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A Safety Evaluation Method for Converter Station Operation Based on Dynamic Fuzzy Theory

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Abstract: In order to accurately evaluate the safety risk level of converter station operations and reflect its changing trends, an evaluation method based on dynamic fuzzy theory is proposed. By constructing an initial Work Breakdown Structure-Risk breakdown structure (WBS-RBS) coupled matrix, identifying risk factors, and using the vague set screening method to screen out key risk factors, a comprehensive safety evaluation index system for converter station operations is established. The dynamic fuzzy values of all levels of evaluation indicators are calculated using dynamic fuzzy theory, intuitively reflecting the risk level and its changing trends of all levels of evaluation indicators. Taking the Suzhou ±800 kV converter station project as an example to verify this method, the results show that the safety risk level of this converter station operation is medium–low and tends to be low. This method can objectively reflect the ambiguity and randomness of risk evaluation, improve evaluation accuracy, and intuitively display the risk-changing trends, providing a reference for similar projects.

Keywords: converter station; safety evaluation; WBS-RBS; Vague set screening method; dynamic fuzzy theory

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1. Introduction

With the rapid development of the Chinese power system, converter stations, as important power transmission facilities, are responsible for voltage conversion between alternating current and direct current, and their safety has attracted more and more attention [1]. However, there are many risk factors in the operation of converter stations, such as equipment failure and human error, which may lead to safety accidents [2]. Therefore, it is particularly important to accurately evaluate the safety risks of converter station operations.

At present, a large number of risk factors are involved in the operation of converter stations, and how to effectively identify and screen key risk factors is one of the main challenges faced by current research. In addition, the existing evaluation methods cannot intuitively reflect the change trend of risk level during the operation of converter stations, which is also the main challenge of current research.

As an effective tool to deal with uncertainty and ambiguity, fuzzy theory allows us to use fuzzy sets to describe those concepts with unclear boundaries, such as "security", "risk", etc., and it has been widely used in the field of risk assessment. In this paper, motion fuzzy theory is used to evaluate the safety risk of converter station operation, and a safety evaluation method based on motion fuzzy theory is proposed to solve the above problems. Firstly, the initial Work Breakdown Structure-Risk breakdown structure (WBS-RBS) coupling matrix was constructed based on the workflow and risk factors of the converter station [3] to identify the risk factors in the operation of the converter station. Then, the vague set screening method was used to screen out the key risk factors [4], and the safety risk evaluation index system of converter station operation was constructed. Finally, dynamic

fuzzy theory is used to calculate the dynamic fuzzy values of the evaluation indicators at all levels to intuitively reflect the risk level and its change trend of the evaluation indicators at all levels and the overall risk. The main innovations of this paper are outlined below:

- Combine the WBS-RBS decomposition structure and the vague set screening method to construct a more comprehensive and systematic security risk evaluation index system.
- Introduce dynamic fuzzy theory to realize static and dynamic analysis of risks and intuitively reflect the trend of risk changes.
- Integrate multiple methods to form a complete safety assessment model for converter station operation.

The paper is organized as follows: Section 2 describes the work; Section 3 introduces the theory of motion blur; Section 4 introduces the safety assessment method of converter station operation in detail, including the establishment of an evaluation index system, the determination of index weights, the classification of risk levels and the construction of an evaluation model; Section 5 verifies the effectiveness of the model through case studies; Section 6 summarizes the full text and looks forward to future research directions.

2. Related Work

Safety assessment is a comprehensive inspection process that includes a detailed review of the environmental conditions, facility status, and operational behaviors of employees in the workplace. Its purpose is to detect and analyze potential hazards and risk points, evaluate the effectiveness of existing safety protection measures, and plan corresponding improvement strategies based on this. This approach aims to reduce the likelihood of accidents and ensure the safety of the lives of the workforce.

Currently, there is still limited research on the operation safety evaluation of converter stations at home and abroad. Among them, Mou Dalin [5] and others proposed a fault segment identification method based on the relative entropy of S-transform energy, which analyzed the difference of electric flow waves between converter station faults and AC line faults based on traveling wave propagation theory, which can effectively identify faults, but the evaluation criteria are too simple. Wang Ting [6] and others used a combination of the interval Analytic Hierarchy Process (AHP) and interval entropy weighting method to evaluate the High Voltage Direct Current (HVDC) protection system and protection equipment of the converter station. The qualitative and quantitative evaluation results of the operation status of the equipment provide important guidance for the selection of new converter station equipment and the operation, maintenance and overhaul of the HVDC transmission protection system of the converter station, but the method was static analysis and was not flexible enough. Liu Tiecheng [7] and others proposed a relay protection reliability evaluation method based on Back Propagation (BP) neural network, which calculates reliability indicators such as reliability, failure rate, and failure probability density from the perspective of dynamic evaluation, so as to evaluate the secondary equipment of converter stations, but this method is currently limited to large-scale converter stations. The above evaluation methods have not yet established a relatively comprehensive safety evaluation system for converter station operation, which is not conducive to the timely and effective assessment and treatment of risks by operators. The comprehensive operation safety evaluation system of converter stations should include the determination of the operation safety evaluation index of converter stations and the construction of an evaluation model.

2.1. Determination of Safety Evaluation Indicators for Converter Station Operations

The determination of operational safety assessment indicators for converter stations depends on how effectively risk factors during operation are identified and the more critical assessment indicators are screened out. Currently, the evaluation indicators for the operation of converter stations are based on past engineering cases and regulations issued by relevant departments, lacking flexibility. In other large-scale engineering projects, Xie Zijun [8] and others have proposed a metro accident cause analysis indicator system based

on fault tree analysis (FTA), but FTA is highly subjective. Marina Bouzon [9] and others have suggested using the Fuzzy Delphi Method (FDM) to obtain a list of key barriers in reverse logistics from the perspective of experts and industry managers, but the effectiveness and accuracy of the FDM depend on the professional knowledge and experience of the participants. You Qiuang [10] and others have proposed a safety risk identification method for the shield construction of the Shenzhen Metro, combining the Work Breakdown Structure–Resource Breakdown Structure (WBS-RBS) decomposition with Principal Component Analysis. The WBS-RBS decomposition structure can comprehensively and systematically identify risk factors throughout the project process based on the characteristics of the engineering project. Building on this, this paper proposes a method that combines the WBS-RBS decomposition structure with fuzzy set screening to determine the operational safety assessment indicators for converter stations. The combination of the WBS-RBS decomposition structure and the vague set screening method provides a comprehensive and precise approach to constructing the operational safety assessment indicator system for converter stations. This integration ensures the systematicness and pertinence of risk identification while addressing the uncertainty and fuzziness of information during operation, enhancing the flexibility and scientificity of the evaluation indicators.

2.2. Construction of Converter Station Operation Safety Evaluation Model

In other large-scale engineering construction fields, Dong Song [11] and others have combined the Analytic Hierarchy Process (AHP) [12], Fuzzy Comprehensive Evaluation (FCE) [13], and Weight Variation Theory (VWT) [14] to establish a mathematical evaluation framework for assessing the feasibility of slope mining. They evaluated the feasibility of open-pit mine wall mining, providing scientific guidance for coal mining enterprises to introduce the Continuous Slope Mining Machine System (CHM) into open-pit mines for lateral wall mining operations. Zhao Zhe [15] and others proposed a risk assessment method for floor water inrush based on combined weighted and hierarchical analysis, and the method was verified using the Shandong Pengzhuang Coal Industry as a case study. Meanwhile, Yang Fengfeng [16] optimized and improved the D-number theory based on an analysis of the limitations of DS evidence theory and proposed a research method for the emergency response capability of coal enterprises in the Longdong region that combines D-number theory with the Fuzzy Analytic Hierarchy Process (FAHP). This method can effectively identify weak links in emergency management and meet the emergency decision-making needs of enterprises under unexpected circumstances, which is of great guiding significance for improving the emergency management capability and level of enterprises. Su Huifeng [17] improved the Analytic Hierarchy Process (AHP) by integrating a mixed triangular fuzzy number logic structure and, in combination with fuzzy comprehensive evaluation, proposed a safety status evaluation method for offshore single-tower steel box girder suspension bridges based on the improved AHP-fuzzy comprehensive evaluation. Although traditional methods such as the Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE), and Weight Variation Theory (VWT) have certain application value in the field of large-scale engineering construction, they generally share some common shortcomings, such as difficulties in handling dynamically changing information, limited adaptability to uncertainty, and potential complexity or lack of flexibility in practical operations. In contrast, the advantages of dynamic fuzzy theory are particularly prominent. It effectively overcomes the limitations of these methods and, through its dynamic adjustment and real-time feedback mechanisms, better adapts to the uncertainty and changes in engineering projects. Dynamic fuzzy theory not only enhances the accuracy and practicality of evaluations but also, due to its flexibility and ease of operation, has a wider application in engineering practice, providing more scientific and timely support for engineering decision making.

In summary, this paper has designed a converter station operation safety evaluation method based on dynamic fuzzy theory on the basis of existing research. This method can flexibly identify and screen evaluation indicators according to the characteristics of

engineering projects and then use dynamic fuzzy theory, which has a natural advantage in handling data with dynamic changes, fuzzy boundaries, and difficulty in quantification, to calculate the dynamic fuzzy values of evaluation indicators at all levels, intuitively reflecting the risk levels and their change trends of each evaluation indicator and the overall risk. Experimental results show that this method can adapt to the dynamic changing converter station operation environment and has good evaluation effects.

3. Prior Knowledge

Dynamic fuzzy theory is, at its essence, a comprehensive evaluation method that incorporates dynamic variables, dynamic fuzzy sets (DFSs), and dynamic fuzzy logic from the realm of fuzzy mathematics, along with the principles of dynamic fuzzy transformation and the maximization of membership degrees [18]. It holds a natural advantage when dealing with data that exhibit dynamic changes, have ambiguous boundaries, and are difficult to quantify.

If there exists a mapping on the universal domain U such that $\left(\overleftarrow{A}, \overrightarrow{A}\right) : \left(\overleftarrow{U}, \overrightarrow{U}\right) \rightarrow [0,1] \times [\leftarrow, \rightarrow]$, $\left(\overleftarrow{u}, \overrightarrow{u}\right) \cdot \left(\overleftarrow{A}(\overleftarrow{u}), \overrightarrow{A}(\overrightarrow{u})\right)$ and denoted as $\left(\overleftarrow{A}, \overrightarrow{A}\right) = \overleftarrow{A}$ or $\overrightarrow{A}$, then consider $\left(\overleftarrow{A}, \overrightarrow{A}\right)$ as a dynamic fuzzy set (DFS) on $\left(\overleftarrow{U}, \overrightarrow{U}\right)$, and $\left(\overleftarrow{A}(\overleftarrow{u}), \overrightarrow{A}(\overrightarrow{u})\right)$ is called the membership degree of the fuzzy set on $\left(\overleftarrow{A}, \overrightarrow{A}\right)$. For any real number $b \in [0,1]$, it can be dynamically fuzzy-ized. For example, the real number b can be dynamically fuzzy-ized as $b = \underline{\underline{DF}}(\overleftarrow{b}, \overrightarrow{b})$, $b = \underline{\underline{DF}}\overleftarrow{b}$ or $\overrightarrow{b}$, $\max(\overleftarrow{b}, \overrightarrow{b}) \triangleq \overrightarrow{b}$ and $\min(\overleftarrow{b}, \overrightarrow{b}) \triangleq \overleftarrow{b}$, which intuitively reflects the dynamic development trend of b.

If there are multiple dynamic fuzzy sets on the universal domain U, then the entire set of dynamic fuzzy sets on U can be denoted as DF(U), i.e., $\mathrm{DF}(U) = \{(\overleftarrow{A}, \overrightarrow{A}) | (\overleftarrow{A}, \overrightarrow{A}), (\overleftarrow{u}, \overrightarrow{u}) b [0,1] \times [\leftarrow, \rightarrow]\} = \{(A \times (\leftarrow, \rightarrow)) | (A \times (\leftarrow, \rightarrow), (u \times (\leftarrow, \rightarrow) b) [0,1] \times [\leftarrow, \rightarrow])\}$. The operation between two dynamic fuzzy sets can be seen as the corresponding operation on their membership functions.

4. Converter Station Operation Safety Evaluation Methods

The selection of operation safety evaluation methods is a crucial link that determines the effectiveness of the risk assessment results. This article mainly includes four steps in the operation safety evaluation method of converter stations: establishing an operation safety evaluation index system for converter stations, dividing risk levels, calculating the optimal weights, and constructing an operation safety evaluation model for converter stations based on dynamic fuzzy theory.

4.1. Establish a Converter Station Operation Safety Evaluation Index System

The operation process of the converter station is complex, with numerous influencing factors, and the same risk factor can vary in different operational processes. Firstly, based on the timeliness and dynamic characteristics of risk factors, the converter station operations are, respectively, decomposed into engineering structures and risks, and a WBS-RBS coupling matrix is constructed to comprehensively identify risk factors throughout the entire operational process. The specific steps are as follows:

- First, clearly identify the scope. According to the implementation process of the project and the requirements of risk management and control, confirm the object, scope and type of risk identification.
- Second, break down the work structure. Combined with the specific content of the project, the project (W) is decomposed layer by layer according to the implementation stage or technical structure of the project work tasks until the work breakdown element (W_{ij}) that can meet the best identification effect is obtained, and finally the work breakdown structure diagram (WBS) is formed.
- Then, break down the risk structure. The overall risk (R) is split one by one according to the source area of the risk or the manifestation of the risk so that the risk decomposition

element (R_{ij}) conforms to the characteristics of the project and the decomposition thickness is suitable for judging the risk, and finally the risk decomposition structure diagram (RBS) is formed.

- Then, establish a risk identification matrix. The overall decomposition element W_{ij} of the base layer of the work breakdown structure is set as the horizontal row of the identification matrix, and the whole decomposition element R_{ij} of the base layer of the risk breakdown structure is set as the vertical column of the identification matrix so that the two are connected to each other to form the risk identification matrix (WBS-RBS) as shown below.
- Then, identify the risks. Identify the existence or absence of the *j*th risk corresponding to the *i*th work breakdown element. If so, mark "✓" on the corresponding form; if it does not exist or the risk impact is negligible, it is not flagged.
- Finally, establish a risk identification checklist. The identified risk factors are described in text and summarized into a risk identification list for reference.

Subsequently, the vague set screening method is employed to identify key risk factors. The comprehensive indicator set $A = \{a_1, a_2, \cdots, a_p\}$ is defined to encompass all risk factors in the entire operational process. Votes from X_1 experts and scholars are collected, encompassing $\{agree, disagree, uncertain\}$, and these results are converted into vague set expressions. Specifically, the feedback for each indicator a_i is represented as $(t_A(a_i), 1 - f_A(a_i))$, where $t_A(a_i)$ and $f_A(a_i)$ denote the true and false membership degrees of the comprehensive indicator set A, respectively. The hesitation degree of a_i relative to A is defined as $\pi_A(a_i) = 1 - t_A(a_i) - f_A(a_i)$. It is noted that $t_A(a_i) \geq 0, f_A(a_i) \geq 0$, $\pi_A(a_i) \geq 0$, and $0 \leq t_A(a_i) + f_A(a_i) \leq 1$. The index ranking function $s_A(a_i)$ is selected and calculated as shown in Equation (1) [19]:

$$s_A(a_i) = t_A(a_i) - f_A(a_i) + (\beta - \gamma) \cdot \pi_A(a_i) \quad (1)$$

where $0 \leq \beta \leq 1, 0 \leq \gamma \leq 1$, and $0 \leq \beta + \gamma \leq 1$. Typically, $0 \leq \beta \leq 1$, $0 \leq \gamma \leq 1$, and $0 \leq \beta + \gamma \leq 1$. There are two types of values. In the first case, at that time $t_A(a_i) - f_A(a_i) \neq 0$, take $\beta = t_A(a_i)$, $\gamma = f_A(a_i)$, then $s_A(a_i) = (t_A(a_i) - f_A(a_i)) \cdot (1 + \pi_A(a_i))$. In the second case, at that time $t_A(a_i) - f_A(a_i) = 0$, then $s_A(a_i) = (\beta - \gamma) \cdot \pi_A(a_i)$. The values of β and γ are determined by the attitude of the decision-maker toward the decision making. When decision-makers are optimistic about the overall situation, they make $\beta > \gamma$. When decision-makers are pessimistic, make $\beta < \gamma$. If the decision-maker's attitude is compromised, make $\beta = \gamma$. Similarly, the higher the value, the more important the indicator.

Finally, based on the screening threshold a $(0 < a < 1)$, when $s_A(a_i) > a$, the indicator a_i is included in the critical set A', obtaining the key indicator set for converter station operations and establishing a safety evaluation index system for converter station operations.

4.2. Determine the Optimal Weight of Evaluation Indices Through an Enhanced Combination Weighting Method

In the context of comprehensive evaluation, the optimal weight of each index is determined by employing an enhanced combination weighting approach. This methodology incorporates the subjective weight derived from an improved three-scale Analytic Hierarchy Process (AHP) [20] and the objective weight calculated using the Entropy Weight Method (EWM) [21]. By linearly combining these subjective and objective weights, the optimal weight for each evaluation index is attained. Specifically, the optimal weight ω_i for index i is calculated as follows:

$$\omega_i = \varepsilon E_i + \mu F_i \quad (2)$$

where E_i represents the subjective weight of index i obtained through the enhanced AHP, and F_i denotes the objective weight determined by the EWM. ε represents the preference coefficient of sovereign weight, the value range is [0, 1], and the larger the value, the more subjective the optimal weight. Similarly, the preference coefficient of the μ represents the objective weight, the value range is [0, 1], and the larger the value, the stronger the

objectivity of the optimal weight. Therefore, $\varepsilon + \mu = 1$. Conventionally, the preference coefficients ε and μ are set at 0.6 and 0.4, respectively [22].

4.3. Determine the Set of Evaluation Results

Considering the actual situation of converter station operation and relevant regulations, the safety risk level of converter station operation is divided into five levels: low, medium–low, medium, medium–high and high, as detailed in Table 1. Among them, the rating result set can be represented as $\mathcal{D} = \{\left(\overleftarrow{d_1}, \overrightarrow{d_1}\right), \left(\overleftarrow{d_2}, \overrightarrow{d_2}\right), \left(\overleftarrow{d_3}, \overrightarrow{d_3}\right), \left(\overleftarrow{d_4}, \overrightarrow{d_4}\right), \left(\overleftarrow{d_5}, \overrightarrow{d_5}\right)\}$ by the motion blur set, where $d_1 \sim d_5$ represents five risk levels from low to high, $\leftarrow$ indicates that the risk level is developing toward a worse trend, and $\rightarrow$ indicates that the risk level is developing toward a better and better trend.

Table 1. Converter station operation risk classification table.

Risk Level	Risk Level Code	Range	Qualitative Description
Low	d_1	(90, 100]	The risk is very low, negligible, no need to adopt risk response measures, only need to carry out routine monitoring, regular inspection.
Medium–low	d_2	(80, 90]	The risk is low and tolerable, but it needs to be noted, and it needs to be monitored and regularly assessed for risk changes.
Middle	d_3	(70, 80]	The risk is average and tolerable, and it is necessary to formulate risk response measures and conduct regular drills; a new round of inspections of personnel, equipment, etc.
Medium–high	d_4	(60, 70]	The risk is relatively high and some of them are bearable, so it is necessary to take risk response measures and formulate risk monitoring and early warning plans; carry out a new round of inspection, screening and update of personnel and equipment, and strengthen the awareness of personnel.
High	d_5	[0, 60]	The risk is extremely high, unacceptable, and there is an urgent need for risk aversion or transfer.

The following measures are targeted for specific risk factors:

- Personnel risk: strengthen personnel training to improve the professional skills and safety awareness of operators; improve the safety management system and clarify the operating procedures; conduct regular safety inspections to identify and eliminate potential safety hazards in a timely manner.
- Equipment risk: strengthen equipment maintenance to ensure that the equipment is in good condition; conduct regular equipment testing, find and deal with equipment failures in a timely manner; establish an equipment spare parts library to ensure that equipment failures can be repaired in a timely manner.
- O & M risk: Improve the O & M management system, clarify the O & M process and operating procedures; conduct regular training for O & M personnel to improve their security awareness and operational skills; strengthen O & M data analysis to identify and deal with potential risks in a timely manner.
- Risk control: Improve the design and operation of the control system to ensure the safety and reliability of the control system; regularly carry out control system testing, find and deal with control system failures in a timely manner; establish a spare parts library for the control system to ensure that the control system failure can be repaired in time.

- Technical risk: Strengthen technology research and development, improve the technical level of the transfer station; conduct regular technical assessments to identify and deal with technical risks in a timely manner; strengthen technical exchanges and learn from advanced technical experience.

4.4. An Evaluation Model Based on Motion Fuzzy Theory Is Constructed

4.4.1. Establish a Dynamic Fuzzy Evaluation Matrix

Based on the index system, a dynamic fuzzy evaluation matrix was established. Firstly, the dynamic fuzzy evaluation value vectors of the *j*th second-level evaluation index of the *i*th first-level evaluation index by X_2 experts are set out as:

$$H_{ij} = \left(\left(\overleftarrow{h_{ij1}}, \overrightarrow{h_{ij1}} \right), \left(\overleftarrow{h_{ij2}}, \overrightarrow{h_{ij2}} \right), \cdots, \left(\overleftarrow{h_{ijd}}, \overrightarrow{h_{ijd}} \right) \right), d = 1, 2, 3, 4, 5 \tag{3}$$

where $\overleftarrow{h_{ijd}}$ is the score of the *j*th second-level evaluation index of the *i*th first-level evaluation index with a tendency to increase the risk level of risk level d after the weighted set of the preference information of individual experts. On the contrary, $\overrightarrow{h_{ijd}}$ is a weighted set of the preference information of X experts, and the dynamically fuzzy evaluation value of the *j*th second-level evaluation index of the *i*th first-level evaluation index has a decreasing trend of risk level in risk level D [23].

Secondly, multiply the weight vector of the second-level evaluation index of the *i*th first-level evaluation index $\omega_i = (\omega_{i1}, \omega_{i2}, \cdots, \omega_{in})$ and H_{ij} to obtain the evaluation vectors of all experts on the mth first-level evaluation index:

$$\begin{aligned} H_i &= (\omega_{i1}, \omega_{i2}, \cdots, \omega_{in}) \cdot \begin{pmatrix} \begin{pmatrix} \overleftarrow{h_{i11}}, \overrightarrow{h_{i11}} \\ \overleftarrow{h_{i21}}, \overrightarrow{h_{i21}} \\ \vdots \\ \overleftarrow{h_{in1}}, \overrightarrow{h_{in1}} \end{pmatrix} & \begin{pmatrix} \overleftarrow{h_{i12}}, \overrightarrow{h_{i12}} \\ \overleftarrow{h_{i22}}, \overrightarrow{h_{i22}} \\ \vdots \\ \overleftarrow{h_{in2}}, \overrightarrow{h_{in2}} \end{pmatrix} & \cdots & \begin{pmatrix} \overleftarrow{h_{i1d}}, \overrightarrow{h_{i1d}} \\ \overleftarrow{h_{i2d}}, \overrightarrow{h_{i2d}} \\ \vdots \\ \overleftarrow{h_{ind}}, \overrightarrow{h_{ind}} \end{pmatrix} \end{pmatrix} \\ &= \left((\overleftarrow{h_{i1}}, \overrightarrow{h_{i1}}), (\overleftarrow{h_{i2}}, \overrightarrow{h_{i2}}), \cdots, (\overleftarrow{h_{id}}, \overrightarrow{h_{id}}) \right) \end{aligned} \tag{4}$$

Finally, according to (4), the evaluation vectors of all first-level evaluation indicators can be obtained, and then the dynamic fuzzy evaluation matrix is obtained:

$$H = \begin{bmatrix} \left(\overleftarrow{h_{11}}, \overrightarrow{h_{11}} \right) & \left(\overleftarrow{h_{12}}, \overrightarrow{h_{12}} \right) & \cdots & \left(\overleftarrow{h_{1\,d}}, \overrightarrow{h_{1\,d}} \right) \\ \left(\overleftarrow{h_{21}}, \overrightarrow{h_{21}} \right) & \left(\overleftarrow{h_{22}}, \overrightarrow{h_{22}} \right) & \cdots & \left(\overleftarrow{h_{2\,d}}, \overrightarrow{h_{2\,d}} \right) \\ \vdots & \vdots & \ddots & \vdots \\ \left(\overleftarrow{h_{m1}}, \overrightarrow{h_{m1}} \right) & \left(\overleftarrow{h_{m2}}, \overrightarrow{h_{m2}} \right) & \cdots & \left(\overleftarrow{h_{md}}, \overrightarrow{h_{md}} \right) \end{bmatrix} \tag{5}$$

4.4.2. The Evaluation Results of Motion Blur Were Calculated

Multiply the dynamic fuzzy evaluation matrix by multiplying the weights of the first-level evaluation index to obtain the dynamic fuzzy evaluation result matrix R.

$$R = (\omega_1, \omega_2, \cdots, \omega_m) \cdot \begin{bmatrix} \left(\overleftarrow{h_{11}}, \overrightarrow{h_{11}}\right) & \left(\overleftarrow{h_{12}}, \overrightarrow{h_{12}}\right) & \cdots & \left(\overleftarrow{h_{1\,d}}, \overrightarrow{h_{1\,d}}\right) \\ \left(\overleftarrow{h_{21}}, \overrightarrow{h_{21}}\right) & \left(\overleftarrow{h_{22}}, \overrightarrow{h_{22}}\right) & \cdots & \left(\overleftarrow{h_{2\,d}}, \overrightarrow{h_{2\,d}}\right) \\ \vdots & \vdots & \ddots & \vdots \\ \left(\overleftarrow{h_{m1}}, \overrightarrow{h_{m1}}\right) & \left(\overleftarrow{h_{m2}}, \overrightarrow{h_{m2}}\right) & \cdots & \left(\overleftarrow{h_{md}}, \overrightarrow{h_{md}}\right) \end{bmatrix} \tag{6}$$

As a result, the motion blur evaluation results are obtained:

$$R = \left(\left(\overleftarrow{r_1}, \overrightarrow{r_1}\right), \left(\overleftarrow{r_2}, \overrightarrow{r_2}\right), \cdots, \left(\overleftarrow{r_d}, \overrightarrow{r_d}\right)\right) \tag{7}$$

where the trend of R can be determined according to the size of $\sum_{j=1}^{d} \overleftarrow{r_j}$ and $\sum_{j=1}^{d} \overrightarrow{r_j}$. If $\sum_{j=1}^{d} \overleftarrow{r_j} > \sum_{j=1}^{d} \overrightarrow{r_j}$, the trend of A is "$\leftarrow$". If $\sum_{j=1}^{d} \overleftarrow{r_j} < \sum_{j=1}^{d} \overrightarrow{r_j}$, the trend of A is "$\rightarrow$". In addition, the weights of the indicators used above are the optimal index weights calculated by the improved combination weighting method.

5. Experimental Results and Analysis

5.1. Dataset

To validate the practical performance of the proposed evaluation method, this study selected the Suzhou ±800 kV converter station as the research object for empirical analysis. Since its operation, the Suzhou ±800 kV converter station has transmitted over 31.2 billion kWh of electricity annually to the eastern China region, while reducing coal consumption by 14 million tons and carbon dioxide emissions by 25.42 million tons, contributing significantly to the optimal allocation of energy resources and green development nationwide. This study conducted a thorough understanding of the operational processes of the Suzhou 800 kV converter station through field investigations, questionnaires, and other methods. In the questionnaire design, a five-point Likert scale [24] was adopted, encompassing risk assessments of operational evaluation indicators for the Suzhou ±800 kV converter station. The questionnaires were distributed electronically and in paper form to operators, commanders, and experts at the converter station, totaling 218 questionnaires. After excluding questionnaires with missing key information and irregular responses, 185 valid questionnaires were collected, yielding an effective rate of 85%. Subsequently, the data were subjected to reliability testing using SPSS 26.0 software. The results indicated that the Cronbach's alpha coefficient was 0.897, passing the test and confirming that the data reliability met the required standards.

5.2. Algorithm Flow and Implementation

Based on the operation safety evaluation method of converter station in Section 4, the schematic diagram of the algorithm of the method is drawn, and the results are shown in Figure 1.

- Step 1: WBS-RBS risk identification method
  According to the implementation process of the project and the requirements of risk management and control, confirm the object, scope and type of risk identification.
  WBS decomposition. Combined with the operation process of the converter station, the work of the converter station (W) is decomposed layer by layer until the work breakdown elements that can achieve the best identification effect are obtained, and finally the work breakdown structure diagram (WBS) is formed.
  RBS decomposition. According to the manifestation of risk, the overall risk (R) is divided one by one, so that the risk decomposition elements conform to the working characteristics of the converter station, and finally the risk decomposition structure diagram (RBS) is formed.

An initial WBS-RBS coupling matrix was created, combined with the data from the questionnaire, to obtain the risk identification list A.

- Step 2: Vague set filtering
  The vague set screening method was used to calculate the $s_A(a_i)$ indicators in the risk identification list A, the evaluation indicators of $s_A(a_i)$ > a were retained, and the safety evaluation index system was established.
- Step 3: Calculation method
  The subjective and objective weights were calculated by using AHP and EWM methods, and the optimal weights were calculated according to Equation (2).
- Step 4: Calculate the dynamic blur evaluation result matrix
  According to the collected questionnaires, the dynamic fuzzy value of the secondary evaluation index was obtained, and the dynamic fuzzy evaluation matrix was constructed based on the optimal weight of the primary and secondary evaluation indicators.
- Step 5: Analyze the risk level and change trend
  Determine the risk level and change trend based on the fuzzy values and trends in the dynamic fuzzy assessment result matrix, and take corresponding measures.

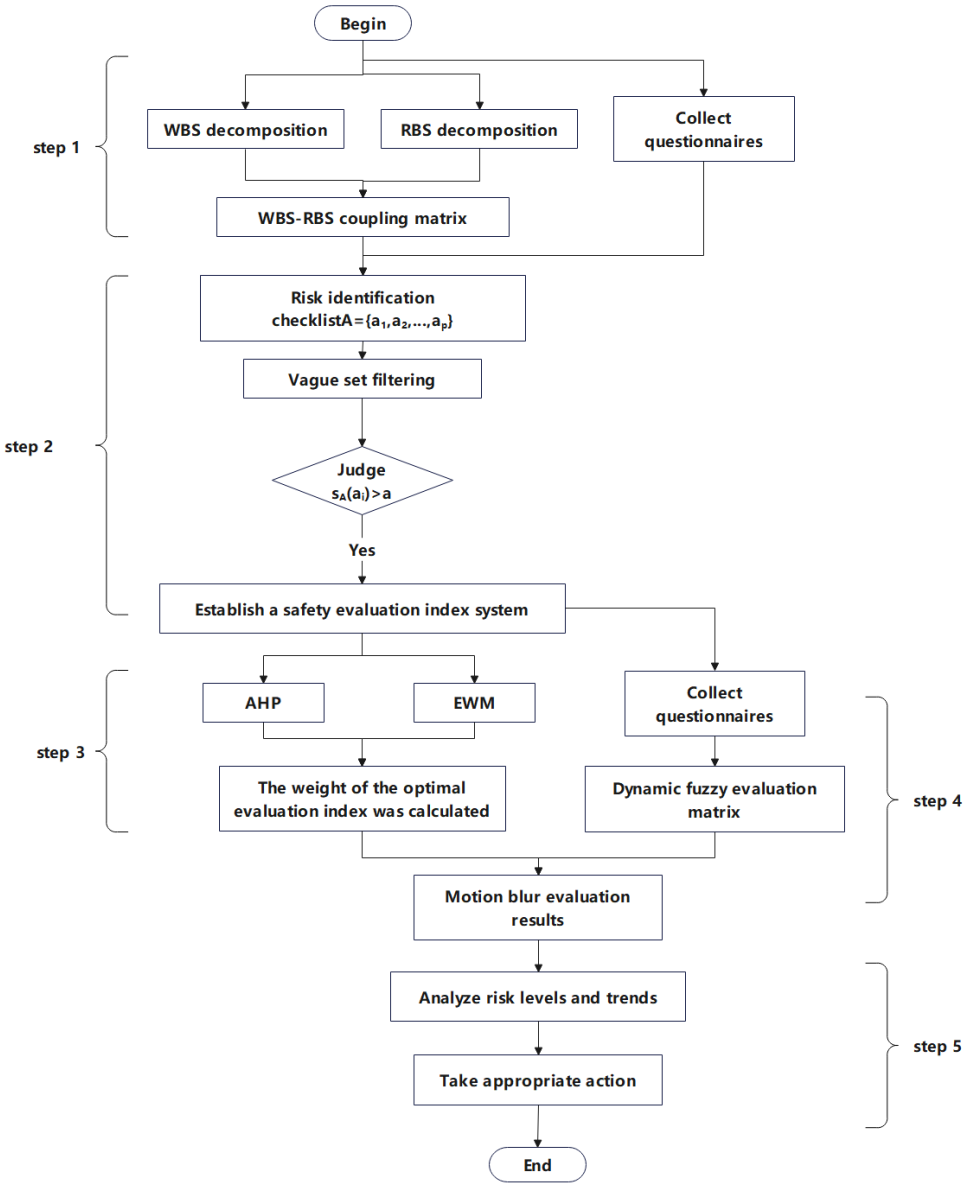


Figure 1. Schematic diagram of the safety evaluation method of converter station operation.

MATLAB R2022b played an important role in this study as a powerful numerical calculation and data analysis software. We performed all simulations and data analyses using MATLAB R2022b (version 9.13.0.2049777, The MathWorks, Inc., Natick, MA, USA).It not only provides a rich mathematical function and toolbox for convenient matrix operations, data processing, and statistical analysis but also has excellent data visualization capabilities, which can visualize experimental results in the form of graphs to help us better understand and analyze data. In this paper, we use MATLAB R2022b to calculate the dynamic fuzz evaluation matrix and the dynamic fuzz evaluation results. Specifically, MATLAB R2022b achieves the following:

- Calculate indicator weights:
  Using Equation (2), the subjective weights obtained based on the improved AHP and the objective weights obtained based on the entropy weight method are linearly combined to obtain the optimal weights of each evaluation index. This is achieved using the basic matrix arithmetic capabilities of MATLAB R2022b.
- Calculate the motion blur evaluation results:
  Using Equation (6), the dynamic fuzzy evaluation matrix is multiplied by the weights of the first-level evaluation index, and the dynamic fuzzy evaluation result matrix R is obtained. Again, this is achieved using the basic matrix arithmetic capabilities of MATLAB R2022b. Finally, using the basic math of MATLAB R2022b, calculate the sum of all the elements in R and determine the risk trend ("←" or "→") based on their size.
- Visualize the results:
  In this paper, MATLAB R2022b was used to generate charts to visualize the index weights and dynamic fuzzy evaluation results. The bar function is used to draw a histogram (bar chart), and the radar function is used to draw a radar chart.

5.3. Evaluation Process

Based on the actual operational procedures of the Suzhou 800 kV converter station, a Work Breakdown Structure (WBS) decomposition was conducted. The operational processes of the converter station were divided into three primary WBS levels: Project Process, Operational Preparation, and Field Implementation. These levels were further refined to obtain the secondary WBS, as shown in Figure 2.

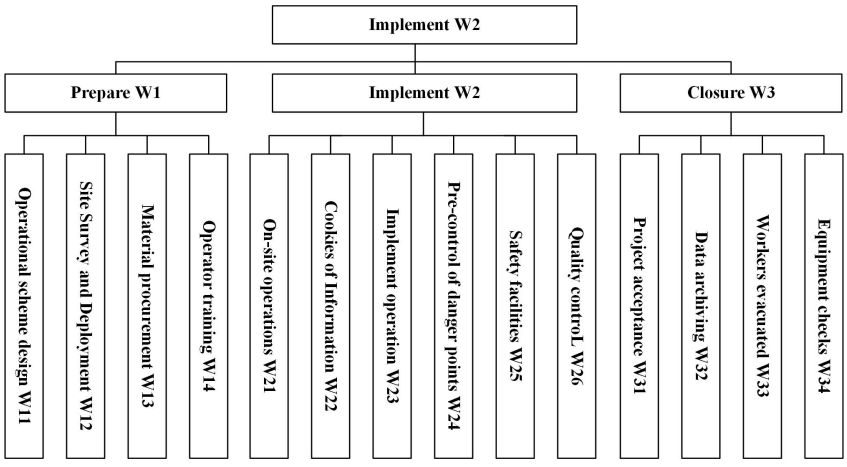


Figure 2. Work Breakdown Structure and Risk Breakdown Structure of Suzhou 800 kV converter station.

Drawing upon relevant engineering practices, various risk-inducing factors were comprehensively considered in conjunction with relevant documents from the State Grid Corporation of China. Using the Risk Breakdown Structure (RBS) principle, the operational risks (R) of the converter station were decomposed into five primary RBS levels: Personnel Safety Risk, Equipment Operation Risk, Operation and Maintenance Risk, Operational Control Risk, and Process Technology Risk, as illustrated in Figure 3.

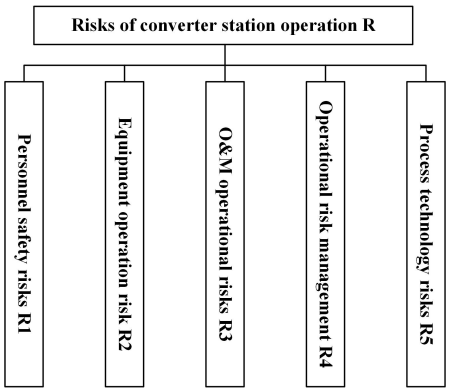


Figure 3. Risk Breakdown Structure of Suzhou 800 kV converter station.

The 70 risk factors associated with the Suzhou ±800 kV converter station project were filtered to eliminate redundant ones, and an operational evaluation index system for the Suzhou ±800 kV converter station was then established based on the set of critical risk factors. Evaluation data from 10 experts were collected for each of the 70 risk factors in the Suzhou ±800 kV converter station project. A threshold of a = 0.3 was set as the critical screening criterion, indicating that a risk factor a_i should be considered critical if the number of experts who support it being a focus of attention exceeds the number of dissenting experts by at least 30% or more. Specifically, when $s_A(a_i) \geq 0.3$ or more experts out of 10 support the criticality of a risk factor, it is deemed reasonable to include that factor in the set of critical risk factors. This process ultimately led to the formation of a risk evaluation index system, which further yielded operational safety evaluation indicators for the Suzhou ±800 kV converter station, as illustrated in Figure 4.

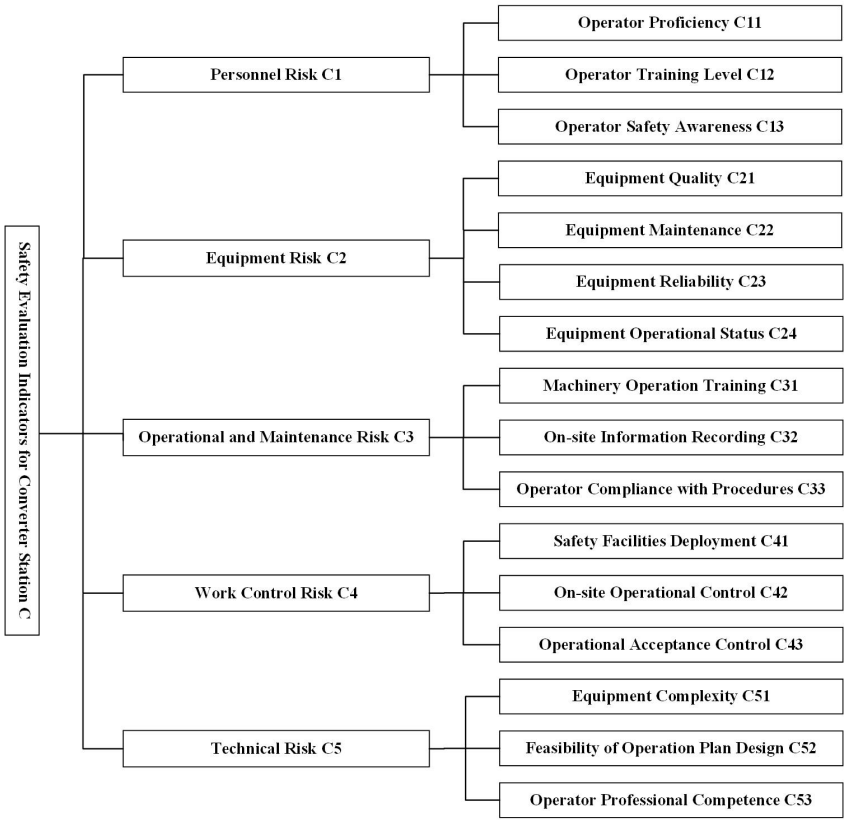


Figure 4. Safety assessment indicators for the operation of the Suzhou 800 kV converter station.

5.4. Evaluation Results

Based on the experimental dataset, after analyzing and processing the valid questionnaire data, the weights of evaluation indicators at all levels were calculated according to Equation (2), and the results are shown in Figure 5.

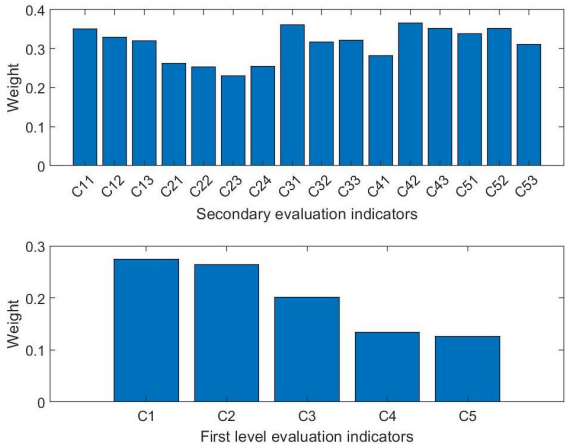


Figure 5. Weight of rating indicators at all levels.

Using MATLAB R2022b software to calculate the dynamic fuzzy evaluation values of rating indicators at all levels, and determine the risk levels and development trends of each risk factor and the overall project, the results are shown in Table 2 and Figures 6 and 7. Among them, Figure 7a is the final result of this experiment. In order to verify the experimental results, two different time periods were selected for the Suzhou ±800 kV converter station to conduct experiments, and the experimental results are shown in Figure 7b,c.

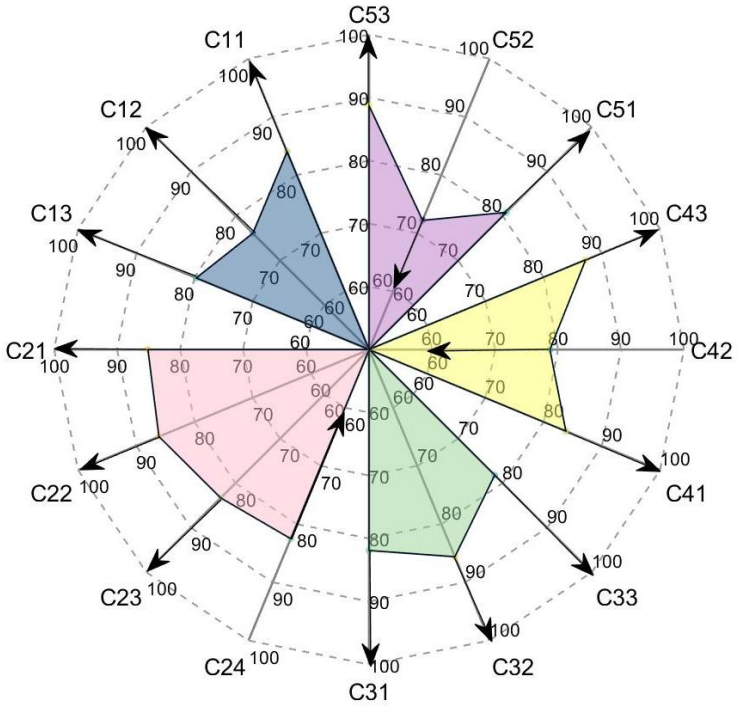


Figure 6. Radar chart of dynamic fuzzy evaluation results of secondary evaluation indicators.

Table 2. Optimal weights of evaluation indicators at all levels and dynamic fuzzy evaluation grade scores.

First-Level Evaluation Indicators	Weight I	Secondary Evaluation Indicators	Weight II	Motion Blur Rating Score
C1	0.2746	C11	0.3505	$((\overleftarrow{7},\overrightarrow{25}),(\overleftarrow{15},\overrightarrow{0}),(\overleftarrow{14},\overrightarrow{16}),(\overleftarrow{0},\overrightarrow{5}),(\overleftarrow{0},\overrightarrow{2}))$
		C12	0.3297	$((\overleftarrow{2},\overrightarrow{6}),(\overleftarrow{0},\overrightarrow{17.5}),(\overleftarrow{22},\overrightarrow{19.3}),(\overleftarrow{4},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{5.3}))$
		C13	0.3198	$((\overleftarrow{0},\overrightarrow{18}),(\overleftarrow{17},\overrightarrow{0}),(\overleftarrow{15.2},\overrightarrow{22.5}),(\overleftarrow{0},\overrightarrow{6}),(\overleftarrow{0},\overrightarrow{1}))$
		Total		$((\overleftarrow{3.1},\overrightarrow{16.5}),(\overleftarrow{10.7},\overrightarrow{5.8}),(\overleftarrow{17},\overrightarrow{19.1}),(\overleftarrow{1.3},\overrightarrow{3.7}),(\overleftarrow{0},\overrightarrow{2.8}))$
C2	0.2637	C21	0.2627	$((\overleftarrow{0},\overrightarrow{5.6}),(\overleftarrow{0},\overrightarrow{34}),(\overleftarrow{7.6},\overrightarrow{22.2}),(\overleftarrow{0},\overrightarrow{13}),(\overleftarrow{2.7},\overrightarrow{0}))$
		C22	0.2526	$((\overleftarrow{6},\overrightarrow{0}),(\overleftarrow{18},\overrightarrow{32.2}),(\overleftarrow{7.9},\overrightarrow{21}),(\overleftarrow{0},\overrightarrow{1}),(\overleftarrow{0},\overrightarrow{0}))$
		C23	0.2298	$((\overleftarrow{0},\overrightarrow{28.5}),(\overleftarrow{17.2},\overrightarrow{8.7}),(\overleftarrow{28.9},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}))$
		C24	0.2549	$((\overleftarrow{9.5},\overrightarrow{0}),(\overleftarrow{17},\overrightarrow{24.3}),(\overleftarrow{15.8},\overrightarrow{15.9}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}))$
		Total		$((\overleftarrow{3.9},\overrightarrow{8}),(\overleftarrow{12.9},\overrightarrow{25.3}),(\overleftarrow{14.7},\overrightarrow{15.2}),(\overleftarrow{0},\overrightarrow{3.7}),(\overleftarrow{0.7},\overrightarrow{0}))$
C3	0.2015	C31	0.3619	$((\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{16.6},\overrightarrow{16.6}),(\overleftarrow{14},\overrightarrow{21}),(\overleftarrow{5.7},\overrightarrow{6.8}),(\overleftarrow{0},\overrightarrow{2}))$
		C32	0.3164	$((\overleftarrow{0},\overrightarrow{9.4}),(\overleftarrow{15.8},\overrightarrow{27.4}),(\overleftarrow{0},\overrightarrow{33}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}))$
		C33	0.3505	$((\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{8.7},\overrightarrow{16.8}),(\overleftarrow{15.2},\overrightarrow{37.5}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}))$
		Total		$((\overleftarrow{0},\overrightarrow{3}),(\overleftarrow{13.8},\overrightarrow{20.1}),(\overleftarrow{10},\overrightarrow{30}),(\overleftarrow{2.1},\overrightarrow{2.5}),(\overleftarrow{0},\overrightarrow{0.7}))$
C4	0.1344	C41	0.2819	$((\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{9.7},\overrightarrow{16.8}),(\overleftarrow{12.8},\overrightarrow{38.5}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{6}))$
		C42	0.3665	$((\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{25.5},\overrightarrow{17.6}),(\overleftarrow{23},\overrightarrow{12.6}),(\overleftarrow{0},\overrightarrow{0}),(\overleftarrow{0},\overrightarrow{0}))$
		C43	0.3516	$((\overleftarrow{0},\overrightarrow{5}),(\overleftarrow{11.8},\overrightarrow{22.6}),(\overleftarrow{26},\overrightarrow{14}),(\overleftarrow{0},\overrightarrow{6.8}),(\overleftarrow{0},\overrightarrow{1}))$
		Total		$((\overleftarrow{0},\overrightarrow{1.8}),(\overleftarrow{16.2},\overrightarrow{19.1}),(\overleftarrow{21.1},\overrightarrow{20.4}),(\overleftarrow{0},\overrightarrow{2.4}),(\overleftarrow{0},\overrightarrow{2}))$
C5	0.1258	C51	0.3379	$((\overleftarrow{4},\overrightarrow{0}),(\overleftarrow{17},\overrightarrow{25.8}),(\overleftarrow{5},\overrightarrow{23.1}),(\overleftarrow{1.9},\overrightarrow{3}),(\overleftarrow{0},\overrightarrow{1}))$
		C52	0.3517	$((\overleftarrow{0},\overrightarrow{6.5}),(\overleftarrow{13},\overrightarrow{11}),(\overleftarrow{14.9},\overrightarrow{4}),(\overleftarrow{9},\overrightarrow{7.8}),(\overleftarrow{0},\overrightarrow{6}))$
		C53	0.3104	$((\overleftarrow{0},\overrightarrow{28.5}),(\overleftarrow{0},\overrightarrow{25.9}),(\overleftarrow{0},\overrightarrow{28.9}),(\overleftarrow{0},\overrightarrow{2.4}),(\overleftarrow{0},\overrightarrow{3}))$
		Total		$((\overleftarrow{1.4},\overrightarrow{11.1}),(\overleftarrow{10.3},\overrightarrow{20.6}),(\overleftarrow{6.9},\overrightarrow{18.2}),(\overleftarrow{3.8},\overrightarrow{4.5}),(\overleftarrow{0},\overrightarrow{3.4}))$
		Total		$((\overleftarrow{2.1},\overrightarrow{8.9}),(\overleftarrow{12.6},\overrightarrow{17.5}),(\overleftarrow{14.3},\overrightarrow{20.3}),(\overleftarrow{1.3},\overrightarrow{3.4}),(\overleftarrow{0.2},\overrightarrow{1.6}))$

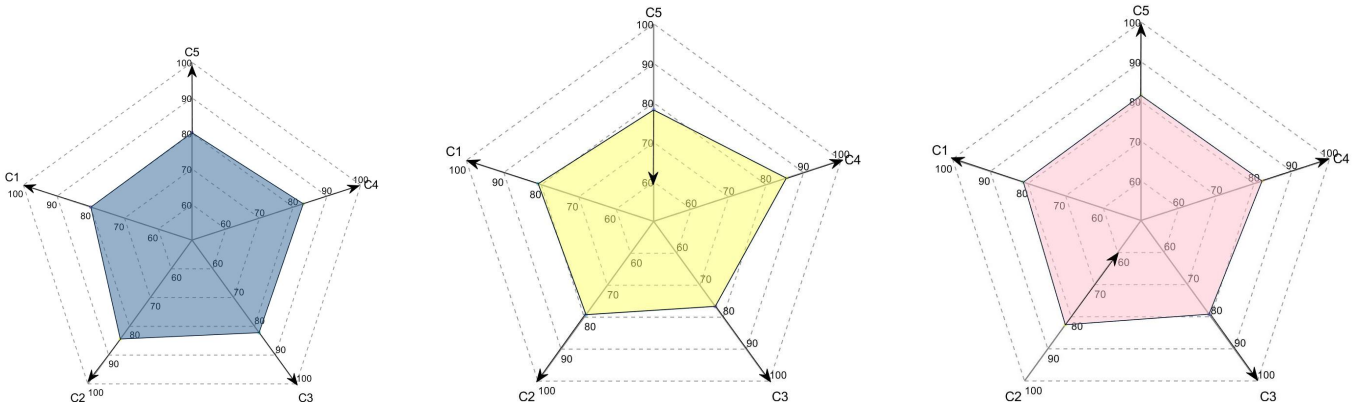


Figure 7. The weights of the rating indicators at each level, where (**a**) represents the final result of the experiment, and (**b**,**c**) represent the results obtained in two different time periods after the above process.

Based on the above results, the following can be concluded:

- Overall, the dynamic fuzzy evaluation score for the safety risk of this converter station operation is $((\overleftarrow{2.1}, \overrightarrow{8.9}), (\overleftarrow{12.6}, \overrightarrow{17.5}), (\overleftarrow{14.3}, \overrightarrow{20.3}), (\overleftarrow{1.3}, \overrightarrow{3.4}), (\overleftarrow{0.2}, \overrightarrow{1.6}))$. Through calculation, the fuzzy value is $\overrightarrow{82.2}$, and the risk level is medium–low with a trend of decreasing risk level. Among them, the fuzzy value of personnel risk is $\overrightarrow{80}$, the fuzzy value of equipment risk is $\overrightarrow{84.4}$, the fuzzy value of operation and maintenance risk is $\overrightarrow{82.2}$, the fuzzy value of operation control risk is $\overrightarrow{83}$, and the fuzzy value of technical risk is $\overrightarrow{80.2}$. The risk levels of all first-level indicators are medium–low and have a decreasing trend, indicating that the evaluation model has good practical performance. The results of the subsequent two experimental evaluations are consistent with the survey experiment, with the safety risk level being medium–low and showing a downward trend, indicating that the evaluation model has good practical performance.
- From a local perspective, as shown in Figure 7a, among the personnel risks, except for the risk level of operator proficiency being medium–low and showing a downward trend, the risk levels of other secondary evaluation indicators are medium and show a downward trend; in terms of equipment risks, all secondary evaluation indicators have medium–low risk levels, but except for the risk level of equipment operation status showing an upward trend, all other secondary evaluation indicators have a downward trend; in terms of operation and maintenance risks, except for the risk level of operator operation specifications being medium and showing a downward trend, all other secondary evaluation indicators have medium–low risk levels and show a downward trend; in terms of operation control risks, except for the risk level of operation site control being medium and showing a downward trend, all other secondary evaluation indicators have medium–low risk levels and show a downward trend; in terms of technical risks, except for the risk level of operation plan design feasibility being medium and showing a downward trend, all other secondary evaluation indicators have medium–low risk levels and show a downward trend.

According to the results of the on-site investigation, the equipment used in the project is qualified and has a short service life, the professional level of the operators is high, the safety control of the site is reasonable, and the overall risk level is low, which is consistent with the evaluation results. However, it is necessary to regularly evaluate the operation requirements of the converter station and optimize the design scheme. At the same time, it is also necessary to strengthen the control of the construction site, pay attention to the observation of the operation status of the equipment, and concentrate manpower, physical and financial resources to monitor and prevent it if necessary.

6. Conclusions

Based on the motion blur theory, this paper proposes a method for evaluating the operation safety of converter stations. By combining the WBS-RBS risk identification method with the vague set screening method, the risk factors were dynamically identified and screened so as to construct a comprehensive safety risk evaluation index system for converter station operation. Then, based on the motion blur theory, the dynamic blur values of the evaluation indicators at all levels were calculated, and the dynamic evaluation of the operation safety of the converter station was completed. The conclusions drawn from the empirical verification are as follows:

- This method adopts the WBS-RBS decomposition structure and the vague set screening method, which can identify and screen risk factors more comprehensively and systematically, and these methods overcome the problems of incomplete and subjective identification of risk factors by traditional methods. At the same time, the introduction of dynamic fuzzy theory can carry out a static and dynamic analysis of risks, which can not only evaluate the current risk level but also predict the trend of risk changes and provide a scientific basis for risk managers to formulate risk early warning systems and risk response measures, which has strong practicability and innovation.
- The experimental data required by this method need to be obtained through questionnaire surveys and other methods, and the data quality has a great impact on the evaluation results, so it is necessary to further improve the data acquisition methods and data quality control measures. In addition, the effectiveness of this method needs to be further verified in other converter stations and engineering projects.

In the future, we will further optimize the way we obtain data, develop an intelligent data collection system, and establish a data quality control mechanism to ensure the accuracy and reliability of data. At the same time, the application scope of the method can be expanded and applied to the risk assessment of other power facilities and fields to improve the level of risk management in related fields.

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Data Availability Statement: The data presented in this study are openly available in [ETDataset] (https://github.com/zhouhaoyi/ETDataset, accessed on 14 November 2024).

Conflicts of Interest: Authors Yanzhe Song and Yanjie Zhuang were employed by the company State Grid Electric Power Research Institute Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Sperstad, I.B.; Kjølle, G.H.; Gjerde, O. A comprehensive framework for vulnerability analysis of extraordinary events in power systems. *Reliab. Eng. Syst. Saf.* **2020**, *196*, 106788. [CrossRef]
2. Feng, J.R.; Yu, G.; Zhao, M.; Zhang, J.; Lu, S. Dynamic risk assessment framework for industrial systems based on accidents chain theory: The case study of fire and explosion risk of UHV converter transformer. *Reliab. Eng. Syst. Saf.* **2022**, *228*, 108760. [CrossRef]
3. Huang, W.; Sun, L.; Yang, Z.; Yin, Y. Using Radial Basis Function and Back Propagation to predicate fault in a railway dangerous goods transportation system considering the Markov Correction. *Appl. Soft Comput.* **2023**, *145*, 110593. [CrossRef]
4. Li, L.; Li, R.; Zhi, M.; Wang, S.; Cao, L. Risk Assessment of Building Foundation Pit Construction Based on Fuzzy Hierarchical Comprehensive Evaluation Method. *Geofluids* **2022**, *2022*, 9317700. [CrossRef]
5. Mu, D.; Lin, S.; Zhang, H.; Zheng, T. A novel fault identification method for HVDC converter station Section based on energy relative entropy. *IEEE Trans. Instrum. Meas.* **2022**, *71*, 3507910. [CrossRef]

6. Wang, T.; Du, Z.A.; Zhang, K.; Chen, K.; Xiao, F.; Ye, P. Reliability evaluation of high voltage direct current transmission protection system based on interval analytic hierarchy process and interval entropy method mixed weighting. *Energy Rep.* **2021**, *7*, 90–99. [CrossRef]
7. Liu, T.; Zhang, T.; Chen, J.; Bin, Y.; Shen, Y.; Liu, X. Research on Optimal Inspection Period of Secondary Equipment of Converter Station in High Altitude Area Based on BP Neural Network. In Proceedings of the 2022 3rd International Conference on Advanced Electrical and Energy Systems (AEES), Lanzhou, China, 23–25 September 2022; pp. 134–138.
8. Qie, Z.; Yan, H. A causation analysis of Chinese subway construction accidents based on fault tree analysis-Bayesian network. *Front. Psychol.* **2022**, *13*, 887073. [CrossRef]
9. Bouzon, M.; Govindan, K.; Rodriguez, C.M.T.; Campos, L.M. Identification and analysis of reverse logistics barriers using fuzzy Delphi method and AHP. *Resour. Conserv. Recycl.* **2016**, *108*, 182–197. [CrossRef]
10. You, Q.; Zhang, Z.; Wang, H.; Xu, M. Risk identification of subway tunnel shield construction based on WBS-RBS method. *Int. J. Crit. Infrastructures* **2023**, *19*, 261–273. [CrossRef]
11. Song, D.; Wang, B.; Pang, J.; Guo, Z.; Wang, A.; Niu, Y. Feasibility Evaluation of Highwall Mining in Open-Pit Coal Mine Based on Method of Integrated Analytic Hierarchy Process–Fuzzy Comprehensive Evaluation–Variable Weight Theory. *Electronics* **2023**, *12*, 4460. [CrossRef]
12. Panchal, S.; Shrivastava, A.K. Landslide hazard assessment using analytic hierarchy process (AHP): A case study of National Highway 5 in India. *Ain Shams Eng. J.* **2022**, *13*, 101626. [CrossRef]
13. Liu, H.; Yang, F.; Wang, X.; Si, J. Mathematical Formula Image Screening Based on Feature Correlation Enhancement. *Electronics* **2022**, *11*, 799. [CrossRef]
14. Yu, H.; Wu, Q.; Zeng, Y.; Zheng, L.; Xu, L.; Liu, S.; Wang, D. Integrated variable weight model and improved DRASTIC model for groundwater vulnerability assessment in a shallow porous aquifer. *J. Hydrol.* **2022**, *608*, 127538. [CrossRef]
15. Zhao, Z.; Gu, J. Risk evaluation of mine-water inrush based on comprehensive weight method. *Geotech. Geol. Eng.* **2023**, *41*, 189–203. [CrossRef]
16. Yang, F.; Zhang, J.; Jin, B.; Wang, S.; Xi, C. Study on the emergency capacity of coal mine enterprises in Longdong Area based on D-FAHP method. *Sci. Rep.* **2023**, *13*, 7503. [CrossRef]
17. Su, H.; Guo, C.; Wang, Z.; Han, T.; Kamanda, D.B.; Su, F.; Shang, L. Research on safety condition assessment methodology for single tower steel box girder suspension bridges over the sea based on improved AHP-fuzzy comprehensive evaluation. *Sci. Rep.* **2024**, *14*, 12079. [CrossRef] [PubMed]
18. Guo, B.H.; Zou, Y.; Fang, Y.; Goh, Y.M.; Zou, P.X. Computer vision technologies for safety science and management in construction: A critical review and future research directions. *Saf. Sci.* **2021**, *135*, 105130. [CrossRef]
19. Hu, Y.; Miao, X.; Si, Y.; Pan, E.; Zio, E. Prognostics and health management: A review from the perspectives of design, development and decision. *Reliab. Eng. Syst. Saf.* **2022**, *217*, 108063. [CrossRef]
20. Mohandes, S.R.; Zhang, X. Developing a Holistic Occupational Health and Safety risk assessment model: An application to a case of sustainable construction project. *J. Clean. Prod.* **2021**, *291*, 125934. [CrossRef]
21. Liang, M.; Yang, G.; Zhu, X.; Cheng, H.; Zheng, L.; Liu, H.; Dong, X.; Zhang, Y. AHP-EWM based model selection system for subsidence area research. *Sustainability* **2023**, *15*, 7135. [CrossRef]
22. Okarma, K.; Lech, P.; Lukin, V.V. Combined Full-Reference Image Quality Metrics for Objective Assessment of Multiply Distorted Images. *Electronics* **2021**, *10*, 2256. [CrossRef]
23. Guo, X.; Ji, J.; Khan, F.; Ding, L.; Tong, Q. A novel fuzzy dynamic Bayesian network for dynamic risk assessment and uncertainty propagation quantification in uncertainty environment. *Saf. Sci.* **2021**, *141*, 105285. [CrossRef]
24. South, L.; Saffo, D.; Vitek, O.; Dunne, C.; Borkin, M.A. Effective use of Likert scales in visualization evaluations: A systematic review. *Comput. Graph. Forum* **2022**, *41*, 43–55. [CrossRef]

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