Research Article

Evaluation Algorithm of Disaster Response Capability of Intelligent Distribution Network Based on Fuzzy Comprehensive Evaluation

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Because most of the production and transmission components of the power system are exposed to the natural environment, they are vulnerable to the threat of natural disasters for a long time and the resulting circuit damage is also large. With the improvement of people’s living standards and the improvement of electricity demand, more and more attention has been paid to the normal operation of the power system. Improving the disaster resistance ability of the power system is an important prerequisite to ensure the national economy and life. In view of the above problems, in order to solve and improve the power supply recovery ability of the distribution network in the face of various disasters, this paper focuses on the analysis of the disaster response stage of the intelligent distribution network under natural disasters and the comprehensive data and related indicators of the power grid system, so as to establish the evaluation index system of the power grid’s predisaster tolerance and postdisaster resilience and, through the introduction of the fuzzy comprehensive evaluation theory, quantifying the disaster response capability of the distribution network. Finally, through the introduction of case analysis, the case results show that the intelligent distribution network disaster response ability evaluation algorithm based on fuzzy comprehensive evaluation constructed in this paper can accurately calculate the disaster response ability of the distribution network and has an important guiding role in the disaster prevention and reduction of the distribution network.

1. Introduction

Power grid is an important foundation for the sustainable development of social economy. In recent years, abnormal global climate change has led to the frequent occurrence of extreme natural disasters, and the impact of various high-risk and small probability extreme natural disasters on the power grid has increased significantly [1–3].

With the continuous development of the power system, its functions and structures have become more huge and complex, and the requirements for the reliability, stability, and accuracy of the electrical components included in the system have become higher and higher. However, during the operation of the power system, when extreme natural disasters occur and have an impact on the power grid, each operating device in the power system will inevitably have problems or even failures. Once the equipment of the power grid fails to be found, solved, and handled in a timely manner, the power grid may have a profound impact on social and economic development and people’s normal life and even cause casualties [4, 5]. Meanwhile, the power system is an uncertain, time-varying, and nonlinear system. For the current existing technology, the system fault also needs to continuously accumulate experience and improve the model to improve the accuracy of fault estimation [6–9]. At present, the damage events caused by system equipment failures have occurred at home and abroad, causing huge losses to all countries. In China, the impact and damage caused by typhoon disasters on the normal operation of power grids in southeast coastal cities every year is huge [10]. Therefore, it is of great significance to study the power grid’s ability to cope with extreme natural disasters and its
recovery ability after disasters. It can not only help the power grid identify the weak links of the power grid under extreme natural disasters, but also help to deal with extreme natural disasters, so as to reduce the losses caused by extreme natural disasters to the power grid and ensure social stability and sustainable development [11–14].

At present, the research on the prevention of tooth decay in the safe operation and maintenance of power grid equipment is reflected in two aspects: one is the research on the model based on parameter evaluation; the second is to build a relevant research index system [15–18]. For the research of the former, both domestic and foreign scholars mainly focus on the research of meteorology and rarely based on the distribution network itself [19]. Literature [17, 20–22] studies the establishment of an index evaluation system for power grid emergency response capacity, but does not consider the dynamics of related indicators, resulting in uncertainty in the evaluation results. Literature [23] improves the relevance between index systems, but the analytic hierarchy process used in the evaluation is subjective and lack of objective factors. Literature [24–26] establishes a multi-index evaluation model based on extreme disturbance events, and weighs the impact of subjectivity and objectivity. However, there is a lack of quantitative analysis of power grid response to events and index redundancy, which has certain limitations [27–30]. In summary, it can be found that the assessment of the disaster response capacity of the distribution network at this stage is basically at the initial stage. Although the research methods of the existing scholars are diverse and have made great achievements, there are still problems such as the depth of the research is not deep, the research methods are single and not intelligent, and the overall assessment effect is poor.

In view of the above problems, this paper proposes a method based on fuzzy comprehensive evaluation to quantitatively evaluate the disaster response capacity of power grid and divide the predisaster bearing and post-disaster recovery stages of the power grid with the time dimension, and use the analytic hierarchy process to build two types of evaluation system and obtain the subjective weight. At the same time, to reduce the subjective and objective influencing factors in the evaluation process, the comprehensive weight of the index is obtained by combining the two weights. Finally, the fuzzy comprehensive evaluation is applied to enhance the correlation between the indicators and quantify the evaluation results of power grid disaster response capacity, and the effectiveness and feasibility of the method are verified by a case.

2. Analysis of Distribution Network Operation Risk Sources and Risk Indicators

2.1. Analysis of Distribution Network Operation Risk Sources

The risks encountered by the distribution network in the operation process come from all aspects, such as bad weather, equipment defects, human factors, load factors, and distributed power factors. These risk sources will be analyzed separately below.

2.1.1. Severe Weather Risk Source

(1) Lightning: lightning stroke is one of the main causes of power failure accidents in distribution network. According to different action modes, lightning stroke can be divided into direct lightning and induction lightning. As the name suggests, direct lightning is that lightning directly hits overhead lines, while induction lightning is that lightning strikes objects near the conductor, and overvoltage is formed on the conductor due to electrostatic induction. Whether direct lightning strike or overvoltage caused by induced lightning, it is easy to cause insulator flashover, and even the thermal effect of lightning will burn out the conductor. It can be seen that lightning strikes pose a great threat to the safe and reliable operation of the distribution network.

(2) Temperature: the influence of temperature on the distribution network is not as obvious as that of lightning. Its influence mode mainly has two aspects: first, the temperature is closely related to the insulation level of power equipment. The current passed by the power equipment during operation will generate a certain amount of heat. If the ambient temperature of the equipment is too high, it is difficult to dissipate the generated heat in time and gradually accumulate, which will lead to the damage of the insulation layer. Second, the temperature determines the load of the distribution network to a certain extent. For example, high-temperature weather will lead to a large increase in the load of air conditioning, and low-temperature weather will lead to a large increase in the heating load of heaters. The sharp increase of these loads will undoubtedly increase the risk of line overload.

(3) Pollution: during the operation of the distribution network, dust, bird droppings, and other pollution will accumulate on the insulator or insulator string. When the accumulation reaches a certain degree, the insulation level of the insulator will be affected, and it is easy to cause insulator flashover in wet weather such as fog or light rain. Generally, insulator flashover caused by pollution is a transient fault.

(4) Icing: in cold weather, ice is easy to accumulate on overhead lines. According to different ways, the risk of icing on distribution network can be divided into five categories: overhead line vibration caused by excessive icing on overhead lines, uneven icing of adjacent gears, falling off of icing, substation icing accident, and insulator flashover.

(5) Windy: under windy weather conditions, due to the action of the transverse force of the wind, it is easy to cause short-circuit discharge between the distribution network lines (non-insulated conductors) or burn the conductors due to insulator flash. In windy weather, the distribution line is most prone to short-circuit grounding. At the same time, the strong wind
2.1.2. Risk Sources of Equipment Defects. In addition to the common defects of power equipment such as aging insulation or reduced insulation level, the factors affecting the operation risk of equipment also include overload, overvoltage, and short circuit. Overvoltage generally refers to the system ferromagnetic resonance overvoltage, which has a high probability in the distribution network. This is because the operation state of power equipment such as voltage transformers and welding machines is prone to sudden changes due to the different lengths and specifications of distribution network lines. When ferroresonance overvoltage occurs in the system, the current flowing through the transformer will increase sharply, causing damage to the transformer. More seriously, it may cause the explosion of the transformer shell or bushing.

For short-circuit fault, when a short circuit occurs at the secondary side of the transformer, if the short-circuit current cannot be limited in time, it will cause the transformer coil to be squeezed, resulting in loose insulation or falling off. In addition, the fault current will also cause the rapid rise of coil temperature, which will seriously affect the health of transformer equipment.

2.1.3. Risk Sources of Human Factors. The human factor risk of distribution network can be divided into external force damage and misoperation:

(1) External force damage: external force damage of distribution network (hereinafter referred to as external damage) generally refers to the damage of cables or overhead lines under the influence of external forces. External damage accidents of the power system are common, such as cutting cables during construction and the crane touching overhead lines during work. In addition, common external damage accidents also include: towers or other power equipments are damaged due to traffic accidents. If the wires are not cleaned up in time, if the fishing line is thrown onto the overhead line in case of fishing and other activities, it is very easy to cause short circuit of the overhead line. When the power system is damaged by these external forces, it will lead to short circuit, disconnection, equipment damage, and other accidents, which will not only seriously affect the safe and normal operation of the power system, but also pose a great threat to personal safety.

(2) Misoperation: since the manual operation of the power system is generally carried out in places such as substations and distribution rooms, misoperation accidents generally occur in these places. Power accidents caused by misoperation are generally serious, so it is necessary to standardize the relevant operation process to avoid power accidents caused by misoperation as much as possible.

2.1.4. Load Factor Risk Sources

(1) User failure: if power users do not comply with the electricity safety specifications, it is also easy to lead to power failure, causing damage to electrical equipment and threatening their own safety. If the fault cannot be removed in time and selectively, it will also lead to the expansion of the fault range and affect the normal power supply of other users.

(2) Peak power consumption: in hot summer or cold winter, power users will turn on air conditioning or heating equipment in a centralized manner, forming a peak power consumption. If the local distribution network develops backward, it is easy to cause line overload and heating, further damage the insulation of power equipment, and even cause unnecessary power cuts.

2.1.5. Risk Sources of Distributed Power. A large number of distributed generators connected to the distribution network will have a certain impact on the original power grid, such as affecting the power flow and voltage distribution of the system. Once the line is overloaded, the overload protection action will be triggered, resulting in power failure of the downstream users. In addition, if the system node has overvoltage, it is easy to increase the risk of equipment damage.

2.2. Analysis of Distribution Network Operation Risk Indicators. According to the difference of the operation state of the distribution network, the risk indicators faced in the operation process of the power grid can be divided into two ways: one is the fixed index; the second is the change index of dynamic time change. The former mainly aims at the static operation state of the distribution network, such as voltage or power flow fluctuation caused by DG output fluctuation and load fluctuation in the system. The latter aims at the transient operation state with large disturbances such as short circuit, and the risk of fault current exceeding the upper limit.

2.2.1. Risk Indicators of Voltage out of Limit of Distribution Network. For distributed power generation, its intervention position in the distribution network is changing, and when it is connected to the grid, it can also transmit and store the excess electric energy to the upper power grid. At this time, the voltage of the parallel node will increase significantly, which has the risk of overvoltage. The expression is

\[ \text{Risk}(U_i) = \sum_{i=1}^{n} \text{Pro}(U_i) \cdot \text{Sev}(U_i), \]

where \( U_i \) represents the \( i \)-th overvoltage state; \( \text{Risk}(U_i) \) represents the risk value of the \( i \)-th overvoltage state; and
Pro ($U_i$) and Sev ($U_i$) represent the probability and severity of overvoltage, respectively.

To ensure the safe and reliable normal operation of power equipment, the voltage shall be kept within the specified range. Low voltage or high voltage has certain risks. Low voltage will affect the normal operation of power equipment, such as dimming and burning motor in addition, it will increase the line loss of the system and affect the stability of normal operation of power equipment. High voltage will aggravate the aging of equipment insulation, and even damage the equipment and even cause fire. Whether the voltage is too high or too low, the protection device may be triggered, resulting in power failure. When the voltage is too high or too low, the protection device may even damage the equipment and even cause fire. Whether the voltage will aggravate the aging of equipment insulation, and stability of normal operation of power equipment. High voltage will increase the line loss of the system and affect the equipment, such as dimming and burning motor in addition.

**Severity out of limit:**

We can get the function to measure the severity of power flow transmission power of the current line, respectively. When the node voltage is too high or too low, the protection device may even damage the equipment and even cause fire. Whether the voltage will aggravate the aging of equipment insulation, and stability of normal operation of power equipment. High voltage will increase the line loss of the system and affect the equipment, such as dimming and burning motor in addition.

$\text{Sev (}V_i\text{)} = \begin{cases} \frac{V_{\text{min}} - V_i}{V_{\text{min}}}, & V_i < V_{\text{min}}, \\ 0, & V_i \geq V_{\text{min}}, \\ \frac{V_i - V_{\text{max}}}{V_{\text{max}}}, & V_i > V_{\text{max}} \\ 0, & V_i \leq V_{\text{max}}, \end{cases}$

where $V_i$ is the voltage amplitude of node $i$, and $V_{\text{min}}$ and $V_{\text{max}}$ are the specified lower limit and upper limit of voltage, respectively.

It can be seen from (2) and (3) that the voltage out of limit severity function is a piecewise function. When $V_{\text{min}} \leq V_i \leq V_{\text{max}}$, it indicates that the voltage is not out of limit, and its risk severity is 0. When the node voltage amplitude is lower than its lower limit or higher than its upper limit, the risk severity will no longer be zero, and the greater the degree of exceeding the limit, the greater the risk severity. The severity function curve can be obtained from (2) and (3), as shown in Figure 1.

**2.2.2. Risk Indicators of Power Flow out of Limit in Distribution Network.** Similarly, the expression of the risk index of tidal current out of limit is

$$\text{Risk} (S_i) = \sum_{i=1}^{n} \text{Pro} (S_i) \cdot \text{Sev} (S_i),$$

where $S_i$ represents the $i$-th power flow out of limit state; Risk ($S_i$) represents the risk value of the $i$-th power flow out of limit state; and Pro ($S_i$) and Sev ($S_i$), respectively, represent the probability and severity of power flow out of limit.

Define scale factor:

$$k = \frac{S_i}{S_N},$$

where $S_i$ and $S_N$ are the actual transmission power and rated transmission power of the current line, respectively. Then, we can get the function to measure the severity of power flow out of limit:

According to the formula, the power flow out of limit severity function is also a piecewise function. When $k < 1$, it means that there is no power flow out of limit and the severity is 0. When $k > 1$, it indicates that the power flow is out of limit, and the severity becomes more serious as the out of limit becomes greater. Figure 2 shows the function curve shown in equation (6).

**2.2.3. Risk Indicators of Distribution Network Loss of Load.** Power system load loss refers to the loss of load due to faults and other reasons, and its risk index expression is

$$\text{Risk} (L_i) = \sum_{i=1}^{n} \text{Pro} (L_i) \cdot \text{Sev} (L_i),$$

where: $L_i$ represents the $i$-th load loss state; Risk ($L_i$) represents the risk value of the $i$-th load loss state; and Pro ($L_i$) and Sev ($L_i$) represent the probability and severity of load loss, respectively.

Load loss risk refers to the product of the magnitude and probability of the load lost by the distribution system due to faults or constraints of electrical parameters of the grid in a certain period of time in the future.

**2.2.4. Long-Term Expected Indicators in Case of Power Failure.** The power supply capacity is an important index to evaluate the power system. The loss of load expectation (LOLE) is used to reflect the power shortage situation. Its meaning is the expectation of hours that the system cannot meet the load demand in a certain period of time in the future. The expression is

$$\text{Risk} (\text{LOLE}) = \sum_{i \in S} P_i \cdot T,$$

where $P_i$ represents the probability of the occurrence of state $i$; $T$ is the number of hours; and $S$ is the set of all States in the system that cannot meet the load demand.
2.2.5. Risk Indicators of Frequency out of Limit of Distribution Network. The rated frequency of China’s power grid is 50 Hz. Too low or too high frequency will lead to insufficient or excessive output of some power loads, resulting in product quality problems, personal or equipment safety problems, and adverse effects on the power generation system. After the power support function of the large power grid is lost, the isolated distribution network is limited by the output regulation ability of the distributed generation, and the active power is more likely to lose balance, resulting in increased frequency fluctuation of the system and increased risk of frequency overrun. For this reason, the frequency out of limit risk index is proposed, and its expression is

\[ \text{Risk}(f) = \sum_{j \in H} F_j \cdot T_j, \]  

where \( F_j \) represents the probability of exceeding the limit of the \( j \)-th occurrence frequency; \( T_j \) refers to the number of hours that the frequency of the \( j \)-th occurrence exceeds the limit; and \( H \) represents the set of states in which the frequency of the island distribution network exceeds the limit.

3. Construction of the Evaluation Index System for Disaster Response Capability of Intelligent Distribution Network

3.1. Division of Disaster Response Stages of Power Grid. To improve the power grid’s ability to cope with natural disasters, it is necessary to adopt corresponding strategies and schemes at different stages of natural disasters for disaster relief. The power grid is greatly damaged by natural disasters, and the damage and impact of natural disasters on the power grid are carried out in the space-time dimension. From the perspective of improving the resilience of power grid, the process of disaster prevention is divided into three stages as shown in Figure 3: planning measures stage, predisaster prevention stage, and disaster recovery stage. The predisaster stage refers to a period of time before a disaster occurs in the distribution network, also known as the disaster avoidance stage. The postdisaster stage generally refers to the stage from the occurrence of power grid disasters to the completion of rescue, which is also an important stage in disasters. The disaster stage refers to the period of time when the disaster occurs. In the disaster stage, the power grid response measures are relatively limited, so this paper divides the power grid response process into the predisaster bearing stage and the postdisaster recovery stage in terms of time dimension.

3.2. Distribution Network Disaster Bearing Index System. In the process of putting power grid equipment into use, the action mechanism of disasters on equipment and the relationship between action factors maintain a certain relationship, which is manifested in disaster factors, i.e., disasters such as environment, disaster bearers, i.e., power grid equipment, and disaster environment, i.e., space conditions [13]. For disaster bearing equipment, it is generally formulated by China’s unified standards. For general disasters, it has a certain resistance, but when facing extreme weather, relevant targeted countermeasures should be considered. For the distribution network, we should pay more attention to the impact of some extreme weather to prevent the impact of extreme weather.

3.3. Postdisaster Resilience Index System of Distribution Network. According to the restoration process of the power grid after being disturbed and divided by the maintenance process and time, the predisaster stage focuses on prevention, while the postdisaster stage focuses on rapid emergency repair to restore the normal operation state of the system [15]. The system restoration process after disaster disturbance is shown in Figure 4.

When the power grid system reaches the lowest point in resisting the absorption disturbance, it enters the postdisaster recovery stage. It is divided into three parts to build the postdisaster resilience index of power grid: the resilience index of power grid frame, the resilience index of power grid load, and the regulation and control ability index of emergency resources.
4. Quantitative Evaluation of Disaster Response Capability of Intelligent Distribution Network Based on Fuzzy Comprehensive Evaluation

4.1. Standardization of Evaluation Indicators. In these two different indicator systems, due to the difference in internal factors, the selected indicators are different, but there is no essential difference between the indicators except for the difference in dimension. Therefore, to achieve scientific and reasonable system configuration, data standardization tools should be used to standardize the relevant indicator data before evaluation, so as to eliminate the impact of data dimensions on the results and ensure the rationality and accuracy of the results [18, 31], and then calculate and allocate the comprehensive weight after processing. Standardization is calculated according to

$$ r_{ij} = \begin{cases} \frac{r_{ij}' - \min r_{ij}'}{\max r_{ij}' - \min r_{ij}'}, & \text{if } r_{ij}' > \min r_{ij}' \text{ and } r_{ij}' < \max r_{ij}' \\ \frac{\max r_{ij}' - r_{ij}'}{\max r_{ij}' - \min r_{ij}'}, & \text{if } r_{ij}' > \max r_{ij}' \text{ or } r_{ij}' < \min r_{ij}' \end{cases} $$

where $r_{ij}$ is the standardized value of the $j$-th index of the $i$-th expert and $r_{ij}'$ is the original data before standardization.

After standardization, the evaluation index matrix can be obtained, as shown in

$$ R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}, $$

where $R$ is the evaluation index matrix; $m$ is the number of experts; and $n$ is the number of comprehensive evaluation indicators.

4.2. Entropy Weight Method to Calculate Weight. When using entropy weight method to analyze various indicators of distribution network, the internal information of relevant indicators should be mined and considered. When using this method to calculate the distribution network’s disaster response capacity for different environments, the calculation formula and process are as follows:

The evaluation index of power grid disaster response ability by multiple experts relies on the judgment matrix $X = (x_{ij})_{m \times n}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$ composed of expert experience assignment. Standardize the $X$ judgment matrix, as shown in

$$ r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, $$

where $r_{ij}$ is the standardized index value and $x_{ij}$ is the score of the $j$-th index of the $i$-th expert.

Calculate the entropy value of the standardized index data. The entropy value of the $i$-th expert for the $j$-th index is shown in

$$ H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} u_{ij} \ln u_{ij}, $$

where $H_j$ is the calculated entropy, $j = 1, 2, \ldots, n$. When $u_{ij}$, let $u_{ij} \ln u_{ij} = 0$, and calculate the entropy weight of the $j$-th index, as shown in

$$ \omega_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}, $$

where $\omega_j$ is the entropy weight of the index and $H_j$ is the entropy of the index.
4.3. Quantitative Analysis of Power Grid Disaster Response Capacity Evaluation. Fuzzy comprehensive evaluation method is a method based on fuzzy set theory, which deals with the fuzzy classification and quantification of the evaluation object, and finally judges and grades the evaluation results. In this chapter, the evaluation results of disaster response capability are divided into five levels, that is, the fuzzy evaluation set $V$ is composed of five levels: $V_1$ (strong disaster response capability), $V_2$ (strong disaster response capability), $V_3$ (general disaster response capability), $V_4$ (weak disaster response capability), and $V_5$ (weak disaster response capability). The fuzzy subsets of different indicators for different comments are described by membership functions. Gauss-type membership function is used $f(x, \sigma, c)$ to calculate here.

$$f(x, \sigma, c) = e^{-((x-c)^2/2\sigma^2)},$$  

(15)

where $f(x, \sigma, c)$ is the membership function; $x$ is the decision index; and $\sigma$ and $c$ are the two parameters of Gauss membership function, and $\sigma$ is taken as 0.3.

To ensure that each index has five evaluation membership degrees, five $c$ values are adopted: $r_{ij}$. The membership functions corresponding to the five evaluation sets are obtained by substituting them into (15). At the same time, the index $r_{ij}$ in $R$ calculated previously is substituted into the membership function of five evaluation levels, and the evaluation matrix is obtained, as shown in

$$F = \begin{bmatrix}
    f_{V_1}(r_{11}) & \cdots & f_{V_1}(r_{1n}) \\
    \vdots & \ddots & \vdots \\
    f_{V_5}(r_{51}) & \cdots & f_{V_5}(r_{5n})
\end{bmatrix},$$  

(16)

where $F$ is the index evaluation matrix and $f_{V_i}(r_{ij})$ ($i = 1, 2, \ldots, 5$; $j = 1, 2, \ldots, n$) is the subordinate degree of index $r_{ij}$ to evaluation grade $V_k$.

Considering that among the four operators commonly used in fuzzy comprehensive evaluation, $M(\bullet, \oplus)$ operator is highly comprehensive and can make full use of the information in the judgment matrix, so $M(\bullet, \oplus)$ operator is adopted and the overall evaluation result $T_i$ obtained by the evaluation system is determined according to the principle of average weighting:

$$T_i = \omega M(\bullet, \oplus),$$  

$$F = [t_i(V_1)t_i(V_2)t_i(V_3)t_i(V_4)t_i(V_5)],$$  

(17)

where $t_i(V_k)$ represents the membership degree of each index relative to $V_k$, that is, the degree that can be described by $V_k$. To intuitively understand the evaluation results, the fuzzy evaluation set is quantified accordingly. The quantification and classification are shown in Table 1, and the calculation formula is

$$Z_i = \sum_{k=1}^{5} T_i(V_k) \times V_k.$$  

(18)

According to the comprehensive score results obtained from the evaluation calculation, judge its range, and then get the grade evaluation results of the disaster response capacity of the distribution network in the region.

4.4. Design of the Fuzzy Comprehensive Evaluation System. Based on the obtained comprehensive weight, the fuzzy comprehensive evaluation method is used to evaluate and grade the disaster response ability of the regional distribution network. The comprehensive weight vector and fuzzy evaluation matrix $f$ are fuzzy multiplied to obtain the evaluation result of disaster response ability. On this basis, the fuzzy comprehensive evaluation system of distribution network is established, as shown in Figure 5.

5. Case Analysis

Take the lightning arrester evaluation of a power supply company as an example. To simplify the calculation and the feasibility of the scheme, only four monitoring indicators are selected into the model, and their limits are shown in Table 2.

5.1. Membership Function. Taking the leakage current under $0.75U_{1mU}$ as an example, let the leakage current belonging to level 1 be less than $40\, \mu A$, while levels 2, 3, and 4 are $47.6, 42.4$, and $50.0\, \mu A$, respectively, and the corresponding deterioration degrees $G$ are $0.76, 0.24$, and $1.0$. Then, the membership functions of levels 1, 2, 3, and 4 can be obtained as shown in

$$\begin{align*}
    1, & \quad g \leq 0, \\
    1 - 3g, & \quad 0 < g < 0.33, \\
    0, & \quad g \geq 0.33, \\
    3g, & \quad g < 0.33, \\
    2 - 3g, & \quad 0.33 < g < 0.67, \\
    0, & \quad g \geq 0.67, \\
    3g - 1, & \quad 0.33 < g \leq 0.67, \\
    3 - 3g, & \quad 0.67 < g < 1, \\
    0, & \quad g \leq 0.33, \\
    1 - 3g, & \quad 0.67 < g < 1, \\
    1, & \quad g \geq 1.
\end{align*}$$

(19) (20) (21) (22)
5.2. Judgment Matrix. Taking the leakage current at 0.75 $U_{1mA}$ as an example, since the measured value is 47.6 $\mu$A, the deterioration degree $g(x) = (47.6 - 40) / (50 - 40) = 0.76$ is calculated accordingly. When the value is derived into the membership function, the membership degrees of level 1, 2, 3, and 4 corresponding to the monitoring and measurement can be generated, which are 0.00, 0.67, 0.33, and 1.00 respectively. The other three state quantity calculation methods are the same. The final evaluation matrix is

$$V = \begin{bmatrix}
0.20 & 0.54 & 0.12 & 0.14 \\
0.52 & 0.16 & 0.42 & 0.00 \\
0.69 & 0.31 & 0.00 & 0.00 \\
0.93 & 0.00 & 0.00 & 0.07
\end{bmatrix}.$$  \hspace{1cm} (23)

5.3. Weight Coefficient. After completing the above two steps, we also need to allocate the weight coefficients of relevant data. The main process is as follows: Step 1: collect information from experts in relevant fields within the scope of ability, and convene experts in relevant fields who may be called to participate in the evaluation of weight coefficient; Step 2: according to the principle of analytic hierarchy process, the relevant data is hierarchized; Step 3: calculate the weight coefficient according to the expert scoring and analytic hierarchy process. The weight coefficient obtained in this paper is $A$.

$$A = [0.32 \ 0.21 \ 0.16 \ 0.00].$$  \hspace{1cm} (24)

5.4. Status Evaluation. The weight is imported into the evaluation matrix, and the evaluation result is

$$B = A \times V = [0.14 \ 0.81 \ 0.13 \ 0.00].$$  \hspace{1cm} (25)

Obviously, based on the idea of maximum membership, the equipment is most likely to be in the “level 2” state.
(because the membership of this level is the largest). In this way, for the evaluated equipment, the following evaluation conclusion can be obtained: although the equipment belongs to the bad state, it is also possible to continue to operate.

6. Conclusion

The distribution network is located at the end of the power grid and is the “capillary” of the entire power system network. It is closely related to the user’s load. Improving the response capacity of the distribution network in the event of disasters can effectively reduce the load blackout range and ensure the power supply reliability of the distribution network in the event of disasters. Therefore, this paper takes the distribution network as the research object, and analyzes and explores the disaster response ability evaluation and disaster resistance planning of the distribution network. Through analysis, the disaster response ability of distribution network is determined as the evaluation target, and based on this, the evaluation index system of safety reliability, power supply economy, intelligent interaction, and disaster resistance is established. The detailed evaluation indexes are obtained by refining the above four characteristics. By processing the evaluation data, the comprehensive weight among the indicators is determined. In addition, the fuzzy comprehensive evaluation method is used to evaluate the data, and its rationality is verified by an example. The results show that the evaluation algorithm of disaster response ability of intelligent distribution network based on fuzzy comprehensive evaluation constructed in this paper has good disaster response ability, and the relevant results also have a certain guiding role for disaster prevention and reduction of distribution network.

Data Availability

The dataset used in this paper is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

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