Research Article

Resilience Capacity Evaluation for the Safety Management System of Power Grid Enterprise Based on AHP-MEE Model

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Received 28 December 2021; Revised 27 March 2022; Accepted 30 March 2022; Published 13 July 2022

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With the rapid development of urbanization and modernization, people’s requirements for electric power are also consequently increasing. It is thus essential to ensure the sustainable and stable supply of power and maintain the safety performance of the power grid. Constructing a modern safety management system (SMS) can effectively improve power enterprises’ ability to respond to emergencies. To effectively evaluate the ability of electric power enterprises to resist risk impact, and the recovery and optimization ability after impact, this paper makes a systematic investigation of the SMS of power enterprises. It evaluates the safety resilience capabilities of the SMS from four basic elements of stability, redundancy, efficiency, and adaptability. A multilevel evaluation system of electric power enterprises’ safety resilience capacity consists of four first-level and 25 second-level indices. Then, an analytic hierarchy process (AHP) and matter-element extension (MEE) joint model—the AHP-MEE evaluation model of the resilience capacity of power enterprises—is proposed. A case study of electric power enterprise safety resilience evaluation is conducted using the proposed resilience evaluation index system and assessment model. The results showed that the provided model agrees with the actual situation and verified the index system and model for electric power enterprise safety reliability and applicability. Improved enterprise safety resilience recommendations are proposed accordingly based on the evaluation results. This work proposes a robust safety resilience capacity evaluation method in the face of upcoming new risks, thus building a good working foundation to construct a new power system with new energy sources.

1. Introduction

The safety of power infrastructure is a concern in many countries. In recent decades, there have been many severe electrical safety incidents, such as the great blackouts of the United States and Canada, the blackout in London in 2003, the blackout in Western Europe in 2006, the blackout in China in 2008, and the blackout in Venezuela in 2019. These accidents always result in significant economic losses and even casualties [1]. Afterward, countries worldwide realized the importance of the power grid’s resilience and other vital infrastructure to withstand major safety risks and gradually shifted their focus from simple disaster prevention to enhancing the power grids’ ability to recover from disasters and accidents. Concurrently, along with China’s primary energy strategy of “carbon peak” and “carbon neutrality,” the development momentum of large-scale grid connection of new energy and clean energy and massive access to new energy facilities has strengthened [2]. The form of the power grid has become increasingly complex, and the pressure on risk prevention and control is increasing. Higher standard requirements are proposed to improve the power grid’s ability to deal with sudden disasters, reduce the risk and loss of large-scale power outage accidents, and guarantee the power grid’s reliability to the maximum extent [3–5].

A safety management system (SMS) can be described as a planned, documented safety program that incorporates basic management concepts and activating elements into a well-
organized safety system [6], which becomes a standard tool in the safety management of large electric companies in China. Many studies have been performed from different perspectives on the design, construction, and modeling of the SMSs [5, 6]. Collier [4] proposed a ten-step plan to create a modern, intelligent, and agile power grid system based on the practical reasons for constantly changing electricity demand and frequent failures of power lines and equipment, which provides a new idea and method for power enterprises to implement intelligent management. Lu et al. [5] identified the basic concepts of power grid operation safety management, described the relationship between different standardized terms through the Venn diagram method, and finally proposed a set of standardized concept systems of power grid operation safety risk management.

For electric power enterprises, the ability to resist risk impact and recover and optimize after impact is an integral part of the safety management level of the power system. Xie et al. [7] simulated the grid bearing capacity under extreme weather, analyzed grid vulnerability and risk tolerance under different environments, and identified the nodes and lines that are highly vulnerable to extreme weather, providing theoretical support for preventing and reducing the impact of extreme weather on the grid. Bian et al. [8] dynamically analyzed the evolution process from the cause to the result of power grid trip accidents and quantitatively calculated the probability of power grid trip accidents caused by natural disasters, providing technical support for the prevention, treatment, and recovery of power grid trip accidents. Although many efforts have been made in constructing SMS, the previous studies primarily investigated accident response and theoretical surveys; few addressed emergency prevention and the recovery capacity from a disaster, which is unfavorable to the safety management of the power grid. It is vital to evaluate the ability to “cope with disasters” of power grids affected by emergencies and to study how to improve the ability of the power grid to manage emergencies and ultimately achieve the goal of maintaining power grid performance after recovering from accident losses. It is critical to study and construct an emergency safety management system for power grids with resilience.

In this paper, we reconstruct the power grid emergency state and SMS by introducing the concept of "resilience." Based on the resilience theory, an optimized AHP-MEE safety resilience capability assessment model is provided to evaluate the electric power enterprise’s ability to deal with emergencies. Engaged in the former matter and afterward, the three stages of response blind spot existing in the safety management system, a corresponding power grid system construction is proposed. This process provides the theoretical basis for constructing an emergency safety management system and has fundamental practical significance for developing a modern safety management system.

2. Basics of the Resilience Theory

The resilience theory has become an essential theoretical foundation in some frontier disciplines and is expected to be integrated into more disciplines [9–12]. A power system’s recovery ability, disaster resistance ability, and postdisaster response ability after suffering various types of accidents and disasters embody its macro-resilience ability. Resilience, as an inherent capability of the system, emphasizes a system’s ability to absorb, adapt, recover, and improve external disturbances and has attributes such as situational awareness, resistance, robustness, responding capacity, recovery, timeliness, and learning ability [13–16].

2.1. Concept of System Safety Resilience. For a system, safety defense and postrecovery capabilities are essential factors that affect system resilience. Therefore, safety resilience is a valuable research subject at the intersection of resilience science and safety science. Bergrström et al. [17] discussed the rationality and necessity of applying resilience theory in safety science. They believed that system safety resilience is a dynamic system attribute closely related to continuous adjustment and adaptability, developed based on vulnerability, safety capacity, and safety redundancy. System safety resilience refers to the ability of the system to absorb and adapt to external disturbances to maintain its stable safety state. It also reflects the system’s resilience, learning, and adaptability, as shown in Figure 1 [18]. System safety resilience is an essential attribute of system safety and is a critical approach to comprehensively understanding the safety attributes of complex systems [19].

Generally, system safety resilience elements can be divided into the following parts, which jointly determine the safety resilience of the system [20].

(I) Stability is the ability of the system to withstand risk shocks and disturbances before failure

(II) Redundancy is the ability of the system to replace parts or components affected by risk and interference

(III) Efficiency is the speed at which the system recovers from the damaged state to the initial state

(IV) Adaptability is the ability of the system to identify safety problems and determine priorities, and the ability to mobilize emergency and disaster relief resources can be further summarized as the availability of human, material, and financial resources in the face of an accident.

The interaction patterns between these four resilience elements and the existing organizational member system, material technology system, management system, and environmental system in the SMS of the enterprise are shown in Figure 2.

2.2. Framework of System Safety Resilience. Based on this analysis, indicators can be defined by the dynamic response curves of the system before, during, and after the event to build the basic framework of enterprise system safety resilience, as shown in Figure 3 [21].

According to Figure 3, when $0 < t < t_1$, the system is in the original safety state. When the disaster-bearing capacity...
of the system cannot absorb risks, $t_1$ is subjected to risk shock and disturbance [21].

(1) When the risk disturbance and destruction exceed the maximum total risk (safety capacity) borne by the system to maintain safe operation, accidents occur, the system is damaged, and the system enters the damage stage ($t_1 < t < t_3$). At $t_3$, recovery measures are performed, and the system enters the recovery stage ($t_3 < t < t_4$). In the recovery phase, the system may or may not recover to presafety state point B and can also improve its safety resilience and recover to a better safety state point A.

(2) The disaster-bearing capacity of the system cannot absorb risk, resulting in damage and loss of the system, and the system cannot recover to the initial safety state but a new state point C. The system still cannot withstand future risk shocks.

(3) The disaster-bearing capacity of the system is sufficient to absorb the risk impact so that no damage or loss occurs. At this time, the system can maintain its presafety state at B and improve its resilience function at A through learning the ability to cope with risk shocks to manage more intense risk shocks in the future.

The quantification of system safety resilience is conducive to applying safety resilience theory. When an accident occurs, the safety state of the system will be broken, and the recovery time and efficiency of the system safety state will depend on the safety resilience capacity of the system.

3. Modern SMS for Electric Power Enterprises

With the diversified development of safety theories, accident causation theory, accident causation linkage theory, and safety resilience theory have been applied to the construction of enterprise safety management systems. We now consider the Zhejiang Electric Power Corporation in China as an example. Through continuous exploration and practice, the enterprise gradually formed a diversified and highly flexible modern SMS called the “1438” management system, where

Figure 1: Connotation analysis of system safety resilience.

Figure 2: System safety, resilience, and the mode of action of subsystems.
“1” represents the building mainline of the diversified and integrated high-flexibility power grid; “4” represents the four guidelines of safety policy, safety objective, safety culture, and safety theory; “3” represents the construction of safety organization system, safety work system, safety rules, and regulations system of three systems; and “8” refers to the improvement of organizational management, team quality, and other eight capabilities. These numbers are the premise of building a “three” system composition.

As shown in Figure 4, the premise of the construction and implementation of an SMS is to establish a safety policy, safety objectives, and safety culture based on safety theory. Establishing the safety organization system, safety work system, and rules and regulations clarifies and improves the responsibility, work content, and management basis of enterprise safety management [22, 23]. The details are as follows.

1. The safety organization system is supported by the safety responsibility system led by the safety production committee by creating a safety assurance system, supervision system, and assurance system to fulfill the safety subject responsibility, supervision and coordination responsibility, and support responsibility, respectively.

2. The safe working system aims to achieve continuous improvement and improvement by creating the working thread of preprevention → in-process control → postprocess treatment, supplemented by external cooperation.

3. The safety rules and regulations system is essential for constructing a safety organization system and work system. The timeliness and accuracy of this system are guaranteed by constantly supplementing the on-site regulations and timely following up on the latest laws and regulations, rules and regulations, and technical standards.

In addition, to ensure the safety organization system and a safety work system, rules and regulation system is correctly constructed and implemented. As shown in Figure 5, constructing a modern SMS of electric power enterprises improves the eight capabilities of organization management, team quality, source prevention, hidden trouble rectification, risk control, emergency response, scientific and technological innovation, and safety investment. To ensure the rationality of capacity building, the safety performance index, safety management index, rules and regulations implementation index, and scientific and technological innovation index are set in each capacity-building improvement process [24].

Although the existing SMS of electric power enterprises is performed based on the three aspects of the organization, system, and safety work, four representative indices, eight capabilities, and 15 safety evaluation indices are proposed to construct the system. However, the system’s resilience level cannot be directly determined by evaluating the above indicators in response to emergencies. Therefore, from the perspective of “safety resilience,” the safety evaluation index is organically combined with four resilience factors: stability, redundancy, efficiency, and adaptability. Additionally, the safety resilience of enterprises is quantified by safety evaluation [25].

4. Construction of the Resilience Evaluation Model

A complex system engineering is used to construct electric power enterprises’ resilience capacity assessment model.
Based on the principles of science, objectivity, and systems, and combining the characteristics of electric power enterprises, this paper integrates the modern safety management system and system safety resilience theory. To ensure the rationality of the model, this paper reconstructs the existing evaluation index system from the perspective of safety resilience. It uses the analytic hierarchy process (AHP) and matter-element extension model to divide and quantify the indices, starting from the four elements of stability, redundancy, efficiency, and adaptability. An enterprise safety resilience assessment model composed of several primary and secondary indicators is constructed. The evaluation process is shown in Figure 6 [26].

4.1. Determination of Safety Resilience Evaluation Index. To effectively assess the safety resilience level of an enterprise, this paper refines the safety resilience elements of each index based on the 15 safety evaluation indicators of the existing safety management system. Four safety resilience elements are used to assess enterprise safety resilience. The 25 refined evaluation indicators are used as the second-level indicators for the first-level indicators. The corresponding relationship between the first-level indicators and the second-level indicators is established from safety resilience. Table 1 shows the refined resilience evaluation indicators [27].

The resilience evaluation indicators are considered secondary indicators and divided according to stability, redundancy, efficiency, and adaptability. The results of the classification are shown in Figure 7.

4.2. Determination of Indicator Weight. The basic principle of using AHP to divide indicators in this paper is now described. Experts construct a $4 \times 4$ judgment matrix for each indicator’s resilience elements, scale them, and then use the root-finding method to find its eigenvectors and conduct consistency tests. This method determines whether the experts are inconsistent when judging the importance of the index [28]. For an expert who passes the consistency test, the eigenvector of the judgment matrix constructed by the expert is the effective weight vector assigned by the expert to each resilience element in a specific index. The effective weights assigned by all experts who passed the consistency test are averaged according to the indicators. Then, the safety resilience weights determined by the expert group can be obtained. The resilience element with the most considerable weight is determined as the primary relevant element of the indicator [29].

The analytic hierarchy process is divided into the following steps to determine the weight.

1. Clarify the problem and establish a hierarchical structure...
Construct a pairwise comparison judgment matrix (see Table 2).

\[ M = (a_{ij})_{mn}, \]  

where \( a_{ij} \) is the expert’s comparison result of index factors \( i \) and \( j \).

The weight vector is calculated from the judgment matrix, and the consistency test is performed.

1. Integrate the judgment matrix \( M \) by rows and then find the roots to obtain the vector \( V \)

\[ v_i = \prod_{j=1}^{n} a_{ij}, \quad i = 1, 2, \ldots, m. \]  

2. Normalize the vector \( V = [v_1, v_2, \ldots, v_m]^T \) to obtain the eigenvector \( W \) of the judgment matrix \( M \)

\[ w_i = \frac{v_i}{\sum_{i=1}^{m} v_i}. \]  

3. Calculate the maximum eigenvalue \( \lambda_{\text{max}} \) of the judgment matrix \( M \)

\[ \lambda_{\text{max}} = \frac{1}{m} \sum_{i=1}^{n} \left( \frac{(MW)_i}{w_i} \right). \]  

where \( (MW)_i \) is the \( i \)-th element of the vector \( MW \).

4. Calculate the consistency index \( CI \) of the judgment matrix \( M \)

\[ CI = \frac{\lambda_{\text{max}} - m}{m - 1}. \]  

5. Calculate the random consistency ratio \( CR \) and judge the consistency of matrix \( M \); the value of \( RI \) is shown in Table 3.

\[ CR = \frac{CI}{RI}. \]  

If the consistency index \( CI \) and the average random index \( RI \) ratio are less than 0.1, the consistency test is satisfied.

4. Determine the weight

Anyone who passes the consistency test is an expert who effectively weights the evaluation index. The eigenvector \( W = [w_1, w_2, \ldots, w_m] \) of the constructed judgment matrix \( M \) is the effective weight vector assigned to the evaluation index. Those who fail the consistency test are experts who provide the evaluation index with an invalid weight. According to the evaluation index, the arithmetic mean of the effective weight assigned by each effective weighting expert in the expert group to the corresponding index is
4.3. Multilevel Extension Evaluation of Enterprise Safety Resilience

4.3.1. Determination of Classical Domain, Node Domain, and Matter to be Evaluated. A resilience evaluation index system composed of various indicators “ci” was developed, and \( U = \{u_1, u_2, u_3, u_4\} \) was used to represent the enterprise safety resilience level domain, as shown in Table 4 [30, 31].

(1) **Determine the Classical Domain.** We let \( R_g \) be the classical domain of the matter element \( R \), as follows:

\[
R_g = \left[ U_g, C, V_g \right] = \left[ \begin{array}{c}
U_g \\
\langle a_{g1}, b_{g1} \rangle \\
\vdots \\
\langle a_{gm}, b_{gm} \rangle
\end{array} \right],
\]

where \( U_g \) is the \( g \) safety level in the enterprise safety resilience level domain \( U = \{g = 1, 2, \ldots, l\}; V_g \) is the value range of the evaluation index set \( C \) regarding the safety resilience level \( U_g; a_{gm} \) and \( b_{gm} \) are indicators; and \( c_i \) is the lower limit and upper limit of the \( g \) safety resilience level, respectively.

(2) **Determine the Section Domain.** We let \( R_n \) be the node domain of the matter element \( R \), as follows:
where $V_n$ is the value range of the evaluation index set $C$ concerning the resilience level domain $U$, and $a_{ui}$ and $b_{ui}$ represent the lower limit and upper limit of the index $c_i$, respectively, at all resilience levels.

(3) Determine the Evaluation Matter Element. $R_i$ is the matter element to be evaluated for matter element $R$, as follows:

$$R_i = [c_i, C_i, V_i] = \begin{bmatrix} c_1 & \langle a_{u1}, b_{u1} \rangle \\ \\ c_2 & \langle a_{u2}, b_{u2} \rangle \\ \\ \vdots & \vdots \\ \\ c_m & \langle a_{um}, b_{um} \rangle \end{bmatrix}, \quad (9)$$

where $c_i$ is the $i$-th first-level indicator to be evaluated for the level of corporate resilience; $C_i = \{c_{i1}, c_{i2}, \ldots, c_{im}\}$ is the set of second-level evaluation indicators for $c_i$, where $c_{ij}$ is the $j$-th second-level indicator of the $i$ evaluation index; $v_{ij}$ is the evaluation and assignment value of $c_{ij}$ by the expert, and $v_i$ is the set of evaluation and assignment values of each secondary evaluation index of $c_i$ by the expert.

4.3.2. Evaluation of Secondary Index Safety Resilience

(1) Calculate the relevance of secondary evaluation indicators. The degree of relevance represents the closeness of the object element to be evaluated to the classical domain. The concept of classic mathematics mid-distance is introduced to establish the correlation function of the second-level evaluation index $c_{ij}$ of the company’s safety resilience evaluation with the company’s safety resilience level $U_g$. Then, the first level can be calculated. The degree of relevance $K_g(c_{ij})$ of the $j$th secondary index of the index $c_i$ for the safety resilience level $U_g$ ($g = 1, 2, \ldots, l$) is as follows:

### Table 1: Refinement of existing safety evaluation indicators.

<table>
<thead>
<tr>
<th>Number</th>
<th>Existing safety evaluation indicators</th>
<th>Resilience factor</th>
<th>Resilience evaluation index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organizational completeness index</td>
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<td>2</td>
<td>Responsibility matching index</td>
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<td>Safety supervision work implementation rate indicators</td>
</tr>
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<td>Source prevention indicators</td>
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<tr>
<td>5</td>
<td>Safety incident evaluation index</td>
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<td>Two measures plan completion rate indicators</td>
</tr>
<tr>
<td>6</td>
<td>Completion index of rules and regulations</td>
<td>Stability index</td>
<td>Indicators of completeness of rules and regulations</td>
</tr>
<tr>
<td>7</td>
<td>Hidden danger rectification index</td>
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<td>8</td>
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<td>Efficiency index</td>
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</tr>
<tr>
<td>9</td>
<td>Emergency response indicators</td>
<td>Efficiency index</td>
<td>Emergency response capability capacity evaluation indicators</td>
</tr>
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<td>10</td>
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<td>Adaptability index</td>
<td>Special exercise coverage index</td>
</tr>
<tr>
<td>11</td>
<td>Risk control indicators</td>
<td>Adaptability index</td>
<td>Equipment and operation risk control indicators</td>
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<td>12</td>
<td>Lean indicators for safety investment</td>
<td>Efficiency index</td>
<td>Risk assessment indicators</td>
</tr>
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4.3.3. Evaluation of First-Level Index Safety Resilience

(1) Calculate the relevance of the first-level evaluation index. The correlation matrix \( K(c_i) \) of the first-level evaluation index \( c_i \) of enterprise resilience to each safety resilience level is related to the weight vector \( W_{ij} \) of each second-level evaluation index and the correlation matrix \( K(c_{ij}) \) of the second-level evaluation index to each safety resilience level. We then multiply the values as follows:

\[
K(c_i) = W_{ij} K(c_{ij}) = (w_{ij})^T (k_{ij}(c_{ij}))
\]

(2) The method for determining the safety resilience level of the first-level evaluation index is the same as above.

4.3.4. Evaluation of the Company’s Comprehensive Safety Resilience

(1) Calculate the comprehensive correlation degree of enterprise safety resilience. The comprehensive correlation degree \( k(c) \) of enterprise safety resilience to each safety resilience level is multiplied by the weight vector \( W = (w_i) \) of each first-level index and

\[
k(c) = \sum_{i=1}^{n} w_i k_i(c_i)
\]
5.1. Basic Profile of Case Company.

5.2. Resilience Assessment

5.2.1. Classic Domain, Knot Domain, and Determination of Matter to be Evaluated

(1) Determine the Classic Domain $R_c$. Based on the literature, we summarized the research content related to resilience done by the predecessors, combined the opinions of experts in the safety field, divided the enterprise’s resilience capability level boundary, and obtained the enterprise safety resilience level domain $U$. Thus, the classical domain $R_c$ of each level of power, the enterprise is determined by formula (7) as follows [27]:

\[
R_1 = \begin{bmatrix}
U_1 & c_1 & \langle 8, 10 \rangle \\
c_2 & \langle 8, 10 \rangle & c_1 \\
c_3 & \langle 8, 10 \rangle & c_2 \\
c_4 & \langle 8, 10 \rangle & c_3 \\
\end{bmatrix},
R_2 = \begin{bmatrix}
U_2 & c_1 & \langle 6, 8 \rangle \\
c_2 & \langle 6, 8 \rangle & c_1 \\
c_3 & \langle 6, 8 \rangle & c_2 \\
c_4 & \langle 6, 8 \rangle & c_3 \\
\end{bmatrix},
R_3 = \begin{bmatrix}
U_3 & c_1 & \langle 2, 6 \rangle \\
c_2 & \langle 2, 6 \rangle & c_1 \\
c_3 & \langle 2, 6 \rangle & c_2 \\
c_4 & \langle 2, 6 \rangle & c_3 \\
\end{bmatrix},
R_4 = \begin{bmatrix}
U_4 & c_1 & \langle 0, 2 \rangle \\
c_2 & \langle 0, 2 \rangle & c_1 \\
c_3 & \langle 0, 2 \rangle & c_2 \\
c_4 & \langle 0, 2 \rangle & c_3 \\
\end{bmatrix}
\]

(2) Determine Section Domain. $R_u$. The section domain $R_u$ is determined by formula (8) as follows:

\[
R_u = \begin{bmatrix}
U & c_1 & \langle 0, 10 \rangle \\
c_2 & \langle 0, 10 \rangle & c_1 \\
c_3 & \langle 0, 10 \rangle & c_2 \\
c_4 & \langle 0, 10 \rangle & c_3 \\
\end{bmatrix}
\]

(3) Determine the Object to be Evaluated. $R_i$. This article takes the first-level index stability $c_1$ as an example, and the matter element $R_i$ to be evaluated is determined by formula (9) as follows:
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5.2.2. Evaluation Index Weight Calculation

(1) First-Level Indicator Weight Calculation. According to the company’s actual situation, the ten invited experts independently compared the first-level indicators and constructed their judgment matrix to obtain the weight of the first-level indicators in the safety resilience level of the company. Considering expert (1) as an example, the method proceeds as follows.

(1) Determine the target of the analysis as the “overall resilience level of the enterprise” and compare the four elements of safety resilience of the enterprise

(2) Construct a judgment matrix M and determine its characteristic vector

$R_I = \begin{bmatrix} c_1 & c_{11} & 8.46 \\ c_{12} & 8.36 \\ c_{13} & 8.09 \\ c_{14} & 7.91 \\ c_{15} & 8.09 \\ c_{16} & 7.64 \\ c_{17} & 7.73 \\ c_{18} & 6.73 \end{bmatrix}$.\quad (17)

(2) Integrate the judgment matrix $M$ by rows and then find the roots. The method is shown in formula (2), and the matrix $V$ is described by

$V = \begin{bmatrix} 2.3403 & 1.3161 & 0.7598 & 0.4273 \end{bmatrix}^T$.\quad (19)

$CR = \frac{\lambda_{max} - m}{m - 1} = \frac{4.0146 - 4}{4 - 1} = 0.0048$.\quad (22)

(3) The random consistency ratio of the matrix is calculated, and the consistency test is performed

(3) ,O_he random consistency ratio of the matrix is calculated, and the result is as follows:

$CR = \frac{\lambda_{max} - m}{m - 1} = \frac{4.0146 - 4}{4 - 1} = 0.0048$.\quad (22)

(3) The method for calculating the random consistency ratio $CR$ is shown in formula (6), and the results are as follows:

From Table 1, when $m = 4$, $RI$ is 0.89, then

$CR = \frac{0.0487}{0.89} = 0.0054$.\quad (23)

Because $CR = 0.0547 < 0.1$, the judgment matrix $M$ constructed by the experts passes the consistency test.

(4) Determine the weight of each resilience element in the index. Because the judgment matrix $M$ constructed by the experts passes the consistency test, the weighting resilience element is effective. The eigenvector $W$ of the judgment matrix constructed is the weight assigned to its resilience element. Thus, $w_{(11)} = 0.4832$, $w_{(22)} = 0.2717$, $w_{(33)} = 0.1569$, $w_{(44)} = 0.0882$.\quad (20)

$\lambda_{max} = \frac{1}{4} \times (1.9383 + 1.0917 + 0.6302 + 0.3539) = 4.0146$.\quad (21)

$\lambda_{max} = \frac{1}{4} \times (1.9383 + 1.0917 + 0.6302 + 0.3539) = 4.0146$.\quad (21)

Similarly, each of the ten invited experts constructs a judgment matrix independently for each of the second-level evaluation indicators of the company’s safety, resilience, stability, redundancy, efficiency, and adaptability and can be calculated. The weights of the secondary indicators under each primary indicator are shown in Table 7.

The relationship between the level of safety resilience of the company and the first-level indicators is shown in Figure 8.
### Table 5: Basic overview of the resilience ability of empirical objects.

<table>
<thead>
<tr>
<th>First-level index $c_i$</th>
<th>Weights $w_i$</th>
<th>Grade</th>
<th>Secondary indicators $c_{ij}$</th>
<th>Weights $w_{ij}$</th>
<th>Expert points</th>
<th>Relevance of secondary indicators</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organizational completeness index</td>
<td>0.1182</td>
<td>8.46</td>
<td>0.417</td>
<td>-0.227</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Responsibility matching index</td>
<td>0.1556</td>
<td>8.36</td>
<td>0.286</td>
<td>-0.182</td>
</tr>
<tr>
<td>Stability index 0.2625</td>
<td>1</td>
<td></td>
<td>Safety supervision work implementation rate indicators</td>
<td>0.1068</td>
<td>8.09</td>
<td>0.050</td>
<td>-0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Two measures plan completion rate indicators</td>
<td>0.1124</td>
<td>7.91</td>
<td>-0.042</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Indicators of completeness of rules and regulations</td>
<td>0.1889</td>
<td>8.09</td>
<td>0.050</td>
<td>-0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outsourcing team credit evaluation indicators</td>
<td>0.0938</td>
<td>7.64</td>
<td>-0.133</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Independent safety management indicators for teams</td>
<td>0.1749</td>
<td>7.73</td>
<td>-0.107</td>
<td>0.136</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&quot;Safety QR code&quot; usage index</td>
<td>0.0494</td>
<td>6.73</td>
<td>-0.280</td>
<td>0.286</td>
</tr>
<tr>
<td>Redundancy index 0.2923</td>
<td>2</td>
<td></td>
<td>Customer-side problem rectification indicators</td>
<td>0.1885</td>
<td>7.36</td>
<td>-0.194</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Safety incident evaluation index</td>
<td>0.1619</td>
<td>7.82</td>
<td>-0.077</td>
<td>0.091</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hidden danger rectification index</td>
<td>0.1917</td>
<td>7.82</td>
<td>-0.077</td>
<td>0.091</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emergency response capacity building evaluation indicators</td>
<td>0.1673</td>
<td>7.91</td>
<td>-0.042</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Equipment and operation risk control indicators</td>
<td>0.1938</td>
<td>8.00</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intelligent indicators for process control</td>
<td>0.0967</td>
<td>8.09</td>
<td>0.050</td>
<td>-0.045</td>
</tr>
<tr>
<td>Efficiency index 0.2467</td>
<td>2</td>
<td></td>
<td>Rectification and improvement indicators</td>
<td>0.2411</td>
<td>8.18</td>
<td>0.111</td>
<td>-0.091</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emergency command center construction index</td>
<td>0.1566</td>
<td>7.73</td>
<td>-0.0107</td>
<td>0.136</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Safety investment indicators</td>
<td>0.4214</td>
<td>8.00</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Safety data paperless utilization index</td>
<td>0.1809</td>
<td>7.00</td>
<td>-0.250</td>
<td>0.500</td>
</tr>
<tr>
<td>Adaptable index 0.1985</td>
<td>2</td>
<td></td>
<td>Safety routine work implementation rate indicators</td>
<td>0.1732</td>
<td>8.36</td>
<td>0.286</td>
<td>-0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Regulations/standards adaptability index</td>
<td>0.1625</td>
<td>7.73</td>
<td>-0.0107</td>
<td>0.136</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Special exercise coverage index</td>
<td>0.1249</td>
<td>7.55</td>
<td>-0.156</td>
<td>0.227</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emergency personnel training indicators</td>
<td>0.1079</td>
<td>7.64</td>
<td>-0.0133</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emergency equipment equipped index</td>
<td>0.1595</td>
<td>7.36</td>
<td>-0.194</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Employee education and training qualification rate indicators</td>
<td>0.1565</td>
<td>8.27</td>
<td>0.188</td>
<td>-0.136</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Risk assessment indicators</td>
<td>0.1154</td>
<td>8.18</td>
<td>0.111</td>
<td>-0.091</td>
</tr>
</tbody>
</table>
5.2.3. Multilevel Extension Evaluation of Enterprise Safety Resilience

(1) Safety Resilience Evaluation of the Secondary Index. Considering the calculation method of the correlation degree of the second-level index with the second-level evaluation index \( c_{11} \) to the first-level evaluation index \( c_1 \) and the calculation of the correlation degree of enterprise safety resilience level 1 as an example, we obtain the following based on formulas (10)–(12).

\[
\rho(v_{11}, V_1) = \frac{|8.46 - \frac{8 + 10}{2}| - \frac{10 - 8}{2}}{0.46,}
\]

\[
\rho(v_{11}, V_n) = \frac{|8.46 - \frac{0 + 10}{2}| - \frac{10 - 0}{2}}{-1.54, (24)}
\]

\[
K_1(C_{11}) = \frac{-0.46}{-1.54 + 0.46} = 0.417.
\]

By analogy, the correlation degree of \( c_{11} \) concerning other resilience levels can be calculated as

\[
K_1(c_{11}) = -0.227, \\
K_1(c_{11}) = -0.6144, \\
K_1(c_{11}) = -0.807.
\] (25)

Similarly, the correlation value of other secondary indicators for each safety resilience level can be calculated. Then, the formula \( \max K(c_j) = k_j(c_{ij}) \) \( j \in \{1, 2, \ldots, l\} \) determines the safety resilience level of each secondary evaluation index, as shown in Table 5.

(2) First-Level Index Safety Resilience Evaluation. Considering the first-level index \( c_1 \) as an example to introduce the first-level index relevance calculation method from formula (13), the correlation value of each resilience grade is determined as

\[
K(c_1) = W_k(c_j) = (w_i)(k_j(c_i))
\]

\[
= [-0.011 \ 0.059 \ -0.468 \ -0.734].
\] (26)

Similarly, the correlation values of other first-level indicators for each safety resilience level can be calculated separately.

\[
K(c_2) = [-0.066 \ 0.095 \ -0.452 \ -0.726],
\]

\[
K(c_3) = [-0.035 \ 0.090 \ -0.455 \ -0.728],
\]

\[
K(c_4) = [0.009 \ 0.058 \ -0.471 \ -0.736].
\] (27)

According to the formula \( \max K(c) = 0.0593 = k_2(c) \), the safety resilience level of each first-level evaluation index is determined, as shown in Table 5.

(3) Evaluation of Comprehensive Safety Resilience of Enterprises. According to formula (14), the total correlation value of the safety resilience level of the enterprise for each safety resilience level can be calculated as

\[
K(c) = W_k(c_j) = (w_i)(k_j(c_i))
\]

\[
= [-0.011 \ 0.059 \ -0.468 \ -0.734].
\] (28)

According to \( \max K(c) = 0.0593 = k_2(c) \), the overall safety resilience level of the enterprise can be determined to be level 2 (i.e., “strong safety resilience”).

5.3. Evaluation Results and Analysis. The power company’s safety resilience grading evaluation results are shown in Table 5. After evaluation, the power company’s comprehensive safety resilience rating is level 2 (i.e., “strong safety resilience”). The overall resilience level is relatively high, but there is still room for improvement. Specifically, from the first-level index safety resilience evaluation results, except for the first-level index stability, the other three first-level evaluation indicators are at the second-level safety resilience level (“more robust safety resilience”), which shows that each first-level evaluation indicator has good defense and resilience to risks. However, some aspects still must be improved. From the evaluation results of the second-level index safety resilience, in addition to the nine second-level indicators such as organizational completeness and responsibility matching, the safety resilience level is level 1 (strong safety resilience), and the safety resilience levels of the remaining second-level indicators all are level 2 (more critical safety resilience). According to the evaluation results and the above analysis results, it is recommended that the electric power company comprehensively implements safety risk rectification while focusing on the following rectification work to ensure the production safety of the electric power company and to prevent gradual failures and prevent problems before they occur.

In terms of stability, it is necessary to promote the implementation of the safety production responsibility system through a detailed inventory, digital empowerment, and personnel training, strengthen the supervision of the implementation of the “two measures,” check the completion of quarterly, find problems and promptly report them,
strengthen the process control and assessment of the outsourcing team, establish the credit evaluation system of the outsourcing team, improve the independent management ability of the team, and promote and popularize the enterprise “safety QR code.”

In terms of redundancy, it is necessary to improve customer-side safety management, communicate with customers quickly about existing problems, propose specific rectification measures, promote intelligent process control, accurately control the entire safe production process, and reduce communication costs.

In terms of efficiency, it is necessary to speed up the construction of emergency command centers and enhance the emergency response capabilities of enterprises to better respond to emergencies; timely feedback on the rectification of safety hazards should also be made to prevent production accidents.

In terms of adaptability, it is necessary to educate and train employees, focus on and improve the qualification rate of education and training, and improve the overall safety level of the enterprise; regularly performing training and inspecting emergency personnel and equipment can ensure the safety of emergency personnel quality and the availability of emergency equipment.

6. Conclusion

This paper investigates and evaluates the electric power enterprises’ resilience capability. The primary conclusions of this study are as follows.

Table 7: Weights of secondary indicators under each primary indicator.

<table>
<thead>
<tr>
<th>First-level index $c_i$</th>
<th>Number</th>
<th>Secondary indicators $c_{ij}$</th>
<th>Weights $w_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability index</td>
<td>1</td>
<td>Organizational completeness index</td>
<td>0.1182</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Responsibility matching index</td>
<td>0.1556</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Safety supervision work implementation rate indicators</td>
<td>0.1068</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Two measures plan completion rate indicators</td>
<td>0.1124</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Indicators of completeness of rules and regulations</td>
<td>0.1889</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Outsourcing team credit evaluation indicators</td>
<td>0.0938</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Independent safety management indicators for teams</td>
<td>0.1749</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>“Safety QR code” usage index</td>
<td>0.0494</td>
</tr>
<tr>
<td>Redundancy index</td>
<td>1</td>
<td>Customer-side problem rectification indicators</td>
<td>0.1885</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Safety incident evaluation index</td>
<td>0.1619</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Hidden danger rectification index</td>
<td>0.1917</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Emergency response capacity building evaluation indicators</td>
<td>0.1673</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Equipment and operation risk control indicators</td>
<td>0.1938</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Intelligent indicators for process control</td>
<td>0.0967</td>
</tr>
<tr>
<td>Efficiency index</td>
<td>1</td>
<td>Rectification and improvement indicators</td>
<td>0.2411</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Emergency command center construction index</td>
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<tr>
<td></td>
<td>3</td>
<td>Safety investment indicators</td>
<td>0.4214</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Safety data paperless utilization index</td>
<td>0.1809</td>
</tr>
<tr>
<td>Adaptability index</td>
<td>1</td>
<td>Safety routine work implementation rate indicators</td>
<td>0.1732</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Regulations/standards adaptability index</td>
<td>0.1625</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Special exercise coverage index</td>
<td>0.1249</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Emergency personnel training indicators</td>
<td>0.1079</td>
</tr>
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<td></td>
<td>5</td>
<td>Emergency equipment equipped index</td>
<td>0.1595</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Employee education and training qualification rate indicators</td>
<td>0.1565</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Risk assessment indicators</td>
<td>0.1154</td>
</tr>
</tbody>
</table>

(1) Based on resilience theory, the evaluation indicators of electric power enterprises are reclassified on the basis of the “1438” SMS, and the resilience capacity evaluation index system of power grid enterprises is proposed, with four first-level indices, stability index, redundancy index, efficiency index, and adaptability index and 25 second-level indices.

(2) An optimized AHP-MEE joint model is proposed; it provides a method to calculate the weights of evaluation indicators, precise analysis of the scope of each indicator, and exact calculation method for system safety resilience.

(3) A case study is conducted to verify the reliability and applicability of the provided safety resilience capacity evaluation index system and the AHP-MEE model. It is determined as a level 2 (stronger safety resilience) for the selected sample, consistent with production reality. The evaluation results also provide targeted rectification and reform measures to strengthen safe production work.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.
Acknowledgments

This work was supported by the National Natural Science Foundation of China (grant numbers 51976205, 51904282, and 51804287).

References


