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Research on Teaching Planning and Teacher Evaluation Integrating Sustainable Development and Renewable Energy Concepts

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Abstract. Energy is an essential basis for human survival, social progress and economic development. With the rapid development of China's economy and the acceleration of urbanization, the problem of energy shortage is increasingly serious, and the problem of energy security is prominent. Based on stochastic power flow algorithm, this paper proposes the safety assessment and teaching planning of wind power generation in renewable energy. Firstly, the dynamic safety domain and thermal stability safety domain of wind power systems are proposed in this paper. Within the selected security domain, the key factors that are most likely to lead to the risk of a distribution network are selected by means of entropy-modified analytic hierarchy process (AHP). The incompleteness of the single weighting method is solved, and the total evaluation score of each layer of the index system is calculated from the subjective and objective perspectives to determine the weak link in the occurrence of accidents in the distribution network. The total score is less than 90 points, which is prone to failure risk. Finally, based on the safety index system, PLF is introduced into the uncertainty safety assessment of wind power systems to overcome the inefficiency of traditional uncertainty assessment methods. Methods PLF was used as a means of system state analysis to replace a lot of conventional power flow analysis in uncertain safety assessment, and related safety indexes were defined based on PLF results. The test system ST-PLF is taken as an example to verify the rationality of the proposed method. The results show that the proposed method can effectively realize the static security assessment of the system and identify the potentially vulnerable elements of the system. The evaluation time of the proposed method is 0.73 s, while that of the traditional method is 48.54 s. The evaluation speed of the proposed method is greatly improved, and the time is only 1.55% of that of Monte Carlo method.

Key words. Renewable Energy, Wind Power Generation, Security Assessment, Random Power Flow, Teaching Planning.

1. Introduction

For a rapidly developing country, energy security is an important topic, which is the focus of government and academic circles. Whether it is the content of state leaders' visits or the emergence of high-level energy management institutions, it highlights its importance [1]. Especially in recent years, some major energy shortages have affected production and life, while at the same time, it is a key moment to maintain stable and rapid economic development. Such an era has pushed the issue of energy security to a more important position [2]. Therefore, the research significance not only reflects the exploration of energy security theory, but also reflects the practice of national energy security, which is the starting point of this paper.

In the conceptual teaching of renewable energy, virtual reality technology can be innovatively applied. Through VR, students can enter a virtual solar power station, observe the working principle of solar panels, understand the photovoltaic effect, and even participate in the installation and maintenance process of solar battery boards. This simulation can help students better understand each part of solar electricity generation. Virtual reality can also be used to simulate the operation of a wind farm, allowing students to explore the working mechanism of wind turbines, including blade rotation, energy conversion, and electrical transmission, and even observe the performance changes of wind turbines under different weather conditions. Globally, educational standards and compliance requirements are essential to ensure the quality and consistency of education. In the field of renewable energy education, these standards help guide the design of courses, teaching methods, and assessment practices, ensuring that students acquire the skills and knowledge necessary to meet current and future needs. Make sure that the content of your renewable energy courses covers the key concepts stipulated in educational standards, such as energy transformation, sustainability, and environmental impact. The courses should help students understand the operating principles, applications, and roles of renewable energy technologies within the energy system.

At present, just as Narula K said, the research on energy security is like a blind person feeling the elephant. Everyone will give different views, so it is necessary to develop different perspectives and research methods in order to understand the comprehensive and true energy security [3]. Cox E evaluated the energy security of the British power system considering the low-carbon background [4]. Turton H and Barreto L believe that energy security issues caused by geopolitical development and climate change are the most important aspects of maintaining a global sustainable energy system [5]. Bollen and Hers et al. measured the impact of energy security policy, climate change response policy and environmental pollution control policy, and pointed out that the benefits of the integrated implementation of the two policies are the largest [6]. Based on the above background, some scholars have given energy security a richer meaning, representative of which are: Cherp A and Jewell J et al. define energy security as the low physical and economic vulnerability of important energy systems. They believe that in the long run, climate policies can reduce the dependence of energy supply, energy structure and energy trade on fossil energy consumption and economic growth [7].

The innovation of this paper lies in the establishment of a security index by entropy-modified analytic hierarchy process and a new method of static security assessment of power grid based on PLF. Firstly, the dynamic safety domain and thermal stability safety domain of wind power systems are proposed in this paper. Within the selected security domain, the key factors that are most likely to lead to the risk of a distribution network are selected by means of entropy-modified analytic hierarchy process (AHP). The incompleteness of the single weighting method is solved, and the total evaluation score of each layer of the index system is calculated from the subjective and objective perspectives to determine the weak link in the occurrence of accidents in the distribution network. The total score is less than 90 points, which is prone to failure risk. Finally, based on the safety index system, PLF is introduced into the uncertainty safety assessment of wind power systems to overcome the inefficiency of traditional uncertainty assessment methods. Methods PLF was used as a means of system state analysis to replace a lot of conventional power flow analysis in uncertain safety assessment, and related safety indexes were defined based on PLF results. The test system ST-PLF is taken as an example to verify the rationality of the method.

2. Security Domain of Wind Power System

A. Dynamic Security Domain

The dynamic safety domain of a wind power system is a space containing all operating points that enable the system to operate safely during dynamic load response:

$$\mathbf{R}_{\mathrm{gd}} = \{\mathbf{L} |\ g(\mathbf{L}) = 0, f(\mathbf{L}) \le 0\} \tag{1}$$

Generally speaking, when solving the security domain, it is only necessary to pay attention to the critical point located on the boundary, and it is unnecessary to obtain all the operation points in the domain [8]. The main difference between different critical point methods lies in the design of search strategy. In order to ensure the method is easy to implement and has strong applicability, this paper proposes a critical point solution method based on load growth direction. Assumed system load:

$$\mathbf{L} = \mathbf{L}_0 + \lambda \Delta \mathbf{L} \tag{2}$$

Due to system security constraints, the load cannot be increased or decreased indefinitely. Therefore, the selection of λ needs to meet certain rules. This property is used to transform critical point finding into a series of optimization problems:

$$\max \lambda$$
$$\text{s.t.} \begin{cases} \begin{bmatrix} \mathbf{C} \\ \mathbf{E} \\ \mathbf{F} \end{bmatrix} \cdot \mathbf{X}(t+k) = \begin{bmatrix} \mathbf{D} \cdot \mathbf{X}(t+k-1) \\ \mathbf{L}_0 + \lambda \Delta \mathbf{L} \\ \mathbf{0} \\ \mathbf{P} \end{bmatrix} \\ P_i^{\min} \le P_{\mathrm{in},i}(t+k) \le P_i^{\max} \\ P_i^{\min} \le P_{\mathrm{out},i}(t+k) \le P_i^{\max} \\ -M_i^{\max} \le M_{\mathrm{in},i}(t+k) \le M_i^{\max} \\ -M_i^{\max} \le M_{\mathrm{out},i}(t+k) \le M_i^{\max} \end{cases} \tag{3}$$

In order to more clearly explain the critical point calculation method based on the load growth direction, a 6-node wind power system with two load nodes to be observed is taken as an example to give the algorithm flow, as shown in Figure 1.

$$\mathbf{L}_{\mathbf{L}_0,\Delta\mathbf{L},\max} = \mathbf{L}_0 + \lambda_{\mathbf{L}_0,\Delta\mathbf{L},\max} \cdot \Delta\mathbf{L} \tag{4}$$

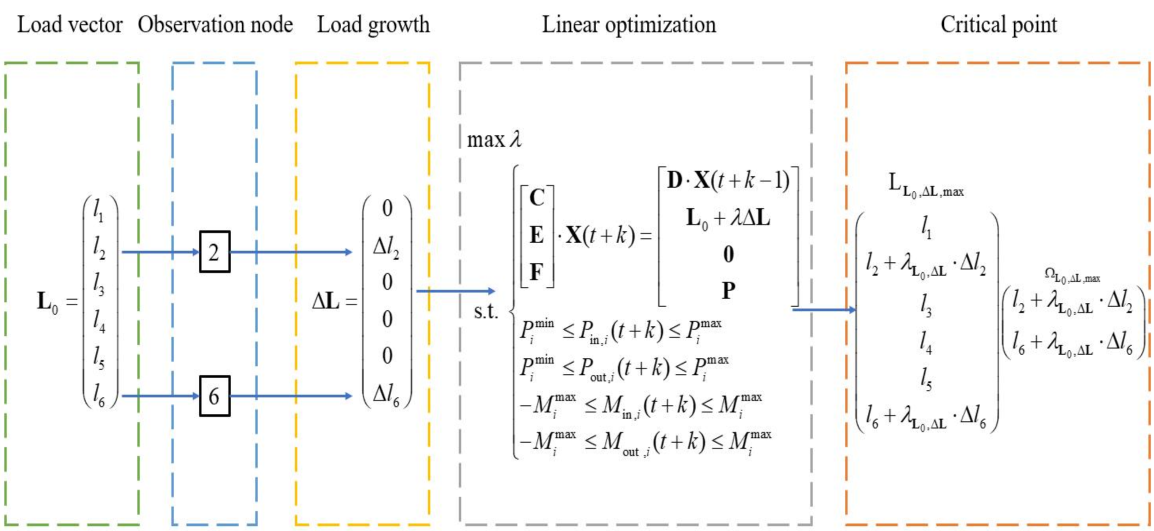

Figure 1. Critical Point Calculation Method Steps Based on Load Growth Direction

The distribution of critical points on the boundary will affect the accuracy of fitting the security domain boundary. Therefore, this paper adopts the multidimensional sphere method to sample the load growth direction to ensure that the critical points are evenly distributed on the security domain boundary [9]. If n is an even number of load nodes to be observed, observe n/2-1 independent random variables that follow a uniform distribution and are arranged by their size:

$$0 = U_0 < U_1 < \cdots < U_{\frac{n}{2}-1} < U_{\frac{n}{2}} = 1 \tag{5}$$

Make:

$$Y_i = U_i - U_{i-1}, \quad i = 1, \cdots, \frac{n}{2} \tag{6}$$

Generate independent uniformly distributed variable $R_1, \ldots, R_M$:

$$\begin{cases} X_{2i-1} = \sqrt{Y_i}\cos 2\pi R_i \\ X_{2i} = \sqrt{Y_i}\sin 2\pi R_i \end{cases}, \quad i = 1, \cdots, \frac{n}{2} \tag{7}$$

A vector is a random point on the n-dimensional unit sphere. If the number n of load nodes to be observed is odd, the first n terms of the n+ 1-dimensional random vector are normalized [10]. To sum up, the critical point sampling steps for dynamic safety domain of wind power systems are as follows:

Determine the number of nodes n to be observed and take it as the dimension of multidimensional unit spherical uniform sampling;
Determine the number of samples N, which should increase with the increase of the number of observed nodes;
N load growth direction samples were obtained by equations (5)-(7);
The critical points corresponding to each load growth direction are calculated through the steps shown in Figure 1 to form a critical point set.

B. Thermal Stability Security Zone

The thermal stability problem involved in this paper is the limit problem of whether the current flow in the remaining line is overloaded when N-1 fault occurs. The method of constructing a thermal stability security domain in a wind power system is as follows: selecting synchronizer nodes and load nodes in power system. The active power injection of the generator node and the load node is selected as the coordinate axis to satisfy the normal power flow feasibility of the system and the thermal stability of the system lines in the case of N-1 failure [11]. In the high-dimensional active power injection space, the transmission limit value of the designated critical section line is searched, and the thermal stability safety region of the power system for the designated section is constructed by fitting a large number of critical system operating points obtained.

In stable operation, wind power system should not only meet the power flow constraint, but also meet the thermal stability constraint of the system, that is, whether the main transformer and line in the system can be within its normal operating range during normal and stable operation or when the fault is expected to occur. Among them, the normal working range of the main transformer refers to its rated capacity value, and the normal working range of the transmission line refers to the upper limit of its current carrying value. The power flow constraint of the system operation, the thermal stability constraint of the line and the thermal stability constraint of the transformer can be expressed by the following formula respectively:

$$\begin{gathered} f(\boldsymbol{x}, \boldsymbol{u}) = 0 \\ |I_k| \le |I_{k,\max}|, \forall k \in B \\ |S_j| \le |S_{\mathrm{j,max}}|, \forall j \in T \end{gathered} \tag{8}$$

In addition, the normal operation of the power system will also be limited by the upper and lower extremes of the active and reactive power output of the generator set:

$$\begin{gathered} P_{gi,\min} \le P_{gi} \le P_{gi,\max}, \forall gi \in G \\ Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max}, \forall gi \in G \end{gathered} \tag{9}$$

In this paper, the active power transmission limit in section D of the power system considering thermal stability constraints is defined as the maximum active power that can be transmitted in section D of active power transmission when the power system is operating normally, that is, subject to both power flow constraints and thermal stability constraints [12], [13]. In the actual calculation of the limit value of the transmitted active power in section D, the mathematical model is established by summing the active power in each transmission line in the section, which can be expressed by the following formula:

$$\max P_D = \sum_{L_i \in D} P_{L_i} \tag{10}$$

The N-1 principle mentioned in the "Guidelines for the Safety and Stability of Power Systems" refers to the normal and stable operation of the power grid, when any component of the system is disconnected due to fault or no fault. Then, the active power transmission limit of the system cross-section with N-1 fault constraint considered can be defined as. When a line in the system is out of operation due to a fault, the maximum active power value that can be transmitted in the specified section under the condition that the power flow constraint and the thermal stability constraint are met.

The thermal stability limit of power system section studied in this paper only considers the thermal stability constraint of transmission line, and does not consider the thermal stability constraint of the main transformer [14]. Therefore, if an N-1 fault occurs on a line in a power system, the active power transmission limit of the fault-constrained system cross-section D can be expressed as:

$$\max P_D$$

$$\text{s.t.} \begin{cases} \mathbf{f}_{(i)}\left(\mathbf{x}_{(i)},\mathbf{u}_{(i)}\right)=0, i=0,1,2,\ldots,m \\ \left|I_{k(i)}\left(\mathbf{x}_{(i)},\mathbf{u}_{(i)}\right)\right| \le I_{k,\max}, \forall k=B_{(i)}, i=0,1,2,\ldots,m \\ P_{gn,\min} \le P_{gn} \le P_{gn,\max}, \forall g_n \in G \\ Q_{gn,\min} \le Q_{gn} \le Q_{gn,\max}, \forall g_n \in G \end{cases} \tag{11}$$

When the line in the system exits due to N-1 fault, the power system not only needs to obey the restrictions in (11). If the current value of a certain line in section D reaches its maximum current carrying value, then the power transmitted in section D has reached its upper limit of thermal stability.

3. Energy Security Index System Based on Entropy Modified Analytic Hierarchy Process

A. Energy Security Index Principle

1) Systematic Principle

Energy security itself is a complex system. Therefore, the index system must consider how to reflect the independent status of each subsystem of the energy security system, as well as the effect of their mutual coordination and interaction and overall operation [15]. The most important thing is that the indicator system should be able to reflect the level and status of the entire energy security, and have clear boundaries with other systems. The systematic principle means that the overall daily standard of the evaluation index should be constructed and the index system should be connected and coordinated.

2) Scientific Principle

According to the characteristics and objective laws of energy security, the selection of indicators and the determination of indicator rights are scientific and reasonable, and comprehensively reflect the nature of energy security and the operation process of energy security system. The scientific principle should ensure the scientific evaluation methods such as investigation methods and mathematical models. In particular, the judgment of qualitative indicators should be scientific and objective in order to make the results more credible.

3) Principle of Comparability

The evaluation indicators selected according to the evaluation objects and objectives should consider the availability and feasibility of data, and try to select common indicators at home and abroad to facilitate the comparison of subsequent evaluation [16].

4) Simple and Practical Principle

The number of indicators should be as concise as possible and reflect the overall state of energy security. Moreover, the calculation and evaluation are simpler and have little error.

After determining the evaluation objects as traditional energy and fossil energy, the system was constructed in four aspects, namely, domestic access ability, foreign access ability, resource endowment and environmental security control ability, with the goal of energy reflecting fossil energy security (Table 1).

Table 1. Evaluation System of Traditional Fossil Energy

EVALUATION OBJECT	BASIC INDEX	FACTOR INDEX
Fossil fuels (coal, oil, natural gas)	Domestically acquired capacity	Degree of external dependence
		Domestic output
		Take up a proportion of
	Capability acquired abroad	Consumption
		Geopolitics
	Resource endowment	Price
		Reserves
	Environmental safety control ability	Reserve production ratio
		Carbon emission

According to the economic factors, technical factors, environmental factors and the characteristics of each energy that affect non-traditional energy security, as well as the principle of considering the selection of indicators, the following indicators with strong operability and covering energy security issues are selected for the establishment of the system (Table 2).

Table 2. Non-traditional Energy Security Evaluation System

EVALUATION OBJECT	BASIC INDEX	FACTOR INDEX
Non-traditional energy sources (wind, hydro, solar, geothermal)	Economic indicator	Generation cost
		Installed capacity
	Technical index	Conversion rate
		Ripeness
	Resource index	Exploitation volume

EVALUATION OBJECT	BASIC INDEX	FACTOR INDEX
		Generating capacity
	Environmental index	Carbon emission
		Other environmental impacts

B. *Risk Evaluation Index Weight Setting*

The selection of risk-critical evaluation factors is the premise of the subsequent entire evaluation process. Different weight values are set for different risk indicators to reflect the degree of influence of different characteristics on power grid situation [17], [18]. The key factors affecting the quality of power grid are found in many indexes by determining the weight value. Finally, the comprehensive weight and severity are obtained, and the comprehensive analysis of the two is carried out, so as to realize the quantification of the comprehensive operation risk assessment results and find the weak link of the power grid.

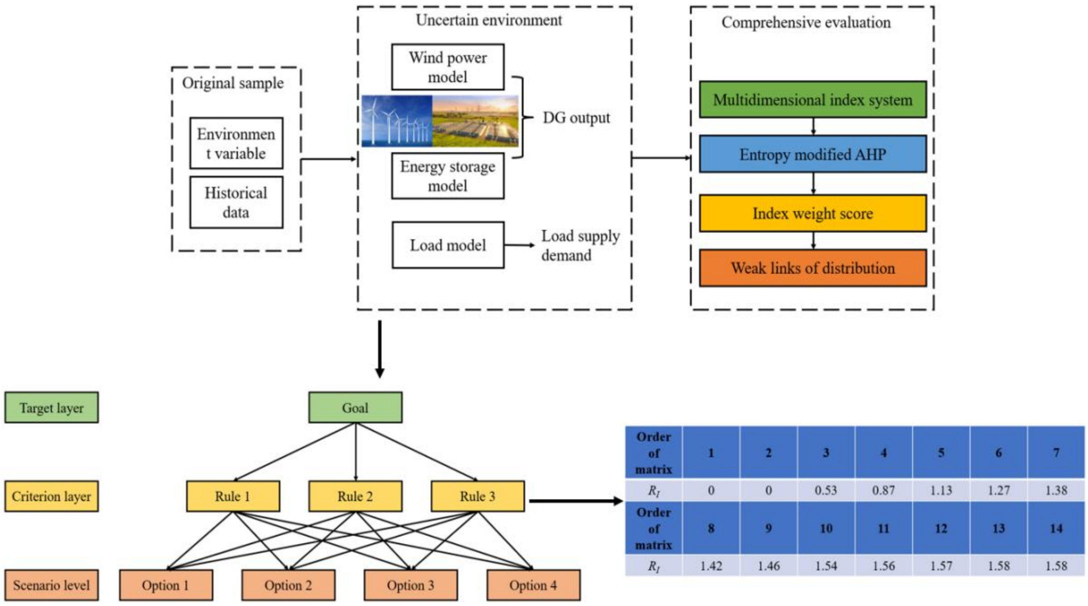

Figure 2. Entropy Modified Analytic Hierarchy Process

As shown in Figure 2, although analytic hierarchy process can reflect the overall results of the evaluation system, it ignores the objective facts and other problems. Moreover, the analytic hierarchy process is centered on the evaluation of experts, which cannot avoid the subjective arbitrariness of human beings [19]. In the objective weighting method, entropy weight method can make up for the defects of subjective weighting method. In terms of objectivity, the final result is close to the most real result. However, entropy weight method does not reflect the preference of decision makers, while analytic hierarchy process has such a role [20]. Therefore, the combination of the two complementary, this paper adopts the combination of subjective and objective weight, a more comprehensive and reasonable consideration of the real situation, eliminates the overlap between the information, more accurately determines the index system weight coefficient, which is one of the important innovation points of this paper.

The entropy-modified analytic hierarchy process proposed in this chapter first uses AHP to calculate the weight coefficient of the risk assessment system, and on the basis of the criterion matrix, uses entropy weight method to correct the weight obtained by AHP [21], eliminating subjective arbitrariness and enhances objectivity, and finally obtains reasonable weight results. The general process is as follows:

Step 1. Using the index calculation method in analytic hierarchy process, a set of index weights W_j is obtained.
Step 2. Using the index calculation method of entropy weight method, a set of index weights u_j is obtained.
Step 3. Based on the information weight u_j, the weight W_j obtained by the modified analytic hierarchy process (AHP) is expressed by the subjective and objective product normalization method as follows:

$$\lambda_j = \frac{\mu_j W_j}{\sum_{j=1}^{n} \mu_j W_j} \quad j = 1, 2, 3, \cdots, n \tag{12}$$

Thus the final combined weight vector is obtained.

C. *Example Analysis*

The following is a case study of the installed capacity of new energy in a certain province and the original data of the distribution network. According to the cumulative power generation of Hainan Province in 2021, 36.31 billion kW, an increase of 4.41 billion kW compared with 2020, various types of power supply are provided, and the distribution is shown in Figure 3.

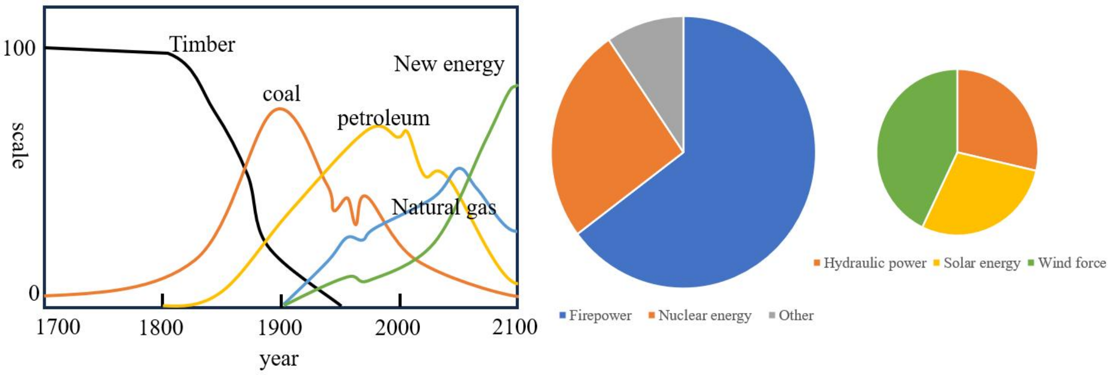

Figure 3. Distribution of Various Types of Energy Generation

In order to truly reflect the operating state of active distribution network, and verify the applicability of the index system proposed in this chapter. In the comprehensive risk assessment of this area, the method used in the whole process is the analytic hierarchy process with the exponential scale method of entropy correction.

In view of the analysis of the grid structure judgment matrix model, the evaluation index judgment matrix is shown in equation (13).

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \end{bmatrix}\begin{bmatrix} 1 & 5.194 & 2.279 & 2.279 & 2.279 \\ 1/5.194 & 1 & 1.316 & 1.316 & 1.316 \\ 1/2.279 & 1/1.316 & 1 & 1.316 & 2.279 \\ 1/2.279 & 1/1.316 & 1/1.316 & 1 & 2.279 \\ 1/2.279 & 1/1.316 & 1/2.279 & 1/2.279 & 1 \end{bmatrix} = \begin{bmatrix} 0.42 \\ 0.15 \\ 0.17 \\ 0.16 \\ 0.10 \end{bmatrix}^T \begin{bmatrix} f_1' & f_2' & f_3' & f_4' & f_5' \end{bmatrix} \tag{13}$$

The main two methods are AHP and entropy weight method to solve the weights of indicators respectively. The third index corresponding to the grid structure is calculated by AHP method: 0.42, 0.15, 0.17, 0.16, 0.10, CR=0.02981, which meets the matrix consistency. Using the entropy weight method to tertiary index entropy respectively e = (0.7614, 0.1538, 0.7461, 0.8043, 0.8010), one of the weights of 0.1376, 0.4882, 0.1465, 0.1129, 0.1148.

Based on the analysis of the power quality judgment matrix model, the specific index judgment matrix is shown in equation (14).

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix}\begin{bmatrix} 1 & 3 & 2.279 & 1.732 & 1.316 & 2.279 \\ 1/3 & 1 & 1.732 & 1.316 & 3 & 1.316 \\ 1/2.279 & 1/1.732 & 1 & 1.732 & 3 & 1.732 \\ 1/1.732 & 1/1.316 & 1/1.732 & 1 & 1 & 1 \\ 1/1.316 & 1/3 & 1/3 & 1 & 1 & 1 \\ 1/2.279 & 1/1.316 & 1/1.732 & 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 0.29 \\ 0.19 \\ 0.18 \\ 0.12 \\ 0.11 \\ 0.11 \end{bmatrix}^T \begin{bmatrix} f_1' & f_2' & f_3' & f_4' & f_5' & f_6' \end{bmatrix} \tag{14}$$

The weights of indicators are calculated by AHP and entropy weight method respectively. The weights of the third-level indicators corresponding to power quality are calculated by AHP method as follows: 0.29, 0.19, 0.18, 0.12, 0.11, 0.11, CR=0.06197, which meets the matrix consistency. Using the latter to tertiary index entropy respectively e = (0.7719, 0.6773, 0.7441, 0.5891, 0.5184), which corresponds to the entropy weight were 0.1061, 0.1501, 0.1190, 0.1911, 0.2249, 0.2088.

In view of the analysis of the power supply reliability judgment matrix model, the specific index judgment matrix is shown in equation (15).

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix}\begin{bmatrix} 1 & 3 & 2.279 & 1.732 & 1.732 & 1.316 \\ 1/3 & 1 & 3 & 1.316 & 1.316 & 3.947 \\ 1/2.279 & 1/3 & 1 & 1.732 & 1.732 & 1.316 \\ 1/1.732 & 1/1.316 & 1/1.732 & 1 & 1 & 1.316 \\ 1/1.732 & 1/1.316 & 1/1.732 & 1 & 1 & 3 \\ 1/1.316 & 1/3.947 & 1/1.316 & 1/1.316 & 1/3 & 1 \end{bmatrix} = \begin{bmatrix} 0.28 \\ 0.22 \\ 0.14 \\ 0.12 \\ 0.15 \\ 0.09 \end{bmatrix}^T \begin{bmatrix} f_1' & f_2' & f_3' & f_4' & f_5' & f_6' \end{bmatrix} \tag{15}$$

The weights of indicators are calculated by AHP and entropy weight method respectively. The weights of the third-level indicators corresponding to reliability are calculated by AHP method as follows: 0.28, 0.22, 0.14, 0.12, 0.15, 0.09, CR=0.09286, which meets the matrix consistency. Using the entropy weight method to tertiary index entropy e = (0.8114, 0.6650, 0.5967, 0.8123, 0.8715, 0.6671), the corresponding weights were 0.1189, 0.2175, 0.2543, 0.1183, 0.0810, 0.2099.

According to the power supply capability judgment matrix model analysis, the specific index judgment matrix is shown in equation (16).

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \end{bmatrix}\begin{bmatrix} 1 & 3 & 3 & 2.279 & 2.279 & 3 & 1.316 \\ 1/3 & 1 & 1 & 1.316 & 1.316 & 2.279 & 2.279 \\ 1/3 & 1 & 1 & 1.732 & 1.316 & 3 & 2.279 \\ 1/2.279 & 1/1.316 & 1/1.732 & 1 & 2.279 & 3 & 3 \\ 1/2.279 & 1/1.316 & 1/1.316 & 1/2.279 & 1 & 2.279 & 2.279 \\ 1/3 & 1/2.279 & 1/3 & 1/3 & 1/2.279 & 1 & 1.316 \\ 1/1.316 & 1/2.279 & 1/2.279 & 1/3 & 1/2.279 & 1/1.316 & 1 \end{bmatrix} = \begin{bmatrix} 0.28 \\ 0.14 \\ 0.15 \\ 0.16 \\ 0.12 \\ 0.06 \\ 0.09 \end{bmatrix}^T \begin{bmatrix} f_1' & f_2' & f_3' & f_4' & f_5' & f_6' & f_7' \end{bmatrix} \tag{16}$$

The weights of indicators are calculated by AHP and entropy weight method respectively. The weights of three indicators corresponding to power supply capacity are calculated by AHP method as follows: 0.28, 0.14, 0.15, 0.16, 0.12, 0.06, 0.09, CR=0.0882, which meets the consistency. Have to level 3 indicators entropy and entropy weight method e = (0.5850, 0.6403, 0.6889, 0.7706, 0.7802, 0.8590, 0.8351), The corresponding entropy weights are

0.2254, 0.1954, 0.1690, 0.1246, 0.1194, 0.0766 and 0.0896.

Similarly, the judgment matrix of the corresponding second-level evaluation index can be obtained, as shown in Equation (17).

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} \begin{bmatrix} 1 & 5.194 & 2.29 & 1.732 \\ 1/5.194 & 1 & 1.732 & 1.316 \\ 1/2.279 & 1/1.732 & 1 & 1.316 \\ 1/1.732 & 1/1.316 & 1/1.316 & 1 \end{bmatrix} = \begin{bmatrix} 0.49 \\ 0.15 \\ 0.17 \\ 0.18 \end{bmatrix}^T$$

$$\begin{bmatrix} f_1' & f_2' & f_3' & f_4' \end{bmatrix} \tag{17}$$

The weights of indexes are calculated by AHP and entropy weight method respectively. The weights of second-level indexes are calculated by AHP method as follows: 0.49, 0.15, 0.17, 0.18, CR=0.07601, which satisfies the matrix consistency. Using the secondary index entropy weight method to e = (0.7123, 0.3246, 0.6614, 0.7354), which corresponds to the entropy weight of 0.1837, 0.4312, 0.2162, and 0.1689, respectively.

Renewable energy technologies such as solar, wind, hydro, and bioenergy have significant low-carbon emission characteristics compared to traditional fossil fuels. Solar PV and wind power have almost no CO_2 emissions over their lifecycle, while hydro and bioenergy typically have much lower carbon emissions than coal and natural gas power. In the past decade, the costs of renewable energy technologies have declined significantly. In particular, solar PV and wind power have been able to increase energy output efficiency through technological advancements and reduce unit costs through large-scale production, making them competitive with traditional energies in certain regions.

4. Safety Evaluation of Wind Power System Based on Random Power Flow

A. Static Security Index Definition Based on Random Power Flow

Considering that the influence of random disturbance or fault on the power system is mainly manifested as branch overload and node voltage overlimit, branch overload may lead to chain failure, and node voltage overlimit may lead to voltage collapse [22]. Therefore, based on PLF results, the static safety assessment of the system is carried out mainly from two aspects: branch overload and node voltage overshoot. The evaluation Angle involves two levels of security risk and security probability, and the relevant indexes include component level index and system level index.

Risk assessment can realize the comprehensive estimation of the probability of system accidents and the severity of consequences, which is more conducive to the coordination and optimization of safety and economy. Risk indicators are generally represented by the product of event probability and event severity, of which the severity generally includes direct measurement of economic loss and indirect measurement of deviation degree [23]. In this paper, the deviation degree measurement method is used to indirectly evaluate the consequences of branch overload, and the utility function is used for nonlinear transformation processing to better describe the relationship between the consequences of node voltage overreach and the deviation, so as to define the severity of branch overload consequences as follows:

$$S_{ev}\left(L_m\right) = e^{a\cdot\omega\left(L_m\right)} - 1 \tag{18}$$

$$\omega\left(L_m\right) = \begin{cases} L_m - L_0, & L_m \geq L_0 \\ 0, & L_m < L_0 \end{cases} \tag{19}$$

It can be seen from equation (18) that the first and second derivatives of overload severity to overload load are greater than 0, that is, with the increase of overload load, the system risk value given in quantitative evaluation increases, and its increase rate also increases [24]. The above quantitative evaluation method fully reflects the operator's psychological endurance to the consequences of failure, that is, with the continuous increase of overload, the scheduler's dissatisfaction degree and its change rate increase. It can be seen that the evaluation quantitative method is consistent with the actual power grid.

Based on the above overload consequence quantification method, the overload risk of branch m is defined as:

$$R_{OL\_m} = \int_{L_0}^{+\infty} S_{ev}\left(L_m\right) g_m(L) dL \tag{20}$$

For PLF results, $g_m(L)$ generally has no analytical expression, but is a discrete point function, and the integral in the above equation represents the meaning of numerical integration, the same as below.

Similarly, the risk of node n voltage exceeding the limit is defined as:

$$R_{OV\_n} = \int_0^{U_{n\min}} S_{ev}\left(U_n\right) f_n(U) dU + \int_{U_{n\max}}^{+\infty} S_{ev}\left(U_n\right) f_n(U) dU \tag{21}$$

$$S_{ev}\left(U_n\right) = e^{a\cdot\omega\left(U_n\right)} - 1 \tag{22}$$

$$\omega\left(U_n\right) = \begin{cases} U_{n\min} - U_n, & 0 \leq U_n < U_{n\min} \\ 0, & U_{n\min} \leq U_n \leq U_{n\max} \\ U_n - U_{n\max}, & U_n > U_{n\max} \end{cases} \tag{23}$$

Although the risk index can comprehensively reflect the characteristics of the possibility and severity of system accidents. However, a single risk assessment method can easily lead to the neglect or neglect of the harm of security events with large probability and small risks [25]. Therefore, it is necessary to use the comprehensive analysis method of probabilistic security and risk security to evaluate the power grid security, and realize the comprehensive analysis of the system security events with large probability and small risk. In order to more comprehensively identify the weak links of the system, so as to guide the system planning and operation more effectively, and improve the safe and stable operation level of the system. In view of this, relevant probabilistic safety indicators are further defined based on PLF results.

$$P_{OL\_m} = 1 - \int_0^{L_0} g_{\mathrm{m}}(L)dL \quad (24)$$

$$P_{OV\_n} = \int_0^{U_{n\min}} f_{\mathrm{n}}(U)dU + \int_{U_{n\max}}^{+\infty} f_{\mathrm{n}}(U)dU \quad (25)$$

The system risk or unsafe probability is a comprehensive reflection of the risk or unsafe probability of each component. Therefore, it can be considered to define the corresponding system level indicators based on the above-defined component level indicators: system overload risk index, system voltage overlimit risk index, system overload probability, and system voltage overlimit probability.

Let vector R represent the overload risk vector of each branch of the system. System overload risk indicators are defined as:

$$R_{OL} = \alpha \times \frac{1}{M} \| R \|_1 + \beta \times \| R \|_\infty \quad (26)$$

The system overload risk index shown in equation (26) reflects the average overload risk level of each branch, and considers the influence of the maximum risk value. If the weight coefficient is properly large, the influence of the branch with greater overload risk can be highlighted, so as to avoid or weaken the possible masking phenomenon of the index.

The other three system-level indicators are similarly defined. Simply replace the vector R in equation (26) accordingly. System level index is the overall evaluation of node voltage and branch power flow safety of the system, which can be used for comparative analysis between different systems.

It is not the ultimate goal of safety evaluation to get the results of each safety index of the system, but to identify the weak link of the system operation and find out the risk source of the power grid through safety evaluation. It provides a basis for the improvement of the system operation and planning scheme to ensure the safe and stable operation of the system. Therefore, it is necessary to further analyze the system vulnerability based on the above assessment results.

The above component level safety indicators can directly reflect the unsafe state of each component in the system, and the weak link in the network can be identified by comparing the component level indicators, which is called the system vulnerable element in this paper.

$$\begin{aligned} &\Omega_{\mathrm{vul}} = \Omega_{\mathrm{vul}\_L} \cup \Omega_{\mathrm{vul}\_N} \\ &\Omega_{\mathrm{vul}\_L} = \left\{ m | \ R_{OL\_m} > R_{L1} \ \text{ or } \ P_{OL\_m} > P_{L1} \right\} \\ &\Omega_{\mathrm{vul}\_N} = \left\{ n | \ R_{Or\_n} > R_{N1} \ \text{ or } \ P_{OV\_n} > P_{N1} \right\} \end{aligned} \quad (27)$$

The identified vulnerable components need to be paid attention to by scheduling operators during operation. By monitoring the vulnerable elements of the power grid, the insecure state of the system can be quickly reflected and the deterioration and expansion of the insecure state can be avoided.

B. Example Analysis

The IEEE RTS-79 system is used to test the effectiveness of the evaluation indexes and methods proposed in this chapter. A 300MW wind farm (wind power penetration rate of 10%) is connected to 24 bus lines. In order to facilitate subsequent analysis of results, the main wiring structure diagram of the system is given here, as shown in Figure 4.

The rated transmission capacity of 138 and 230kV transmission lines is set at 120 and 300MVA respectively. The allowable variation range of bus voltage is 0.95~1.05pu. The voltage level of the original system is high, and the probability of voltage exceeding the limit is too small. In order to facilitate the validity verification of the method, the terminal voltage of the generator in the system is properly adjusted during the test.

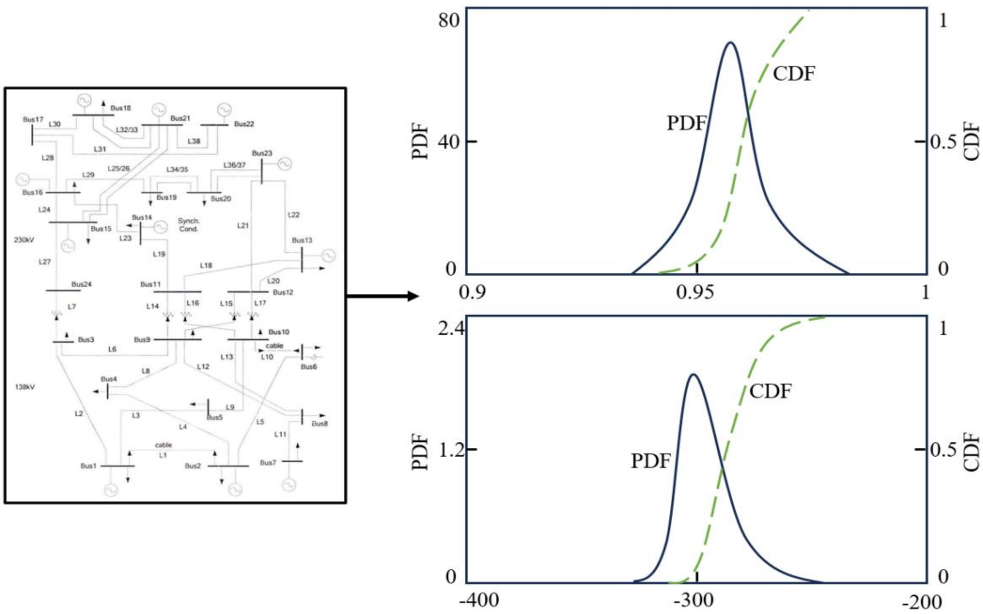

Figure 4. Test System and Power Flow Analysis

In order to verify the accuracy of the evaluation method, the evaluation results of the proposed method in this chapter are compared with those of the traditional uncertainty evaluation method -Monte Carlo method. Table 3 lists the comparison of unsafe probability and the top 10 unsafe risks obtained by the above two methods respectively. It can be seen from the table that the unsafe probability and unsafe risk ranking obtained by the proposed method are basically consistent with Monte Carlo method. As can be seen from the time cost of the two methods shown in Table 4, the evaluation speed of the method in this chapter has been greatly improved, and the time consumption is only 1.55% of that of Monte Carlo method. The above results show that the method in this chapter not only ensures the accuracy and effectiveness of the evaluation, but also greatly improves the evaluation efficiency.

Table 3. Comparison of Evaluation Results

UNSAFE PROBABILITY					UNSAFE RISK				
RANKING	NODE		BY-PASS		RANKING	NODE		BY-PASS	
	METHOD OF THIS PAPER	MONTE CARLO	METHOD OF THIS PAPER	MONTE CARLO		METHOD OF THIS PAPER	MONTE CARLO	METHOD OF THIS PAPER	MONTE CARLO
1	B3	B24	L28	L28	1	B5	B5	L23	L23
2	B8	B3	L23	L23	2	B3	B3	L28	L28
3	B4	B8	L7	L7	3	B8	B24	L9	L3
4	B24	B4	L22	L22	4	B24	B6	L3	L9
5	B9	B9	L11	L11	5	B6	B8	L11	L11
6	B12	B12	L24	L24	6	B4	B4	L7	L7
7	B6	B6	L3	L19	7	B9	B10	L22	L22
8	B5	B11	L9	L10	8	B12	B9	L24	L24
9	B11	B5	L19	L9	9	B11	B12	L17	L10
10	B10	B10	L10	L3	10	B10	B11	L10	L17

Table 4. Calculation Time

METHOD	METHOD OF THIS PAPER	MONTE CARLO
Time-consuming	0.73	48.54

When the method shown in equation (27) is used to identify the system's fragile elements, the selection of the filter reading value will directly affect the rationality of the identification results. However, for different systems, the size and distribution of the index values are also different. Therefore, the screening thresholds of each vulnerable element should be determined in combination with the index values of each node or branch of the system.

The rationality analysis of the above identification results is as follows: As can be seen from the IEEE RTS-79 wiring diagram in Figure 4, the power supply in the system is mostly distributed in the 230kV system, and the reactive power support of the power supply is relatively sufficient. However, there are relatively few power supply support points in the 138kV system, and there is the risk of voltage exceeding the limit. In addition, considering the constant power factor of $\cos\varphi=-0.98$, the wind field needs to absorb a certain reactive power from the system during operation, so the nodes near the grid-connected bus are also the risk points of node voltage exceeding the limit. Figure 5 shows the load rate of each branch of the system when considering the 80% output cross-section of wind power (without taking into account the impact load and the expected value of the load of each bus). It can be seen from Figure 5 that the load rate of wind power sending channels such as L7/23/28 is high, indicating that the above identification results are consistent with the actual system.

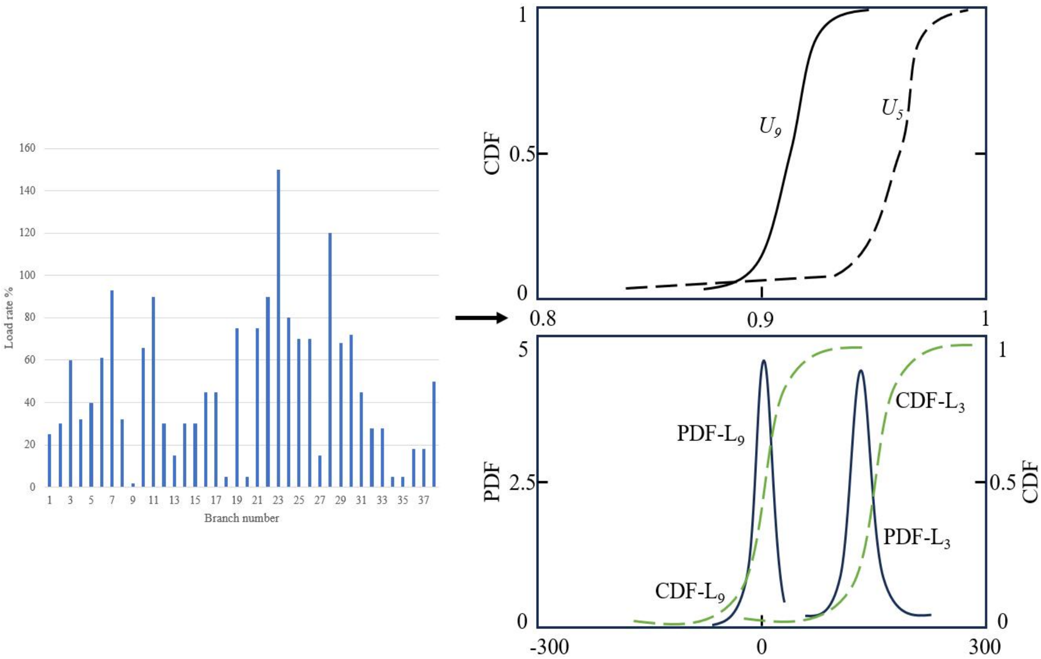

Figure 5. Node Probability Distribution

Figure 5 shows the voltage probability distribution of B5 and B9. It can be seen that although the voltage exceeding-limit probability of bus 5 is smaller than that of bus 9, the probability distribution of U5 presents a long tail due to the impact load at bus 5, and U5 drops to 0.88 at the lowest. Therefore, the low voltage risk is relatively large. Shock loads have a similar effect on their connected lines. As shown in Figure 7-7, both L3 and L9 power flow probability distributions have long tail characteristics (around 200MW), which makes L3\L9 power flow overload an unsafe event with small probability and big risk in the system.

The above results show that the method in this paper can better distinguish the vulnerable elements of the system, including the vulnerable elements with small probability and large risk, through the comprehensive analysis of insecure probability and insecure risk.

C. Renewable Energy Teaching Planning

Adopt interactive learning methods such as simulation software, laboratory experiments, and field visits to let students personally experience the operation of renewable energy technology. Integrate knowledge from multiple disciplines such as physics, engineering, economics, and social sciences to develop students' comprehensive analytical abilities and critical thinking skills. Encourage students to participate in actual projects such as designing and constructing small wind or solar installations, or conducting community energy audits, to deepen their understanding and application of renewable energy technology. By incorporating the latest trends and technologies in renewable energy into teaching modules, education can provide a dynamic learning environment for students, preparing them to face the ever-changing energy industry. This educational method not only imparts knowledge but also cultivates students' innovative spirit and problem-solving abilities, laying the foundation for their contributions in future careers.

1) Classroom Teaching

Teaching tasks: Classroom teaching content includes introduction, solar energy, biomass energy, wind energy, geothermal energy, ocean energy, hydrogen energy, etc. For example, the introduction mainly describes the definition and classification of energy, and the utilization and development of renewable energy; The biomass energy part mainly describes the physical, thermochemical and biological methods of biomass energy conversion. The ocean energy section mainly describes the sources of ocean energy, and requires students to understand the specific different forms of ocean energy, such as tidal energy, wave energy, and ocean current energy.

Design Scheme: Because this link is still theoretical teaching, it mainly focuses on the reform of classroom teaching mode. According to students' own cognitive characteristics and laws, guide students to understand renewable energy. With students as the main body, in accordance with the teaching concept of "learning, practice and innovation integration", we strengthen the integration of teaching and practice, adopt a variety of teaching modes, and inspire students to actively participate in the process of teaching and learning. Thus, it cultivates the students' interest in learning, the ability of independent exploration, the spirit of innovation and the ability of innovation, and improves the teaching quality. According to different teaching contents, different teaching modes such as interactive teaching, lecture teaching mode, task-driven teaching mode, discussion teaching mode, case teaching mode, etc. For example, when telling the introduction part, we can start with the shortage of fossil energy in China and acid rain in some areas, introduce renewable energy and deepen the understanding of renewable energy. When talking about the biomass Energy Department, experts in the field can be invited to talk about the latest developments in biomass energy through expert lectures. In the part of ocean energy, situational teaching can be introduced to help students learn ocean energy knowledge through a large number of ocean pictures.

2) Practical Links

Teaching task: Help students to carry out specific cognition and feeling of renewable energy design plan: this link will be carried out after the classroom teaching, and the practical teaching will be carried out in combination with the relevant laboratory of the college and the new energy-related demonstration project of the city. In addition to the demonstration related to renewable energy, the practice will also introduce the latest research content and results including renewable energy research, so that students can learn and master the ways and methods to improve the efficiency of renewable energy conversion through the laboratory.

5. Conclusion

Under the complex background of the global development of low-carbon economy and China's stepping into the new normal, this paper studies some issues of sustainable energy security. Based on stochastic power flow algorithm, this paper proposes the safety assessment and teaching planning of wind power generation in renewable energy. The innovation of this paper lies in the establishment of a security index by entropy-modified analytic hierarchy process and a new method of static security assessment of power grid based on PLF. Specific conclusions are as follows:

Establish a set of multi-dimensional risk index system from nodes and lines, put forward the entropy-modified analytic hierarchy process, calculate the weight based on its subjective and objective, and conduct the final score according to the actual data of the distribution network in a certain area, identify the weak points of the distribution network, and determine the node voltage, line power flow, distribution network load loss and other quantitative indicators.

A static safety assessment method for grid-connected wind power systems based on stochastic power flow calculation is proposed. The safety index based on PLF results is defined from probability and risk respectively, and the system vulnerability is further identified based on the evaluation index. The test results based on ST-PLF show that the evaluation time of the proposed method is 0.73 s, while that of the traditional method is 48.54 s. The evaluation speed of the proposed method is greatly improved, and the time of the proposed method is only 1.55% that of the Monte Carlo method. The proposed method can evaluate the static security of the system well, and identify the potential risks and corresponding vulnerable points of the system.

At the higher education level, future research can focus on developing advanced courses and specialized modules that delve into the complexity of renewable energy technology, as well as economic and policy issues. Technical education, on the other hand, should emphasize the development of practical skills, such as the installation, maintenance, and management of renewable energy systems. Research should also explore new teaching methods, such as flipped classrooms, project-based learning, and remote laboratories, to enhance student participation and learning outcomes. Teaching modules should include issues related to electric power quality, such as the causes and impacts of voltage fluctuations and harmonic waves, as well as their control methods. Students of the future should learn how to use modern measurement tools and analysis software to monitor and diagnose these issues.

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