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Intelligent Planning of Transmission Networks: Addressing Uncertainties Through Artificial Intelligence

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Abstract

Power grid planning is a critical aspect of power grid topology, traditionally relying on manual methods that are prone to various uncertainties. These uncertainties, both subjective (stemming from human judgment) and objective (resulting from data limitations), can significantly affect the reliability and efficiency of the planning process. This paper presents an artificial intelligence (AI) method aimed at improving the smart planning of transmission networks. By utilizing AI, the proposed method systematically analyzes and optimizes the factors contributing to uncertainties in traditional planning methods. The AI-based model processes and evaluates topology data comprehensively, leading to more accurate and reliable planning outcomes. Furthermore, continuous monitoring is integrated into the system to ensure that the planning process remains dynamic and responsive to real-time changes. The final planning results are generated with a high degree of precision, effectively minimizing the uncertainties that plagued earlier methods. Consequently, AI-driven techniques not only meet the stringent requirements of intelligent transmission grid planning but also facilitate the continuous evolution and optimization of transmission network planning. This approach is well-suited to support the ongoing development and complexity of modern power grids, ensuring more resilient and efficient grid topology.

Keywords: Artificial intelligence, grid planning, grid topology, planning process, transmission network planning

INTRODUCTION

The intelligent planning of the transmission grid is a comprehensive evaluation method of the power grid modeling topology, and the modeling topology data and power grid planning should be carried out. The data are comprehensively evaluated, but the original manual planning method is prone to subjective and objective uncertainty [1]. Currently, the original manual planning for transmission grid planning faces more uncertainties [2]. Applying artificial intelligence (AI) methods to transmission network planning and identifying interference factors for better planning. However, load forecasting and power planning analyses are still not ideal [3]. To this end, some scholars have proposed artificial intelligence methods to improve the intelligence of transmission networks by analyzing [4] the load forecasting and power planning of transmission grids [5] and conducting time-series analysis on transmission network planning formulation rationality and certainty of planning.

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INTELLIGENT PLANNING AND ANALYSIS OF TRANSMISSION GRID

Intelligent planning analysis of transmission networks makes reasonable planning for power grid planning and load forecasting [6] and detects the change characteristics of the target data [7]. Intelligent planning of transmission grids [8]. Intelligent planning analysis of the transmission network is mainly based on the modeling algorithm and the peak of the application [9]. The artificial intelligence method completes the comprehensive intelligent planning of the transmission network by assembling and analyzing the modeling topology data [10] where the direction of change in the peak of the target data represents the amplitude [11]. There are four definitions of AI methods, which are as follows.

Definition 1: The arbitrary modeling topology data is x_i, the target data formulation function is J_i, the planning set is $p(y_i)$, and the time length is c_i. The calculation process is shown in Equation (1).

$$p(y_i) = \frac{1}{2} \cdot \sqrt{a^2 + b^2} \cdot J \times c_i \cdot x_i \tag{1}$$

Definition 2: The forecast plausibility function is $f(x)$, where l is planning reasonableness, Yl is planning reasonableness, and Yq is determinism. The calculation process is shown in Equation (2).

$$f(x,P) = x \xrightarrow{y} \sqrt{Y_m \cup Y_b} \div \sqrt{b^2 - 4ac} \cdot x \tag{2}$$

Definition 3: Planning result function, planning change is $l(x_i)$, planning set is $\bar{x}_i$, and modeling number is col_i. The calculation process is shown in (3): h_i $l(x_i)$

$$l(x_i) = \sum c_i \div h_i \cdot x_i \cdot \frac{dy}{dx} \cdot (a+c) \tag{3}$$

Definition 4: The load forecast function is $f(x,b)$, the threshold of the plan is w, l is the planning error. The calculation process is shown in Equation (4).

$$f(x) = \sum_{i=1} x_i \times w \div \tau_i \cdot \frac{1}{n} \cdot \mu_X \tag{4}$$

ARTIFICIAL INTELLIGENCE METHODS FOR PLANNING

In artificial intelligence transmission network planning, the grid topology information should be comprehensively calculated to reduce uncertainty in planning. The constraints with differences are identified according to artificial intelligence theory, and the rationality of the planning formulation is calculated. Therefore, conducting a random analysis of the planning and related constraints of different electricity market conditions is necessary.

Definition 5: The target data function is $F(J_i)$, When a peak occurs, the planning variable is, and the constraint is calculated as shown in Equation (5).

$$F(x_i) = \frac{k(x_i^{\,2}) \cdot (1-P_i)}{Ya \cdot \sqrt{1-k^2}} \cdot \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{5}$$

Formula: If $F(x_i) \geq A$ is used, the intelligent planning results are reasonable; otherwise, the constraints that do not meet the requirements must be analyzed. If $F(x_i) \lhd A$ states that the smart planning results do not meet the constraints, they are readjusted.

Definition 6: The constraint determination function is $j(k)$, calculated using Equation (6).

$$j(k) = \sqrt{2} \cdot y(x_i, y_i) \cdot e_i \cdot f(x_i) \cdot (y-x) \tag{6}$$

Intelligent planning to reduce the occurrence of uncertainties requires sampling analysis of load forecasting and grid planning, including subjective and objective uncertainties. In addition, the planning scheme was analyzed using an artificial intelligence method.

Step 1: The planning data of the AI method are collected, the binding nature of the intelligent planning is determined, the intelligent planning is comprehensively evaluated, and the planning is determined for the conditions for judgment.

Step 2: Collective calculation of load forecasting and grid planning included in the transmission grid and continuous analysis of the multistage transmission network planning.

Step 3: Ensemble the calculation for planning formulation, and terminate the analysis if the constraints are exceeded, or the forecast data changes; otherwise, perform the set calculation.

AI method planning was analyzed based on the original AI method, and the specific parameters are listed in Table 1.

Table 1 shows that the AI method can analyze the network scale, network branches, and network nodes, and there is a large difference between the AI method and the artificial intelligence analysis method. From this result, we can see that the AI method can realize a comprehensive data analysis and provide relevant support for future research. The data distribution state of the AI intelligent analysis method is illustrated in Figure 1.

Table 1. Planning data status of artificial intelligence methods (unit: %).

Parameter	Discreteness	Effectiveness
Grid size	93.51	89.76
Number of branches	92.64	92.22
Number of nodes	91.20	91.67
Number of loads	92.76	92.84

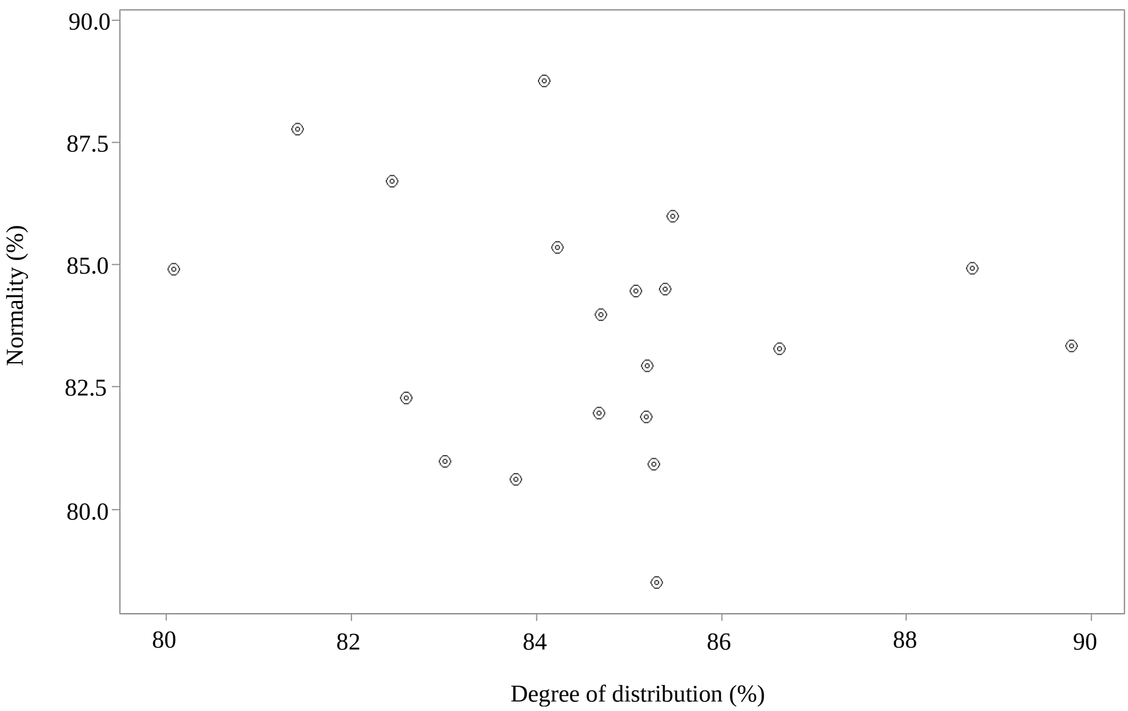

Figure 1. Data distribution status of artificial intelligence methods.

From the contents in Figure 1, the data of the AI method are discrete and mainly distributed between 82% and 86%, which shows that the data dispersion is scattered and meets the relevant analysis requirements. At the same time, there is no concentrated result in the overall distribution of data, which shows that the normality of data is good, and the overall structure and data value are reasonable, which can lay the foundation for later analysis and will not affect the later calculation results.

The planning of artificial intelligence methods should be completed; otherwise, it will increase the randomness and ambiguity of planning, and the accuracy and rationality of the planning results of artificial intelligence methods will be detected and specifically planned, as shown in Table 2.

From the data analysis in Table 2, there was no significant difference between the analysis results of the early and late levels of the artificial intelligence algorithm, and the randomness, complexity, and change range did not change significantly. The calculation accuracy, rationality, and average change are at a high level, greater than 90%, significantly superior to the traditional artificial method. Although the accuracy and rationality of the traditional artificial method is better than 80%, it is slightly inferior to that of the artificial intelligence method. Therefore, the artificial intelligence method proposed in this study is more effective. In addition, from the data in Table 2, the accuracy and rationality of the artificial intelligence methods are relatively stable, and the change range is small. This result shows that the artificial intelligence analysis method has strong data processing ability, can judge complex data, is not interfered with by external data, and the calculation result is relatively stable. To better reflect the calculation results, it is necessary to continuously analyze the above data and observe the continuity of the calculation results. The calculation process is shown in Figure 2. It can be seen from Table 2 that the accuracy and rationality of the artificial intelligence methods are greater than 91%, the mode change is less than 2, and the change amplitude of the different methods is greater than 8. There are significant differences. At the same time, the randomness, ambiguity, and complexity changes are relatively small; therefore, the overall planning of artificial intelligence methods is better. However, the rationality and accuracy of artificial methods vary significantly, and the accuracy and rationality of manual methods are less than 80%, which is relatively poor. In market conditions, the rationality and accuracy of AI method planning changes are shown in Figure 2.

Table 2. Comparative planning of accuracy and rationality (unit: %).

Methods	Plan direction	Parameter	Accuracy	Rationality	Average change
Artificial intelligence approach	First-level planning	Randomness	92.66	92.64	0.15
		Ambiguity	94.21	91.20	2.09
		Complexity	91.54	92.76	1.32
	Secondary planning	Randomness	94.43	92.66	1.75
		Ambiguity	93.39	90.06	2.25
		Complexity	93.51	94.05	0.76
Original manual method	First-level planning	Randomness	89.48	89.16	1.36
		Ambiguity	80.04	81.48	1.53
		Complexity	85.60	86.55	1.15
	Secondary planning	Randomness	86.76	83.47	3.09
		Ambiguity	87.17	78.31	8.32
		Complexity	81.77	83.69	2.75
Plan for comparison		X2=16. 121, P<0.06			
Parameter mining times = 56 times					
Parameter adjustment rate = 0.35					
Parameter compatibility = 0.89					

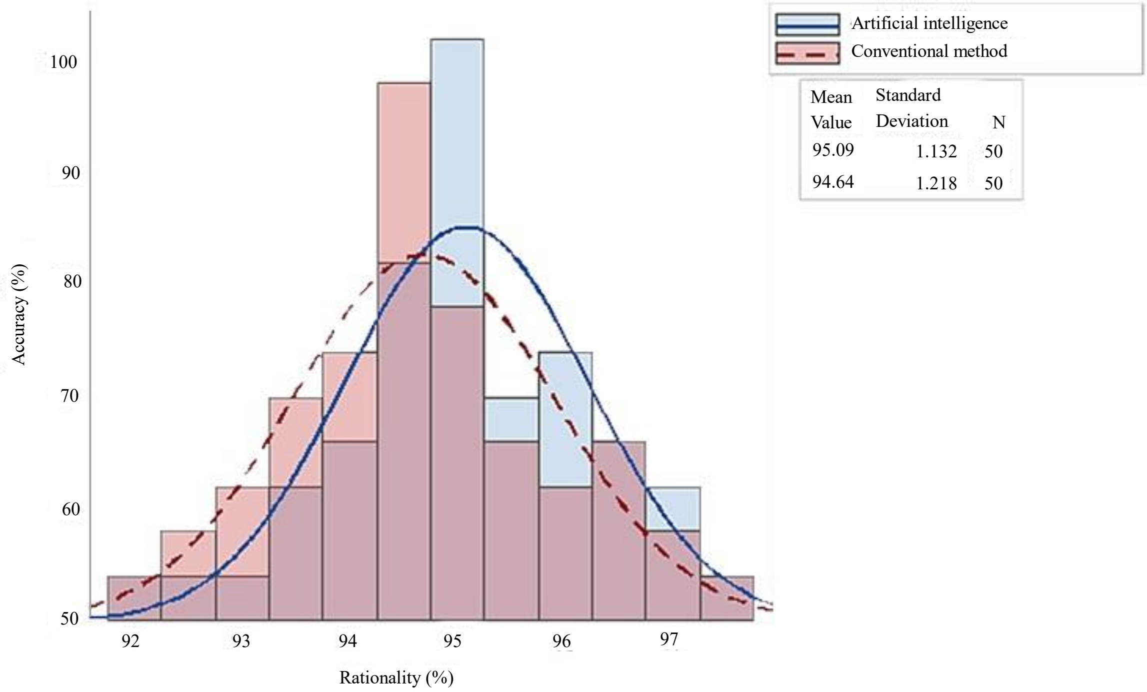

Figure 2. Comparison of accuracy and rationality of planning of different algorithms.

It can be seen from Figure 2 that in the data sampling comparison, the rationality and accuracy of artificial intelligence method planning are more concentrated, whereas the traditional manual method concentrates more on the rationality and accuracy of the planning, which is consistent with the results of the study in Table 2. This is because the artificial intelligence method analyzes the rationality of the planning, such as the formulation of transmission network planning, and calculates the convex function values of different values, which removes the uncertain factor values in the transmission network planning to simplify its complexity.

From the data analysis in Figure 2, it can be observed that the rationality and accuracy of artificial intelligence algorithms are higher than those of traditional methods, and the peak curve is biased to the right, which further proves the effectiveness of the calculation results. In the area of the peak curve, the area of the artificial intelligence algorithm is larger, which shows that its results are more effective and the overall calculation results are better. The main reason for the above results is that artificial intelligence algorithms combined with big data, cloud computing, and other aspects can comprehensively judge complex data, optimize data results, and eliminate redundant data in the middle.

The time of the AI method planning is an essential indicator of planning efficiency, including subjective and objective uncertainties, and the specific planning is shown in Table 3.

According to the data in Table 3, the results of the artificial intelligence method in time planning are relatively stable and require less time, which shows that the calculation time of the intelligent planning method is relatively rational. The traditional manual calculation method takes a relatively long time, which shows that the manual calculation method has certain disadvantages in data processing and redundant data elimination. Artificial intelligence algorithms use big data, cloud computing, and other techniques to obtain more comprehensive data eigenvalues, better build network topology, and carry out multidimensional analysis of data, which can effectively eliminate abnormal values of data, reduce the complexity of data, and provide support for later simplified calculations. The relevant data were calculated in stages to analyze the advantages of artificial intelligence algorithms better, and the specific calculation results are shown in Table 3.

Table 3. Planning time of artificial intelligence methods (unit: minutes).

Method	Time	Subjective uncertainty	Objective uncertainty	Data dispersion
Artificial intelligence approach	10~20	95.03	95.64	0.342
	20~30	93.18	92.57	
	30~40	93.15	91.68	
Traditional manual methods	60~70	82.19	84.89	
	70~80	84.74	89.57	
	80~90	86.86	84.76	
Difference of different methods = 0.56				
Method independence = 0.23				
Data relation = 0.421				

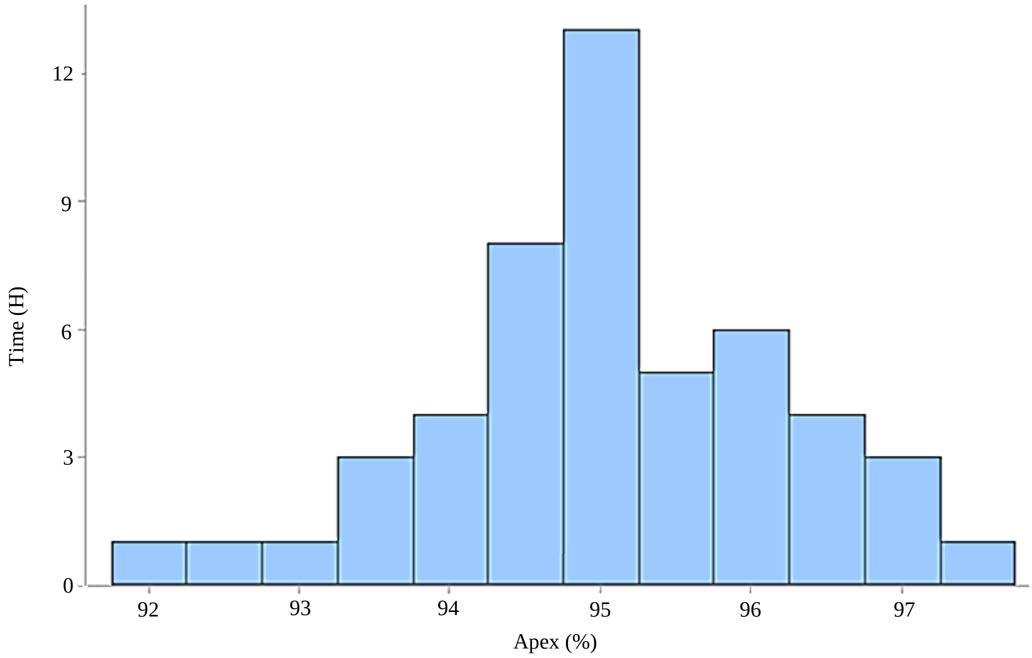

Figure 3. Comparison of planning data and time for different methods.

From the data in Figure 3, the calculation time of the artificial intelligence algorithm is less than 12 s, the calculation peak value is relatively concentrated, and it decreases from the peak value to both sides, which meets the requirements of normal distribution. In addition, the peak value of the artificial intelligence algorithm is 95%, which is significantly better than that of the traditional manual calculation method. In addition, in terms of peak distribution, the reduction range of the right side is smaller than that of the left side, which shows that the latter calculation process is relatively stable, whereas the previous results are larger, mainly because of the complex data analysis in the early stage to reduce the effectiveness of the analysis results. From the analysis of Figure 3, the planning data value of artificial intelligence methods is higher, and the time is faster while planning traditional manual methods. Comprehensiveness is poor, and planning time is slow.

CONCLUSION

In the transmission grid planning process, manual methods from the past cannot be effectively planned. Based on this, this paper suggests an artificial intelligence approach for a comprehensive evaluation of transmission network planning and selection of the final plan. The complexity of the planning process is reduced by comprehensively calculating the planning expectations using artificial intelligence methods. Intelligent planning is performed with constraints, and the uncertainties in transmission network planning are studied to improve the rationality of planning. The results indicated that the comprehensiveness and rationality of artificial intelligence methods exceeded 90%. However, the rationality and comprehensiveness of the traditional artificial methods are quite different, and the uncertainty factors are highly disturbed and relatively poor. Additionally, the planning time for artificial intelligence methods is relatively short, with minimal variation. Among them, the value of uncertainties in the planning of artificial intelligence method is stable, the time is short, and the overall transmission network planning scheme is ideal.

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