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Safety Evaluation of mining machinery and electrical system based on improved Analytic Hierarchy Process

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Abstract. With the increasing of automation degree of mining machinery and electrical equipment machinery, Mining Machinery occupy an increasingly important position in security management. Without the safe operation of the electrical and mechanical equipment, safety production can not be guaranteed in mines. Therefore, strengthening the scientific management of electrical equipment, correct and rational using electrical equipment is modern development of mining electrical equipment safety management requirements. Safety evaluation is an important aspect of safety management.In this paper, we put forward an improve Analytic Hierarchy Process, which combined with the advantages of the fault tree analysis and AHP, based on the consistency of structure importance weights, to comprehensively evaluate various factors which affect mining electrical safety, explore reasonable measures for the prevention and treatment based on evaluation results, and hope to offer some reference for electrical safety management of mine.

1.Introduction

Coal mine safety management is a dynamic system engineering, it has characteristics of multiple factors, multiple link and perplexing. Due to particularity of mine production environment, the safe operation of coal mine electrical equipment requirements are higher and more stringent. The main problems existing in current mine electrical safety management include the overall quality of electrical workers and management is low, lack of understanding of electrical standardization work, lots of hidden dangers of electrical equipment, lack of targeted electrical training.

The aims of this paper are to analyze the causes of mining electrical accidents, evaluate coal mine electrical safe production by the method of analytic hierarchy process based on fault tree. The remainder of our paper is organized as follows:Section 2 introduces the principle of the analytic hierarchy process and fault tree analysis method, and constructs the model of analytic hierarchy process based on fault tree. Section 3 analyzes the degree of importance of the factors which may cause the accident, and evaluate coal mine electrical safe production. Section 4 makes recommendations on how to enhance the management level according to the evaluation results of the factors. Section 5 summarizes the full text and proposes the future research directions.

2.The introduction of electrical safety management of mine

2.1 General situation of mine electrical safety

Mine is divided into open pit mines and underground mines, and the production system of underground mine is complex. The prominent characteristic of underground mine is operating in the pit, mainly includes mine development, mineral mining,cutting, stoping etc.. The whole production process involves drilling, blasting, ventilation, transportation,power supply, water supply and drainage, dust and tailings disposal etc. Because the underground the environment is not suitable for people to live and work, so it needs electrical facilities to work together, such as fan blowers, pumps and hoists.

2.2 Problems of electrical safety management of mine

With the development of science and technology, continually improving performance of equipment and improvement of production process, the equipment management level will continue to improve, can gradually adapt to the management of modern enterprises. So there should be find out the problems of electrical equipment safety management in mine production, and find out the correct measures to keep up with the pace of modern industry equipment management.

2.3 Methodology

2.3.1AHP

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then[1]. The procedure for using the AHP can be summarized as: Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. Synthesize these judgments to yield a set of overall priorities for the hierarchy. Check the consistency of the judgments. Come to a final decision based on the results of this process[2]

2.3.2 Fault Tree Analysis

Fault tree analysis (FTA) is a top down, deductive failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in the fields of safety engineering and reliability engineering to understand how systems can fail, to identify the best ways to reduce risk or to determine (or get a feeling for) event rates of a safety accident or a particular system level (functional) failure.

2.3.3 AHP based on fault tree

Although the fault tree can determine the logic relationship of basic events leading to hidden trouble, but probability of basic events and the external environment have a great influence on the top event. Therefore, a single structure important degree to analyze the causes of accidents is not accurate, the statistics is relatively difficult, and the dispersion is not easy to comprehensive analysis. So we decided to improve the method of the fault tree analysis by using the principle of analytic hierarchy process. The weight of each factor in the index layer is the reflection of the level of an important impact on the target layer in AHP, and the structure important degree in FTA is similar, so we can use the judgment matrix of AHP to obtain the weight coefficient of each factor.

3.Model Establishment

3.1 FTA analysis of electrical safety system

In power system the hidden danger as the top event to structure the FTA model. Use the methods of quantitative analysis and qualitative analysis to analyze each basic event. The system short circuit and Safety protection gear of each one-way device as a whole not listed separately.

The most basic power supply system of coal mine as an example, the problems are mainly the power failure, transmission and distribution network fault, electrical equipment failures, Use them as intermediate events gradually spread. There are 12 basic events. These are the system the hidden dangers of accidents. The accident tree as shown in Figure 1,the symbol meaning as shown in Table 1.

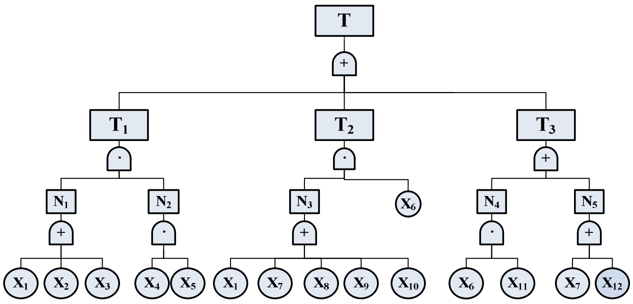

Fig 1

Table 1

Symbol	Meaning
T1	Power failure
T2	Transmission and distribution network fault
T3	Electrical equipment fault
N1	External power supply network risks
N2	A self-contained power supply hidden danger
N3	Cable fault
N4	The live shell
N5	Electric sparks
X1	Neutral directly grounding
X2	Lack of storage of the main transformer
X3	Transmission and distribution plate failure
X4	No a self-contained power supply
X5	The self-contained power supply fault
X6	Protective device error
X7	Short circuit
X8	Cable failure
X9	The load overload starting
X10	Distribution board component failure
X11	Exceed the rated voltage
X12	Improper use of equipment

Quantitative analysis of fault tree: simply fault tree by using Boolean algebraic, and get the minimum cut set, The minimum cut sets represent the basic combination of events have an impact on the accident. Analyzed the importance of basic events by using structure important degree. This is a key step in quantitative analysis. The formula to calculate the importance degree is as follows: $I_{\varphi}(i) = \frac{1}{k}\sum_{j=1}^{m}\frac{1}{n_j}$

Among them, k is the total number of minimal cut sets, m is the number of minimum cut sets which contains the basic events, n_j is the number of the j minimum cut set which basic event X_i belongs to the j Calculation of Boolean algebra:

$$
\begin{aligned}
T &= T_1+T_2+T_3 = N_1\cdot N_2+N_3\cdot N_6+N_4+N_5 = (X_1+X_2+X_3)\cdot X_4\cdot X_5+(X_1+X_7+X_8 \\
&+X_9+X_{10})\cdot X_6+X_6\cdot X_{11}+X_7+X_{12} = X_1\cdot X_4\cdot X_5+X_2\cdot X_4\cdot X_5+X_3\cdot X_4\cdot X_5+X_1\cdot X_6 \\
&+X_7\cdot X_6+X_8\cdot X_6+X_9\cdot X_6+X_{10}\cdot X_6+X_{11}\cdot X_6+X_7+X_{12} = X_1\cdot X_4\cdot X_5+X_2\cdot X_4\cdot X_5 \\
&+X_3\cdot X_4\cdot X_5+X_1\cdot X_6+X_8\cdot X_6+X_9\cdot X_6+X_{10}\cdot X_6+X_{11}\cdot X_6+X_7+X_{12}
\end{aligned}
$$

The minimum cut set is calculated: $P_1=\{X_1,X_4,X_5\}$ $P_2=\{X_2,X_4,X_5\}$ $P_3=\{X_3,X_4,X_5\}$ $P_4=\{X_1,X_6\}$ $P_5=\{X_8,X_6\}$ $P_6=\{X_9,X_6\}$ $P_7=\{X_{10},X_6\}$ $P_8=\{X_{11},X_6\}$ $P_9=\{X_7\}$ $P_{10}=\{X_{12}\}$

The number of the minimum cut sets is 10, so the k=10, The calculated results of the structure importance of each basic event are: $I_1=\frac{1}{12}$, $I_2=I_3=\frac{1}{30}$, $I_4=I_5=I_7=I_{12}=\frac{1}{10}, I_6=\frac{1}{4}, I_8=I_9=I_{10}=I_{11}=\frac{1}{20}$.

3.2Construct an analytic hierarchy process model

Convert the "AND gate" and "The OR gate" of the fault tree, and make all the events' "happen" to "not happen", marked $X_i^{'}$, its structure important degree is same to X_i .The 12 $X_i^{'}$ as factors of the index layer, after classification are 4 influencing factors, the AHP model as shown in fig 2.:

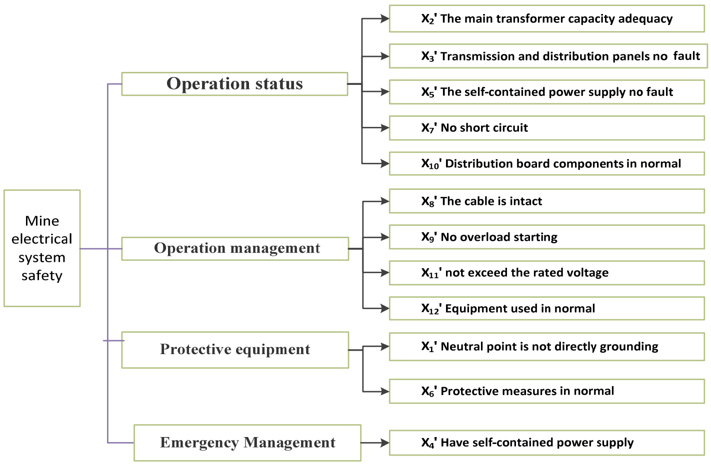

Fig. 2

3.3 Construct judgment matrix according to the hierarchical structure

The method of constructing judgment matrix is: each factor which has a downward affiliation elements as the first element of judgment matrix (located in the upper left corner), Each element attached to it are orderly arranged in the first row and the followed first column.

Using the two two comparison of the structure important degree of n elements in the same level, fill in the judgment matrix. judgment factors in the criterion layer to construct the judgment matrix. Calculate the least common multiple of structure important degree, marked LCM, Judgment factor of each basic event is $\chi(i)=I_\varphi \times LCM$ .Four criterion layers contain a certain amount of factors, so the judgment factor can be represented by the total number of judgment factors of all the basic events.

Through two two comparison of the criterion layer, elements of judgment matrix between the target layer and the criterion layer is determined by the following formula:

$$a_{ij}=\frac{\sum_{i=1}^{n}\chi_\varphi(i)}{\sum_{j=1}^{m}\chi_\varphi(j)}, \text{ and } a_{ji}=\frac{1}{a_{ij}} \qquad (1)$$

In the formula, i, j represent the subscript of judgment matrix (a_{ij}), $i, j=1,2,3,4$; n, m is the number of factors in each index layer. Importance judgments between various factors are represented by integer multiples, so when $a_{ij}\geq 1$, a_{ij} keeps one decimal place.

Similarly, the two two comparison of factors in index layer, judgment matrix can be obtained by the following formula:

$$b_{ij}=\frac{\chi_i}{\chi_j}, \text{ and } b_{ji}=\frac{1}{b_{ij}} \qquad (2)$$

In the formula, i, j represent the subscript of judgment matrix（b_{ij}）, when $b_{ij} \geq 1$, b_{ij} keeps one decimal place.

3.4 Calculate the weight and comprehensive evaluate factors

According to the summation of factors in each index layer,get the judgment factor criterion layer are respectively 19, 15, 20, 6. According to the formula obtained judgment matrix between the index layer and rule layer as shown in the table:

Table 2

A	B1	B2	B3	B4	W
Operation status	1	15/19	20/19	6/19	0.318
Operation management	19/15	1	4/3	2/5	0.247
Protective equipment	19/20	3/4	1	3/10	0.339
Emergency management	19/6	5/2	10/3	1	0.096

According to equation (2), get the weight of each factor in index laye, Combined with the weight of criterion layer, obtain the total weight of Each factor which represents the relative effect on the target layer. From X'_1 to X'_{12}, the weight of the effects on the target layer respectively:

$\{0.0283,0.0106,0.0106,0.0096,0.0318,0.0565,0.0318,0.0124,0.0124,0.0159,0.0124,0.0247\}$

4.Discussion and Suggestion

After using the qualitative and quantitative analysis of AHP based on fault tree model, we can draw: the structure important degree of the basic event “protective device error” (X_6) is the highest. This shows that the protection devices of power supply equipment, power transmission line and power facilities are important for mine electrical safety, protective device exception is extremely easy to cause an accident; A self-contained power supply failure (X_5) and short circuit (X_7) is an important cause of mine electrical accident. In case of a power cut of supply equipment, a self-contained power supply will be timely distribution, avoiding all kinds of potential safety problems due to a sudden power failure. Therefore, the self-contained power supply fault is very easy to cause electric shock or electrical injury accident. Short circuit is often produced by electrical facilities, and it may lead to sparks or leakage, which caused the accident. So to ensure good operation and self-contained power supply to prevent short circuit is very important to the mine safety production; Neutral directly grounding（X_1）and improper use of equipment（X_{12}） belong to protective equipment and operation management, Prevent the ground directly grounded neutral point is an important measure to prevent electrical accidents, and to ensure all equipment reasonable operation is the foundation of the normal operation of the mine; Distribution board component failure（X_{10}）, exceed the rated voltage（X_{11}）, cable failure（X_8）and The load overload starting（X_9）are relatively important for the maintenance of mine electrical safety. It has higher requirements to the power supply facilities, transmission line, power facilities, and need to ensure that there are no short circuit or current anomaly. Lack of storage of the main transformer（X_2）, transmission and distribution plate failure（X_3）, no a self-contained power supply (X_4) are not easy to generate electrical accidents compared with the other basic events. But for this kind of events, it Should do well in management to prevent, and avoid fault.

5.Conclusion

We establish a new model, an improve Analytic Hierarchy Process based on fault tree, to evaluate the mine electrical safety. Fault tree analysis can be applied to risk assessment of mining electrical equipment, but it is difficult to make quantitative analysis accurately. It can express the influence degree of the basic event to the top event, and the weight of index layer in the analytic hierarchy also reflects the importance of the target layer. And we draw a valid conclusion, “Protective equipment” has the biggest effect on the operation safety management, and “Operation status” also has much influence on the safety management. Followed by the effects of “Operation management”, as for “Emergency management”, it has the minimal impact on the electrical safety management. According to the analysis results, we found that attention to the mine electricity supply system security should be mainly in the protection and management of equipment. We respectively from four aspects of “Protective equipment”, “Operation status”, “Operation management” and “Emergency management”, gives reasonable suggestions for electrical safety management, and hope to offer some reference for electrical safety management of mine.

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