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DESIGN OF A RISK MODEL AND ANALYTICAL DECISION INFORMATION SYSTEM FOR POWER OPERATION IN THE CONTEXT OF SMART GRID

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Abstract

With the increasing requirements of society for energy conservation and emission reduction, electricity is seen as an important energy supply method to promote energy conservation and emission reduction. The study combines hierarchical analysis, rough set theory and fuzzy comprehensive evaluation method to propose a new power system operation effectiveness assessment method based on improved fuzzy hierarchical analysis. The study uses Institute of Electrical and Electronics Engineers Power & Energy Society (IEEE PES) Power System Test Cases Data Set, Power System Analysis Toolbox and GridLAB-D Test Cases as the objects of the study. The distribution is more distinctive and hierarchical. The results show that after the application of the model proposed by the research institute, the overall generation efficiency has been significantly improved. All sampling times have exceeded 85.5%, and most of them are concentrated at about 88%. At the same time, the proposed model runs only 22.17 s, which is more efficient, and the overall correlation is as high as 0.97097. The fit degree is very high, which proves high training accuracy. Overall, this study contributes to the development of smart grid technology and the improvement of power system operation and management.

Key Words

New power system, evaluation index system, fuzzy hierarchical analysis, operational effectiveness, decision information system

1. Introduction

In recent years, with the rapid development of the social economy and the continuous growth of people's demand for electricity, power operations are facing unprecedented challenges and changes [1]. In order to solve these problems, smart grids have emerged [2]. Smart grid is an advanced power system based on information and communication technology, which has the characteristics of automation, intelligence, high reliability, and strong security. The smart grid achieves precise matching of power supply and demand through real-time monitoring, analysis, and regulation of the operating status of the power system, improves the efficiency and reliability of the power system, and reduces energy waste and environmental pollution [3]. Currently, due to the increasing complexity and uncertainty of the power system, traditional risk management experience is no longer able to meet practical needs. To address this issue, this study uses the application of analytic hierarchy process (AHP), rough set theory (RST) and evaluation method of fuzzy mathematics (EMFM) to improve the operational efficiency of the new power system. The research aims to improve the efficiency of energy use, reduce environmental pollution and achieve a sustainable carbon footprint. At the heart of this research is the combination of the Internet of Things (IoT) and smart grids.

2. Related Work

With the development of smart grids, the design of risk models and analytical decision information systems for power operations has become increasingly important. Numerous scholars at home and abroad have analysed the evaluation system of the model. Bougahariou *et al.* [4] used fuzzy analytical hierarchy analysis (FAHP), frequency ratio (FR) and weight of evidence (WOE) models to define groundwater potential in the Tunisia Sfax area. Bohra *et al.* [5] used AHP to assess multi-criteria planning for rural electrification microgrids. Nguyen [6] used FAHP and SERVQUAL methods to determine and study hotel service quality in order to improve service quality.

Elshaboury [7] uses FAHP to prioritise risk events for large-scale hydropower projects and confirm the best clustering method. Al [8] studied the problem of selecting organic food sellers and used fuzzy hierarchical analysis

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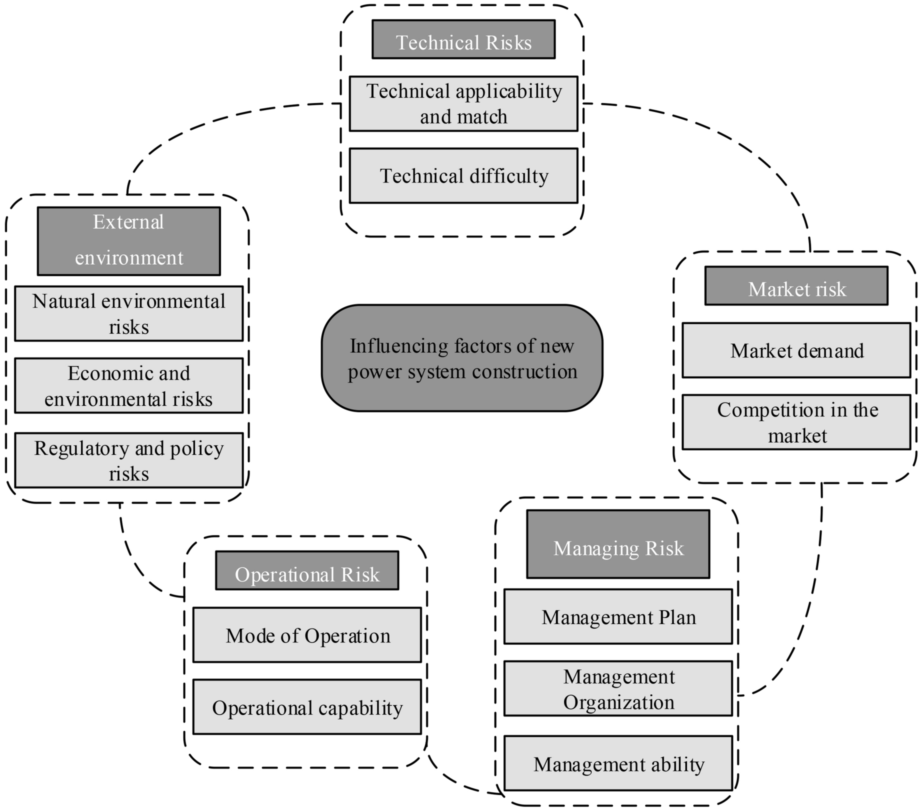

Figure 1. Analysis of the factors influencing the operation of the power system diagram.

to identify the most credible sellers. Canmolu *et al.* [9] developed a fuzzy hierarchical analysis questionnaire based on previous studies and combined with expert opinions.

To sum up, there are few new methods to evaluate the operation efficiency of power system by FAHP. RST and EMFM are used to evaluate the effectiveness of new power systems to carry a higher proportion of new energy generation access.

3. The Establishment of a Risk Model for Power Operations and the Design of an Information System for Analysis and Decision Making

3.1 New Power System Operational Effectiveness Evaluation Index System

When studying the impact factors of the operation project, comprehensive evaluation from the perspectives of integration of innovative resources, combination of policy tools, operation and management models, and construction of value chains [10]. This is shown in Fig. 1.

The regulatory and policy environment in Fig. 1 is a crucial risk indicator, followed by market risk factors. Building a new type of power system is important to correctly understand the contradictions between the market and the market [11]. The third is the technical risk factor, which refers to the uncertainty of various technologies used in the operation of the new power system. Finally, managing risk factors is an important tool for improving the brand quality and core competitiveness of a company through innovation [12]. Combined with the characteristics of the power grid company, a smart grid enterprise safety evaluation index based on regional characteristics is proposed, as shown in Table 1.

3.2 A Risk Model for Power Operation Based on Improved Fuzzy Analytic Hierarchy Process

Due to the numerous factors that affect the evaluation of the operational efficiency of the new power system, and the complex logical relationship between each factor. Fuzzy mathematics methods are suitable for handling subjective evaluations and fuzzy information, and can provide fuzzy results. RST is a mathematical tool for dealing with incomplete and uncertain information, which processes a large amount of incomplete information in power operation and analyses and constructs models to provide risk prediction and decision support. Therefore, the study establishes an impact evaluation system based on the AHP–RST–EMFMcomprehensive evaluation method, which combines the AHP, RST and the EMFM to further investigate the operational impact of the new power system, as is shown in Fig. 2.

The fuzzy composite rubric is an effective method for the comprehensive assessment of various impact factors [13]. A multi-level fuzzy judgement model is used for the multi-level stratified impact factor problem.

$$A \circ R = \underline{B} \tag{1}$$

Table 1
New Power System Operational Effectiveness Risk Assessment Indicator System

First Order Index	Secondary Index	Three Level Index	Attribute
External environmental risk A_1	Natural environment B_1	Probability of natural disaster C_1	Quantitative
		Sustainability of development C_2	Qualitative
	Economic environment B_2	Infrastructure completeness C_3	Quantitative
		Economic system C_4	Qualitative
		Economic development C_5	Qualitative
	Regulatory and policy environment B_3	Support of funds C_6	Qualitative
		Talent incentive C_7	Qualitative
		Construction of environment C_8	Qualitative
Market risk A_2	Market demand B_4	Market demand C_9	Qualitative
	Market competition B_5	Competition in the market C_{10}	Qualitative
Technical risk A_3	Technical suitability match B_6	Technology absorbing capacity C_{11}	Quantitative
		Ability to transform scientific and technological achievements C_{12}	Quantitative
	Technical difficulty B_7	Technical difficulty C_{13}	Qualitative
Managing risks A_4	Manage plan B_8	Management Plan C_{14}	Qualitative
	Management Organization B_9	Management organization C_{15}	Qualitative
	Management ability B_{10}	Management ability C_{16}	Qualitative
Operational risk A_5	Business model B_{11}	Mode of operation C_{17}	Qualitative
	Operating capacity B_{12}	Operational capability C_{18}	Qualitative

In the application of new power system operation evaluation, the first step is to obtain new power system operation evaluation indicators and information systems, as shown in (2).

$$S = (U, A, V, f) \tag{2}$$

In (2), U represents the non-empty set of valid objects of the domain of argument, A represents the set of all indicators, V represents the range of values of the index a in the new power system operation assessment system, and f is the information function that assigns attribute values to each object in U. The importance of the attributes is shown in (3).

$$\mathrm{Sigx}(a) = 1 - |X \cup \{a\}| \,/\, |X| \tag{3}$$

In (3), a is the importance to X, $|X \cup \{a\}| \,/\, |X|$ represents the indistinguishable decrease from X with the addition of the attribute a and also the identifiable increase. Then normalise the obtained attributes as shown in (4).

$$\lambda_i = \mathrm{Sig}(a_i) / \sum_{i=1}^{n} \mathrm{sigx}(a_i) \tag{4}$$

In (4), $\mathrm{SigX}(a_i)$ is the attribute importance, λ_i is the weight value of each sub-assessment indicator, and the confidence level of each attribute a_i in the primary, secondary and tertiary indicators. $C = \{a_1, a_2, \ldots a_n\}$is based on the experience of the system, and an appropriate empirical experience factor is selected to find the overall confidence level of $a_i M_i'(A_i)$, as shown in (5).

$$M_i'(A_i) = M_i(A_i) \times \theta + \lambda_i \times \sum_{A \subseteq \theta} m(A) \times (1 - \theta) \tag{5}$$

In (5), $\theta = [0, 1]$, smaller indicates a higher importance to objectivity and larger indicates a higher level of attention to experience, $\sum_{A \subseteq \theta} m(A) = 1$. The formula for its evidence-theoretic combination is shown in (6).

$$m(A) = K^{-1} \times \sum_{\cap A_i \leq A} \prod_{1 \leq i \leq n} M_i'(A_i) \tag{6}$$

The study used (6) to obtain the evidence-theoretic combination formula and the final score for the assessment of the operational effectiveness of the new power system. As the scores of the three main indicators, *i.e.*, Level 1, Level 2 as well as Level 3, are not comparable, the weighting of the

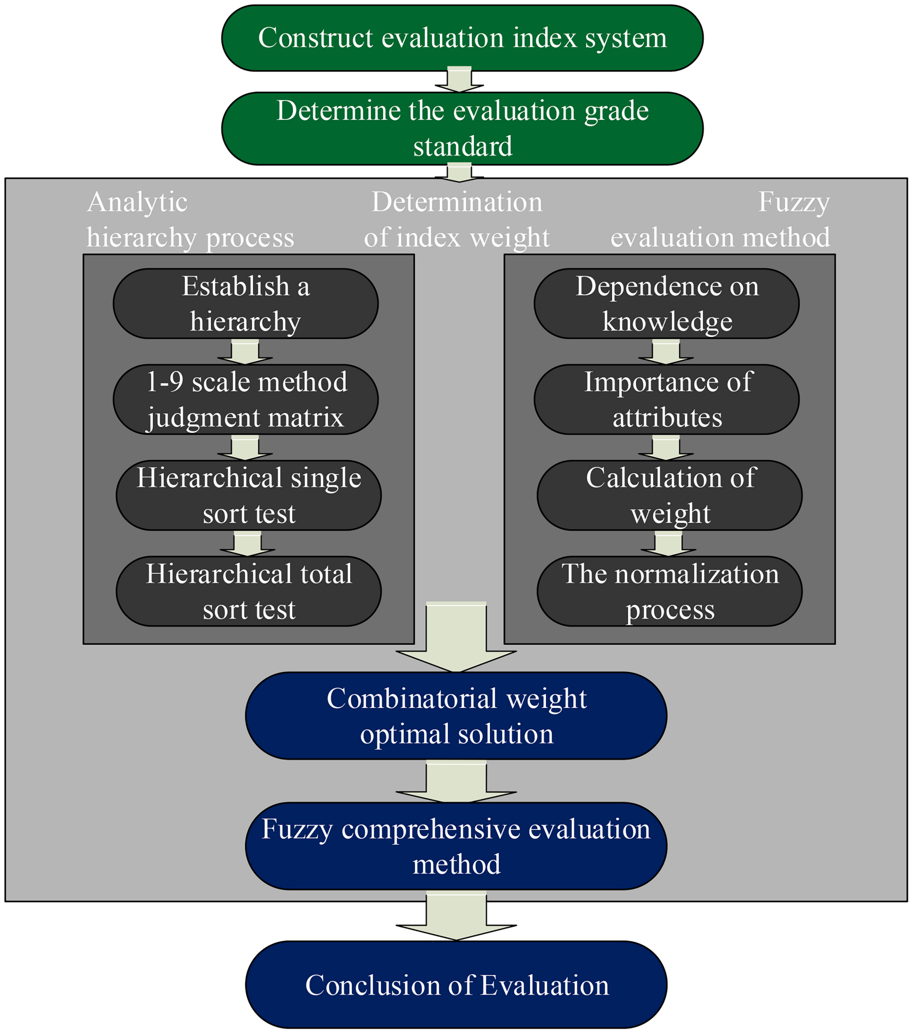

Figure 2. AHP–RST–EMFM ecological effect evaluation model.

different types of indicators in the overall score is different, which is a major issue to be addressed [14]. In practice, it is necessary to derive the general term for each factor, as shown in (7).

$$b_{\mathrm{ij}} = b_{\mathrm{ij}} / \sum b_{\mathrm{ij}} (i, j = 1, 2, 3) \tag{7}$$

The normalised judgement matrix is summed by row and the total terms of each element are represented by (8) and then normalised according to (9) for W.

$$w_i = \sum_{j=1}^{3} b_{\mathrm{ij}} (i = 1, 2, 3) \tag{8}$$

$$w_j = w_i / \sum_{j=1}^{3} w_i (i = 1, 2, 3) \tag{9}$$

In (8) and (9), $W = (w_1, w_2, w_3)$ obtains the weight occupied by each subject, and the weights obtained need to be verified, *i.e.*, a consistency check. Finally, the above obtained $M(A)$ is multiplied by W and finally the effectiveness of the new power system operation in the region is determined.

3.3 Design of Model Analysis Decision Information System

The framework structure of the analytical decision information system for this power operations risk model is shown in Fig. 3. The structure is divided into: sensing layer, data storage layer, data access layer, business logic layer, and expression layer. Model layer is throughout these parts among the data access layer, business logic layer and expression layer, the following is a detailed analysis of each layer [15]. The sensing layer mainly includes real-time measurement and collection equipment for power operation data. For decision support systems, the business logic layer develops algorithms related to decision making in a process to obtain corresponding decision results [16]. The representative layer is the level at which the system presents information to users and provides feedback on the results.

4. Analysis of the Application Effect of Combining Models with Evaluation Systems

The IEEE PES Power System Test Cases Data Set, Power System Analysis Toolbox and GridLAB-D Test Cases are the three power operations databases extracted from the

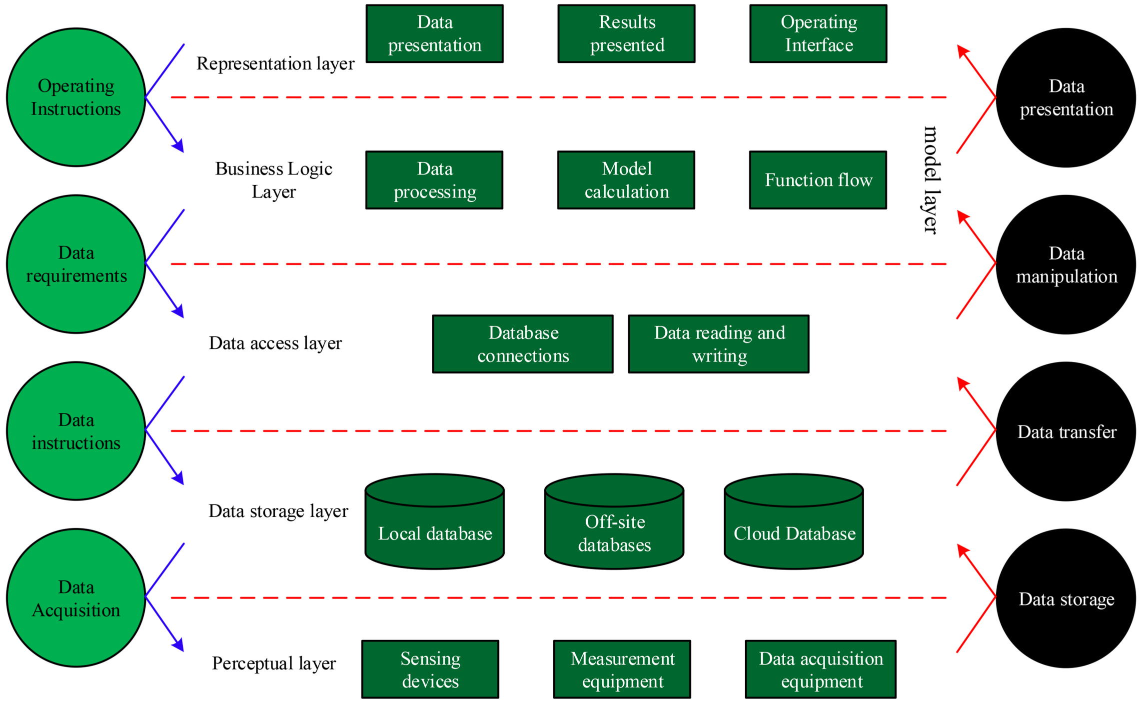

Figure 3. Framework structure of an analytical decision information system for power operational risk modelling.

study. The IEEE PES Power System Test Cases Data Set contains over 700 power system operation evaluation tests based on real power system data. The database is the most comprehensive database of large-scale real power system operation evaluation tests involving different types of power systems. The Power System Analysis Toolbox provides a wide range of databases, models, and algorithms for the operation and design of power systems, enabling better analysis and evaluation of the state and operation of power systems. The GridLAB-D test case provides a complete database for evaluating power system operation, which helps power system operators and researchers evaluate different power system operations. The training of the power operation risk and information assessment system at different data scales is shown in Fig. 4.

In Fig. 4, Chart1 represents the power system analysis toolbox database, while Chart2 represents the GridLAB-D test case database. It was found that as the number of iterations increased, the rating quality of the four comparative models showed a fluctuating upward trend, and the improved models were all higher than the other three multiple changes. This indicates that the power system model designed in this study has overall stronger robustness. The research divides the influencing factors into: technology risk factor, external environment factor, operational risk factor, management risk factor and market risk. These are shown in Table 2, where a, b, c, d and e are the five indices at the criteria level, D is the determinant, 1 is the positive impact on the operation of the power station and 2 is the negative impact on the operation of the power station, represented by values from 1 to 5 (very good, better, fair, poor and very poor).

At present, we use AHP analysis and rough set method to find out the first level index weight,

Table 2
Decision Table for Ecosystem Assessment

U	Conditional Attribute					Attribute of Decision Making
	a	b	c	d	e	D
1	2	3	3	4	1	2
2	2	3	3	3	1	1
3	4	4	1	2	2	2
4	2	1	3	4	1	1
5	3	4	3	2	2	2
6	3	4	1	2	2	1

i.e., $\mu = 0.383$, and set the ratio of subjective and objective weight coefficients to the "golden mean" according to the theory. The best combined weighting scheme was calculated and the evaluation results are shown in Fig. 5.

From Fig. 5, it can be seen that the comprehensive value index for the operational impact of the park power station is level 3. Overall results show positive operational impact effects, but is still in the transition period from weak to strong, and due to the increasing role of climate change and human factors, if unreasonable engineering management and operational measures are not appropriate, there will be negative effects, such as insufficient energy supply and energy waste. After applying the model, the study summarised the daily energy efficiency of the power station and the results are shown in Fig. 6.

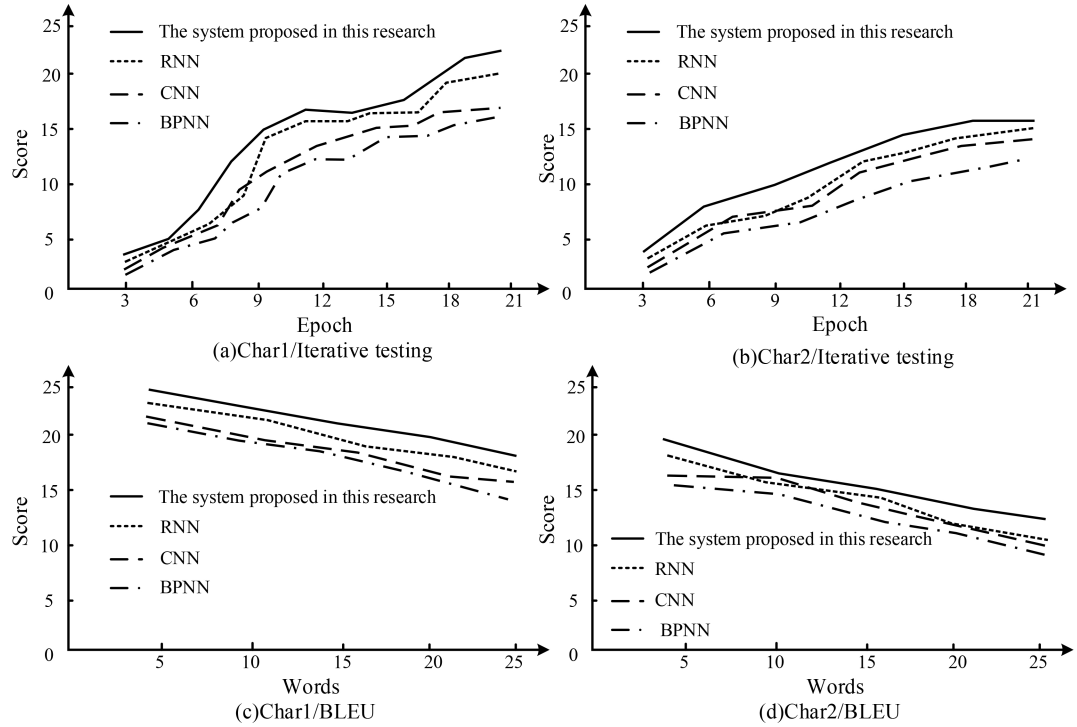

Figure 4. Predicting trends in quality.

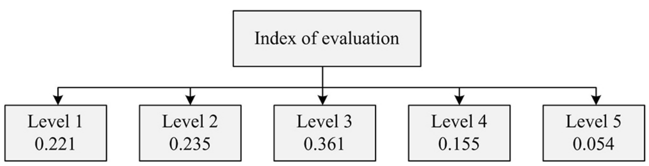

Figure 5. Comprehensive evaluation results of target layer.

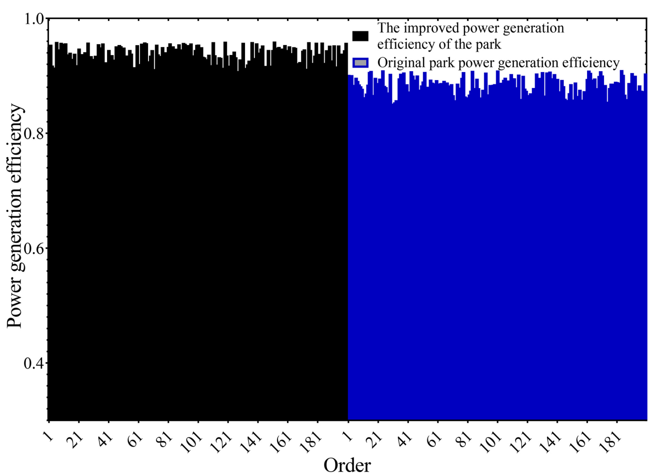

Figure 6. The sampling collection results of power generation data of the power station in the industrial park within 200 days.

Figure 6 shows the sampling collection results of power generation data of the power station in the industrial park within 200 days. Results obtained that before the application of the new power system, the lowest and highest power generation efficiencies are 82.5% and 85.5%, respectively. Mostly around 85%. After the application of the model proposed by the research institute, the power generation efficiency of all samples exceeded 85.5%, mostly around 88%. The power system evaluation model based on the improved FAHP has strong practicality and superiority. Compare the proposed model with the latest research, including the methods in [17]–[19], and [20], and the results are shown in Table 3.

Table 3
The Comparison Results Between the Proposed Model and the Latest Research in This Article

Method Type	Run time/s	Accuracy/%
Reference [17]	33.56	87.26
Reference [18]	29.83	89.58
Reference [19]	28.75	90.07
Reference [20]	30.06	91.33
Research method	22.17	95.79

From Table 3, it can be seen that the model in this article is only 22.17 s, with an accuracy of 95.79%. The highest efficiency and accuracy. Overall, the model proposed in this article has significant advantages in terms of runtime and accuracy. To further validate the effectiveness of the proposed prediction model, the model was validated, tested, and trained in the industrial park power database. Predict the risk level of the power system using the fitted curve after training, as shown in Fig. 7.

From Fig. 7, it can be seen that the R values for training, validation, and testing of the model are

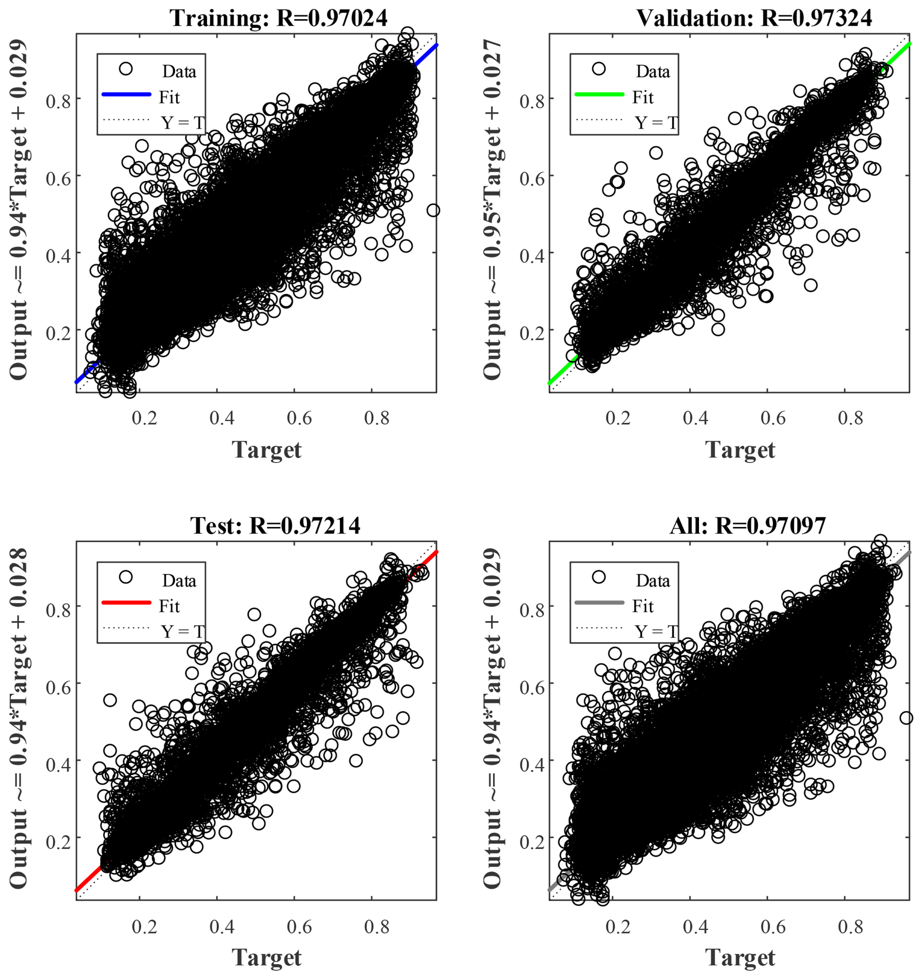

Figure 7. Fitted curve after training.

0.97024, 0.97324, and 0.97241, respectively. The overall test correlation reaches 0.97097, with a high degree of fit. Indicates that its model has high training and prediction accuracy.

5. Conclusion

In the context of smart grids, designing a reliable power operation risk model and analysing decision information systems is crucial for improving the reliability of power systems and addressing risks. The study combines AHP, RST and EMFM to analyse new power system operation problems. The results show that the improved algorithm achieves the target accuracy after 20 ms of training, after the application of the model proposed by the research institute, the power generation efficiency of all samples exceeded 85.5%, mostly around 88%. At the same time, the R values for training, validation, and testing of the model were 0.97024, 0.97324, and 0.97241, respectively. The overall test correlation reached 0.97097, with a high degree of fit, so the new power system evaluation model based on the improved fuzzy hierarchical analysis method proposed in this study is extremely practical. However, this article also lacks a detailed systematic introduction and evaluation description of existing research results. So future research work should evaluate the implementation and application effectiveness of information systems, and continuously improve and optimise system design.

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Data Availability Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no competing conflicts.

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