies on the wireless communication module and uses the Internet of Things technology (such as 4G/5G, NB-IoT+4G+5G) to realize data communication with the monitoring and security early warning platform[14]. The data layer uses advanced big data technology to establish a big data resource center for new energy vehicle charging equipment, which is responsible for the centralization, storage, processing, analysis and mining of equipment data, cataloging, showing and managing equipment data, and providing data services and showing for the application layer[15]. The application layer uses data services to analyze and apply vehicle data, constructs a safety early warning model, and realizes safety early warning and data display of new energy vehicle charging equipment [16].

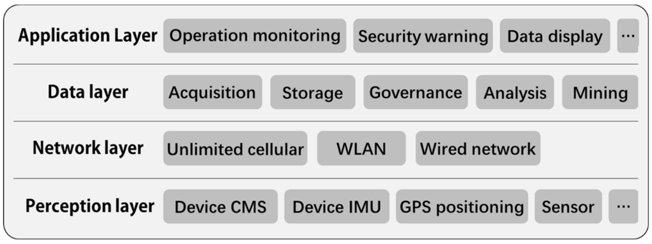

Figure 2. Fault diagnosis system structure diagram of charging equipment

5. Conclusion

This paper deeply studies the fault diagnosis problem of electric vehicle charging equipment, introduces the establishment process of charging equipment fault model, uses fuzzy fault tree algorithm to subdivide various possible fault events, and provides a framework for fault diagnosis. In addition, this paper designed a fault diagnosis system for charging equipment based on Internet of things technology, aiming at realizing real-time monitoring and rapid processing of charging equipment faults.

The application of fuzzy fault tree theory provides a new idea for fault diagnosis, and taking uncertainty factors into consideration has positive significance for improving the accuracy and practicability of diagnosis. The fault diagnosis system of charging equipment based on Internet of things technology provides technical support for the development of electric vehicles, which can ensure the stability of charging equipment and improve user experience.

However, it is still necessary to further improve the model and system and incorporate more actual data and application scenarios to improve the accuracy and practicality of the system[17]. At the same time, the continuous research and improvement of fault diagnosis technology for new energy vehicle charging equipment is crucial to promote the sustainable development of the electric vehicle industry.

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