Electric Shock Analysis Based on AHP-DEMATEL Model in High-Voltage Switch Room

Song Gao1*, Fuguo Jin1, Yuanbo Zhang1, Xiwen Yao2 and Xinyue Pei2

1 State Grid LiaoNing Electric Power Supply CO. LTD., Shenyang, 110006 China
2 School of Resources and Civil Engineering, Northeastern University, Shenyang, 110819 China
Email: 13889286262@163.com

Abstract. Electric shock accident in high-voltage switch room based on AHP-DEMATEL was analyzed. In order to solve the problem that the AHP method is too subjective and lacks the consideration of the indirect influence between events, the AHP-DEMATEL method is constructed by introducing the comprehensive weight in combination with DEMATEL. Taking the electric shock accident in high-voltage distribution room as an example, 16 accident causing factors were identified firstly, then the weight of each factor was calculated by AHP method, and the interaction between the factors was analyzed by DEMATEL method. Finally, the AHP-DEMATEL method is used to obtain the causation factors, and the comprehensive weight under indirect influence is considered. It is concluded that leakage protection failure, operating tool insulation damage and illegal live working are the important causation factors of the accidents, which provide help for the distribution of high voltage electric shock accident prevention.

Keywords. Analytic hierarchy process (AHP), Decision-making trial and evaluation laboratory (DEMATEL), switching room, prevention of accidents, hazard identification.

1. Introduction
The switch room is a high-voltage place, which is generally set as a Class A hazard source point by the unit, and is usually used as a key part of safety management, and it is required that the staff must be certified to work. [1] Accidents in switch rooms are mainly due to lax safety awareness, ineffective implementation of rules and regulations, and operational errors. In addition, the consequences of accidents caused by them are often more serious. The injury accidents that may occur in the high-voltage switch room include electric shock, fire, explosion, object strike, mechanical injury, burning, noise, etc. Therefore, it is necessary to analyze the hazards in the switch room systematically, so as to further improve the safety of the switch room and reduce its risk.

At present, the commonly used risk identification and evaluation methods include Accident Tree Analysis [2], Event Tree Analysis [3], Analytic Hierarchy Process [4], LEC [5], Layer of Protection Analysis [6], Set Pair Analysis [7], etc. Analytic hierarchy process (AHP) is a widely used risk assessment method. Through the comparison of two factors, we can get the relative weight of each factor, but it lacks the indirect influence between each factor. Decision-making Trial and Evaluation Laboratory (DEMATEL) is an analysis method oriented to the analysis of complex system factors. The algorithm analyzes the causal relationship between various factors of the complex system and distinguishes the importance relationship between them. Therefore, it is widely used in system engineering and management science.[8] Therefore, in order to solve the insufficient analysis and
consideration caused by a single evaluation method, two or more evaluation methods are usually used at the same time to make the risk identification more comprehensive.

In this paper, based on the fault tree, the AHP-DEMATEL method is used to further construct the hazard evaluation system in switch room. According to this system, the weights of each index of hazard in the switch room are identified, so as to guide the safety management work in the switch room and reduce risks.

2. AHP-DEMATEL Model

2.1. Establishment of Index System

According to the relevant accidents and their causation factors, the fault tree models of the accidents are established. Based on the basic events that caused the accidents, the top event is regarded as the target layer in AHP. According to the classification of personnel, machinery equipment, protective measures and safety management, they are regarded as the criterion layer in the index system, and the basic events in the fault tree model are taken as the index layer in AHP.

2.2. Construct the AHP Judgment Matrix

Through the established AHP index system, the factors causing the accidents are compared in pairs, and the judgment matrix of the accident is constructed. Using the scale of 1 ~ 9, as shown in table 1, the judgment matrix A is obtained by comparing the various causation factors in pairs.

\[ A = (a_{ij})_{n \times n} \quad a_{ij} = A_i / A_j \]

The judgment matrix has the following properties:

1. \( a_{ij} > 0 \)
2. \( a_{ij} = 1 / a_{ji} \)
3. \( a_{ii} = 1 \) \((i = j)\).

Psychological research shows that the vast majority of people generally have five levels of ability to distinguish differences in the same attributes. Therefore, people usually use the same, slightly strong, strong, very strong, and extremely strong to express the difference in the same attributes of things. Therefore, this paper uses a scale of 1-9 to represent these five judgments, and can be further subdivided into 2, 4, 6, and 8 to represent their relative compromise judgments. Thus, the importance of each part can be obtained through the judgment matrix.

Table 1. 1~9 scale.

|   | Indicates that two elements are equally important |
|---|--------------------------------------------------|
| 1 | Indicates that one element is slightly more important than the other |
| 3 | Indicates that one element is obviously more important than the other |
| 5 | Indicates that one element is strongly more important than the other |
| 7 | Indicates that one element is extremely more important than the other |

2.3. Construct the DEMATEL Influence Matrix

The DEMATEL influence matrix usually uses scales of 0, 1, 2, 3, 4 to express the relationship between different factors, where 0 means no influence, 1 means weak influence, 2 means normal influence, 3 means strong influence, and 4 means extremely strong influence. Through the scores and different weights of invited experts in related fields, the direct influence matrix B of the relevant index system under the accident causation factor is obtained. Using the obtained direct influence matrix B and equation (1), the normalized direct influence matrix C is obtained. Finally, equation (2) is used to calculate the comprehensive influence matrix T, so as to calculate the degree of influence \( f_i \), the degree of affected \( e_i \), the degree of cause \( m_i \) and the degree of centrality \( r_i \) of each cause.
\[
c = \frac{1}{\max_{i \leq n} \sum_{j=1}^{n} \beta_{ij}} \sum_{j=1}^{n} \beta_{ij}
\]

In the equation, \( \max_{i \leq n} \sum_{j=1}^{n} \beta_{ij} \) is expressed as the row and maximum value of the initial direct influence matrix B. Through normalization, \( 0 < \alpha_{ij} < 1 \).

Comprehensive influence matrix T:
\[
T = C(I - C)^{-1}
\]

2.4. Determination of AHP-DEMATEL Weight
AHP needs to rely on the experience and actual level of the judge, by considering the relative importance of the two factors in the accident causation factor, so as to obtain the relevant weight. However, AHP did not consider the indirect influence between its factors and the ripple effect caused by the change of an accident factor. In this paper, by combining AHP and DEMATEL, the relative influence of causative factors is added to the relative weight in AHP. Based on this, the AHP-DEMATEL model is constructed, and the comprehensive weight is obtained through calculation, thereby improving the accuracy of the final result. The specific steps are as follows:

1) Use AHP to determine the weight \( W_A \) of each indicator. By comparing the strength and weakness relationship between the accident causation factors, construct a judgment matrix. Then calculate the judgment matrix to obtain the weight of each causation factor and check its consistency, and finally obtain the relative weight \( W_{Ai} \) of each indicator;

2) Use DEMATEL method to determine the influence weight \( W_D \) of each index. After constructing the direct influence matrix, the comprehensive influence matrix T is obtained through calculation, and the degree of influence \( f_i \), the degree of affected \( e_i \), the degree of cause \( m_i \) and the degree of centrality \( r_i \) of each causation factor are calculated. The influence degree \( d_i \) of index i is obtained by equation (3). According to equation (4), the influence weight \( W_{Di} \) of DEMATEL is obtained.

\[
d_i = f_i e_i
\]

\[
W_{D} = d_i / \sum_{i=1}^{n} d_i
\]

3) Determine the comprehensive weight \( W \) of each indicator. Through the AHP and the DEMATEL method, we can obtain the weights \( W_{Ai} \), \( W_{Di} \). According to equation (5), the comprehensive weight \( W \) can be obtained.

\[
W = \sum_{i=1}^{n} \frac{W_{Ai} W_{Di}^{D}}{\sum_{i=1}^{n} W_{Ai} W_{Di}^{D}}
\]

3. Case Analysis
The high-voltage switch room is a high-risk area, which is usually regarded as a key part of safety management, and it is required that the staff must be certified to work. Once the operator's safety consciousness is lax, the rules and regulations are not implemented effectively and the operation error occurs, it will often cause serious consequences. In this paper, the AHP-DEMATEL method is used to reduce the subjectivity in AHP by comprehensively considering the causes of electric shock accidents in high-voltage distribution room. At the same time, the indirect influence in DEMATEL is used to judge the main causes of electric shock accidents in high-voltage distribution room more accurately, which provides further guidance for safety management and operation procedures of distribution room.

3.1. Establishment of Index System of Electric Shock Accident in High-Voltage Switch Room
Through the establishment of high-voltage switch room electric shock fault tree, as shown in figure 1, symbol meaning is shown in table 2. The establishment of the index system for high-voltage switch room is based on the 16 basic events in the fault tree, and the top event in the fault tree is taken as the target level in the index system to express the desired result. According to the classification of personnel, power equipment, protective equipment, and safety management, they are regarded as the criterion layer in the index system to express the influence weight of each part on its target layer. Finally, 16 basic events are taken as 16 indicators to further subdivide the criteria layer. In the criterion layer, personnel include: incorrect wearing of protective equipment, power transmission without observing whether someone is working, and no safety communication between operators and operators on duty; power equipment includes: leakage protection failure, neutral line touching the shell, three-phase serious imbalance, point display device failure; protective equipment includes: insulation damage of operating tools, circuit breaker failure, isolation switch failure, grounding wire is not connected, grounding wire is disconnected; safety management includes: the quality of protective articles is not up to standard, the live shell is contacted without electricity inspection, the live working is against regulations and the operation is not listed. The establishment of AHP-DEMATEL index system is shown in figure 2.

| Symbol | Meaning                                      | Symbol | Meaning                                      | Symbol | Meaning                                      |
|--------|----------------------------------------------|--------|----------------------------------------------|--------|----------------------------------------------|
| T      | Electric shock in high-voltage switch room  | D_4    | Shell is not grounded                        | X_7    | The neutral line touches the shell           |
| A_1    | Personnel in contact with electrified bodies| E_1    | Mistransmission                              | X_8    | Serious three-phase imbalance                |
| A_2    | Failure of human protection measures         | E_2    | Working part is not grounded                 | X_9    | Fault of live display device                |
| B_1    | Personnel touching live parts in the device  | E_3    | Mistakenly think that the device cabinet is  | X_10   | Circuit breaker failure                     |
|        | cabinet                                      |        | powered off                                  |        |                                              |
| B_2    | Personnel touching the shell of live device  | X_1    | Unqualified protection products              | X_11   | Disconnector failure                        |
|        | cabinet                                      |        |                                              |        |                                              |
| C_1    | Device cabinet is live                       | X_2    | Improper wearing of protective equipment     | X_12   | Ground wire not connected                   |
| C_2    | The shell of the device cabinet is live     | X_3    | The insulation of operating tools is         | X_13   | The ground wire is disconnected             |
|        |                                              |        | damaged                                      |        |                                              |
| D_1    | The equipment is accidentally energized     | X_4    | Touch the live shell without checking        | X_14   | Unlisted operation                          |
|        | during power off operation                  |        |                                              |        |                                              |
| D_2    | Mistakenly think that the device cabinet is  | X_5    | Leakage protection failure                   | X_15   | Send power without observing whether        |
|        | powered off                                  |        |                                              |        | someone is working                          |
| D_3    | Device cabinet is live                       | X_6    | Illegal live work                            | X_16   | No safety disclosure between operator and   |
|        |                                              |        |                                              |        | operator on duty                            |

Table 2. Event symbols and meanings in fault tree.
Figure 1. Fault tree of electric shock accidents in high-voltage switch room.

Figure 2. AHP index system.
3.2. AHP Analysis

According to the basic principles of analytic AHP, a judgment matrix is constructed in terms of personnel A, power equipment B, protection equipment C and safety management D. The structure of the judgment matrix is as follows:

\[
\begin{bmatrix}
1 & 1/3 & 1/7 & 1/7 \\
3 & 1 & 1/5 & 1/3 \\
7 & 5 & 1 & 1/2 \\
7 & 3 & 2 & 1
\end{bmatrix}
\]

According to the square root method, the eigenvalues obtained by the computer program are:

\[
W^A = [0.052, 0.121, 0.369, 0.459]
\]

The consistency ratio C•R is 0.06 less than 0.10, so the assignment is reasonable. Similarly, for the three index levels in personnel, four index levels in power equipment, four index levels in protective equipment, and four index levels in safety management, the judgment matrix is constructed as follows:

\[
\begin{bmatrix}
1 & 7 & 5 & 1 \ 17 & 1 & 3 & 1/3 \ 1/5 & 1/3 & 1 & 7
\end{bmatrix}
\]

\[
\begin{bmatrix}
1 & 1/3 & 1 & 1/3 & 2 \\
1/3 & 1 & 1 & 1 & 2 \\
1/2 & 3 & 1 & 1 & 3
\end{bmatrix}
\]

\[
\begin{bmatrix}
1 & 3 & 1/7 & 1/5 \\
3 & 1 & 1/5 & 1/3 \\
7 & 5 & 1 & 2
\end{bmatrix}
\]

3.3. DEMATEL Analysis

The use of AHP analysis can only judge the relative weight between the two factors, but lacks the indirect influence between the various causative factors. Therefore, in the established index system, DEMATEL is introduced to increase the consideration of indirect influence, so as to make the relative weight of each causative factor more accurate. According to the 16 accident causation factors proposed in this paper, the direct influence matrix B is constructed as table 3:

| Factor | A1 | A2 | A3 | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 | C5 | D1 | D2 | D3 | D4 |
|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| A1     | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| A2     | 1  | 0  | 4  | 1  | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| A3     | 1  | 2  | 0  | 1  | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 4  | 3  |
| B1     | 3  | 1  | 1  | 0  | 4  | 1  | 2  | 4  | 2  | 2  | 1  | 1  | 1  | 1  | 1  |
| B2     | 3  | 1  | 1  | 1  | 0  | 3  | 4  | 1  | 1  | 1  | 4  | 4  | 1  | 4  | 1  |
| B3     | 1  | 1  | 1  | 4  | 1  | 0  | 4  | 1  | 3  | 1  | 3  | 3  | 1  | 1  | 1  |
| B4     | 3  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| C1     | 2  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 3  | 1  | 1  | 1  | 1  |
| C2     | 1  | 1  | 1  | 4  | 1  | 2  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  |
| C3     | 1  | 1  | 1  | 1  | 4  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  |
| C4     | 1  | 1  | 1  | 4  | 1  | 4  | 1  | 1  | 1  | 0  | 4  | 1  | 4  | 4  | 1  |
| C5     | 1  | 1  | 1  | 4  | 4  | 1  | 1  | 1  | 1  | 0  | 3  | 4  | 4  | 1  | 1  |
| D1     | 1  | 1  | 1  | 2  | 1  | 1  | 1  | 4  | 1  | 1  | 1  | 1  | 0  | 1  | 1  |
| D2     | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 4  | 2  |
| D3     | 3  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 3  |
| D4     | 1  | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  |

Through the calculation of equation (2), the degree of influence, degree of affected, degree of cause, and centrality of each causation factor can be obtained, as shown in table 4. Finally, the weight of each accident causation factor can be calculated by using equation (3) and (4), as shown in table (5).
Table 4. DEMATEL Results.

| Factor | Influence degree | Affected degree | Cause degree | Centrality | Centrality ranking |
|--------|------------------|-----------------|--------------|------------|-------------------|
| A_1    | 2.063            | 2.765           | -0.702       | 4.828      | 10                |
| A_2    | 2.301            | 2.096           | 0.206        | 4.397      | 14                |
| A_3    | 2.597            | 2.260           | 0.337        | 4.857      | 9                 |
| B_1    | 3.343            | 3.441           | -0.098       | 6.784      | 1                 |
| B_2    | 3.654            | 2.285           | 1.370        | 5.939      | 5                 |
| B_3    | 3.393            | 3.200           | 0.194        | 6.593      | 2                 |
| B_4    | 2.053            | 2.679           | -0.627       | 4.732      | 11                |
| C_1    | 2.167            | 2.548           | -0.381       | 4.714      | 12                |
| C_2    | 2.417            | 2.556           | -0.139       | 4.973      | 8                 |
| C_3    | 2.280            | 1.998           | 0.282        | 4.278      | 15                |
| C_4    | 3.782            | 2.587           | 1.195        | 6.369      | 4                 |
| C_5    | 3.555            | 2.934           | 0.620        | 6.489      | 3                 |
| D_1    | 2.301            | 2.338           | -0.036       | 4.639      | 13                |
| D_2    | 2.275            | 3.338           | -1.063       | 5.613      | 6                 |
| D_3    | 2.351            | 3.213           | -0.862       | 5.564      | 7                 |
| D_4    | 1.971            | 2.267           | -0.296       | 4.238      | 16                |

3.4. Comprehensive Weight of Electric Shock Accident in High-Voltage Switch Room

Using equation (5), calculate the comprehensive weight of each accident causation factor, as shown in the following table. And draw the weight analysis diagram, as shown in figure 3.

Table 5. Weight of each analysis method.

| Factor | AHP weight | DEMATEL weight | Comprehensive weight |
|--------|------------|----------------|---------------------|
| A_1    | 0.038      | 0.050          | 0.032               |
| A_2    | 0.009      | 0.042          | 0.006               |
| A_3    | 0.005      | 0.051          | 0.004               |
| B_1    | 0.067      | 0.101          | 0.113               |
| B_2    | 0.012      | 0.073          | 0.015               |
| B_3    | 0.005      | 0.095          | 0.008               |
| B_4    | 0.036      | 0.048          | 0.029               |
| C_1    | 0.160      | 0.048          | 0.129               |
| C_2    | 0.048      | 0.054          | 0.043               |
| C_3    | 0.060      | 0.040          | 0.040               |
| C_4    | 0.057      | 0.086          | 0.082               |
| C_5    | 0.044      | 0.091          | 0.067               |
| D_1    | 0.045      | 0.047          | 0.035               |
| D_2    | 0.032      | 0.067          | 0.036               |
| D_3    | 0.243      | 0.066          | 0.269               |
| D_4    | 0.139      | 0.039          | 0.091               |
Through the comprehensive weight calculated by AHP-DEMATEL, it can be seen that AHP only compares two factors without considering the interaction and influence between various causative factors. Therefore, the comprehensive weight after introducing DEMATEL is more comprehensive than the weight obtained by AHP alone. It can be seen from the results that the leakage protection fails B1, the damage of the insulation of operating tools C1 and illegal live working D3 account for a large proportion, while the proportion of leakage protection fails and illegal live working in AHP-DEMATEL increases, and the damage of insulation of operating tools decreases. Therefore, it can be seen that the causation factors of the increase in the proportion have a greater impact on other causation factors, while the causation factors of the decrease in the proportion indicate that the indirect influence with other causation factors is small, and the proportion has decreased.

4. Conclusions
(1) By introducing the DEMATEL method, the AHP-DEMATEL method is constructed. AHP-DEMATEL method makes up for the problem that AHP method does not consider the indirect influence in the analysis of accident causes, and makes the analysis results more accurate.
(2) Using the weight difference between AHP-DEMATEL and AHP, we can see that the indirect impact is relatively weak, but the indirect impact will be more significant in the case of complex system or more factors.
(3) The AHP-DEMATEL method is used to analyze the electric shock accidents in the high-voltage switch room, and it is concluded that leakage protection failure B1, operating tool insulation damage C1, and illegal live working D3 are the important causation factors of the accidents, and measures should be taken to prevent the occurrence of the above events.

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