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BP Neural Network Evaluation Model Combined with Grey-Fuzzy Based on Included Angle Cosine

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Abstract: This paper is aimed to establish a novel evaluation model. It has verified the validity of the model based on the application of thermal power project. First of all, this paper analyzed the theoretical and practical significance of thermal power project. Secondly, it built a specific evaluation system from multi-angle and multi-level. The index system is a great innovation of this article. Thirdly, this paper established a model combining BP neural network with grey-fuzzy evaluation model. Finally, this paper selected a 2×630 MW air cooling thermal power unit in China. Then do the empirical research based on the data of 2010 to 2012 using Matlab. The combined evaluation model can avoid the subjectivity of grey-fuzzy model and the instability of BP neural network model. It has carried on the empirical research of comprehensive benefits, concluded the level.
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Keywords: Combined evaluation model, Grey-fuzzy evaluation model, BP neural network model, Included angle cosine.

1. Introduction

Nowadays a growing number of researchers are focusing on the renewable energy. However, thermal power occupies a very important position in China. It provides the base load of power grid. Thermal power projects are of large investment, high energy consumption, remarkable social benefit and high pollution [1, 2]. For the administrative departments of electric power, it is useful to find problems, adjust economic policy and technical parameters and optimize thermal power enterprise's management to study on the evaluation of thermal power project benefits. Besides, it can promote the improvement of thermal power project overall benefit, strengthen investment management and optimize the macro decision-making. To the five power generation groups in China, it is related to their own economic benefit closely with the deepening of the reform of electric power. As an independent legal entity and the economic interests of the entity, the power generation investment group needs a set of thorough index system and a scientific evaluation method eagerly in order to improve their competitiveness.

The scientific development, the green economy, the energy saving and the consumption reducing are becoming the main energy polices in China since the 11th five-year plan. As the pillar of the national economy, electric power industry began to take on more and more social responsibility. However, there was a long time that only attached great importance to the construction ignoring the management, only attached great attention to electricity ignoring the economy and only attached great importance to the

construction cost ignoring environmental impact in the process of power construction in China.

In addition, the traditional benefit system is given priority to financial evaluation indicators. Financial evaluation indicators are given priority to profit indexes such as profitability. In this evaluation system, it is easy to guide the enterprises to expand their scale blindly, pursuit the quantity excessively and ignore the motivation development and the ability to create value.

Therefore, it is necessary to consummate the evaluation system of thermal power project and innovate the evaluation model under the new environment and the request.

2. Evaluation Index System

There are numerous influence factors of thermal power project benefit [3]. This paper selects the related indicators from the multi-angle, multi-level and systematically to ensure the effectiveness and applicability when constructing the evaluation index system. The specific evaluation system is shown in Fig. 1.

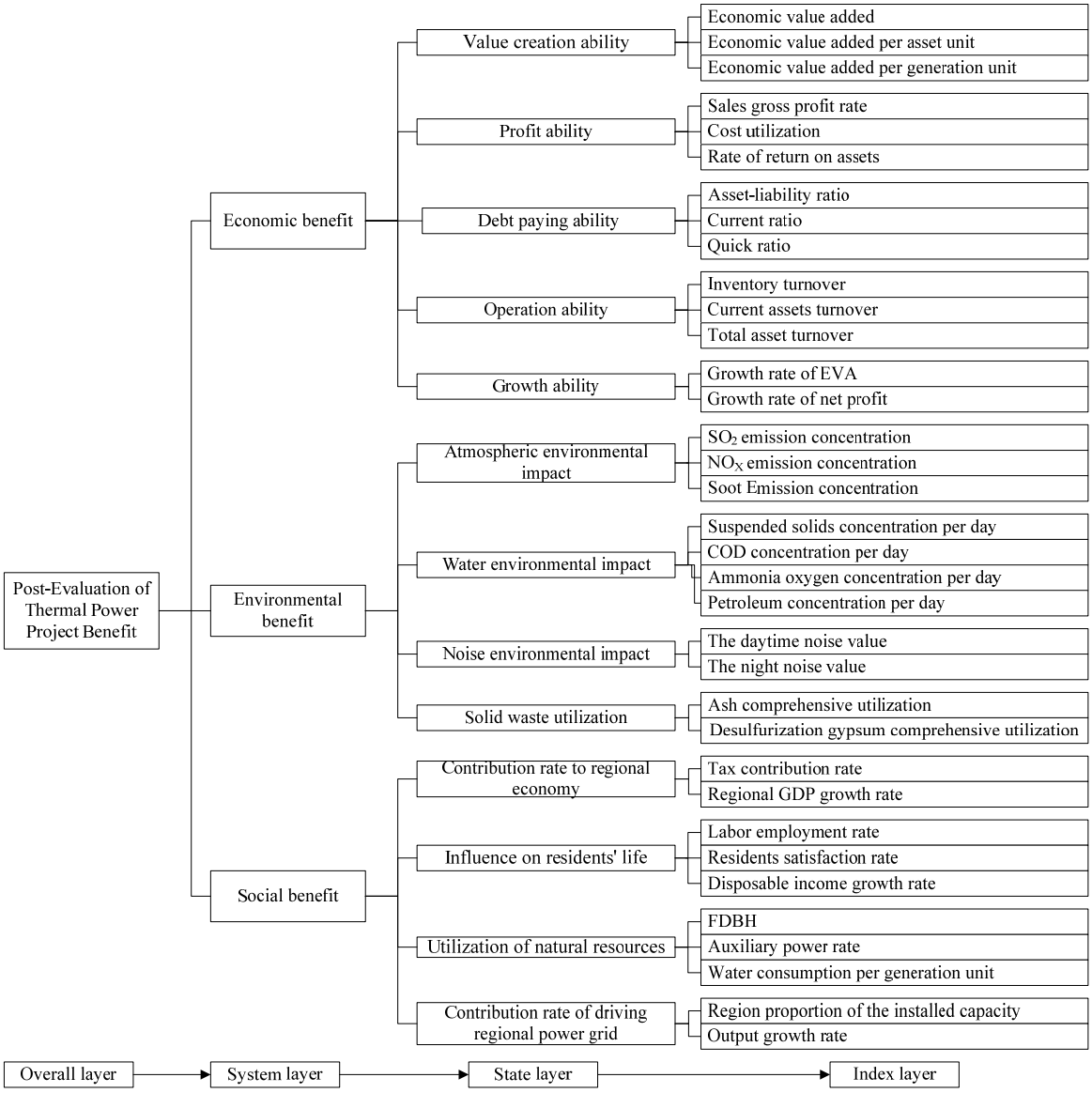


Fig. 1. The index system of evaluation.

3. Evaluation Model

This paper compares and chose the grey-fuzzy comprehensive model and BP neural network evaluation model using the included angle cosine model to couple the two models [5].

3.1. Grey-Fuzzy Comprehensive Evaluation Model

In this paper, the grey comprehensive evaluation method and fuzzy comprehensive evaluation method are combined to build a new model. And the steps as follows:

1. To determine the index weight.

This paper selects the Analytic Hierarchy Process (AHP) to determine the index weights of thermal power project.

2. To structure fuzzy membership degree matrix based on theory of grey clustering structure:

1) To determine the comment set.

The comments for thermal power project benefit can be divided into five levels, namely "excellent, good, medium, bad, worst". And the evaluation sets is $V=(v_1,v_2,v_3,v_4,v_5)$.

2) To determine the gray classes of evaluation.

The value range of each indicator can be divided into M grey classes. In this paper, $M=5$.

To divide the value range of each indicator $[a_1,a_6]$ into $[a_1,a_2],...,[a_k,a_{k+1}],...,[a_5,a_6]$. Among them the values of $a_k(k=1,2,...,5)$ are based on the nature of evaluation index and the industry standards.

3) To establish triangular whitenization weight function.

Establish the whitenization weight function according to the theory of related gray evaluation theory. Let the function value of λ_k, $\lambda_k=(a_k+a_{k+1})/2$ is 1. The numerical range $(\lambda_k,1)$ connects the starting point of grey class $k-1(a_{k-1})$ and the last point of grey class $k+2$ (a_{k+2}). Then get the whitenization weight function $f_j^k(x)(j=1,2,...,m;k=1,2,...,5)$ which is the indicator *j* on class *k*. As for $f_j^1(x)$ and $f_j^5(x)$, we can expands the index number field to the left to a_0, to the right to a_7.

For the realization value of the index j, we can calculate the membership degree $f_j^k(x)$ belonging to the grey class $k(k=1,2,...,5)$ according to the following formula.

$$f_j^k(x)=\begin{cases}0 & x\notin[a_{k-1},a_{k+2}]\\ (x-a_{k-1})/(\lambda_k-a_{k-1}) & x\in[a_{k-1},\lambda_k]\\ (a_{k+2}-x)/(a_{k+2}-\lambda_k) & x\in[\lambda_k,a_{k+2}]\end{cases}, \quad (1)$$

where $\lambda_k=(a_k+a_{k+1})/2$.

4) To construct the fuzzy membership degree matrix

3. Fuzzy comprehensive evaluation

We can use the fuzzy vectors to represent the membership degree information on the upper layer. To fuzzy synthesize the fuzzy matrix and the weight vector using the weighted average algorithm $M(\bullet,+)$.

3.2. BP Neural Network Evaluation Model

1. The evaluation principle.

BP neural network is a kind of multilayer forward feedback networks according to the error back propagation algorithm training [6]. It is the most widely used type of artificial neural network. It has strong generalization ability and fault tolerance ability. BP neural network model topology includes input layer, hidden layer and output layer [7].

2. The evaluation procedure.

1) To determine the network structure

In this paper, the network model figure of evaluation is shown in Fig. 2:

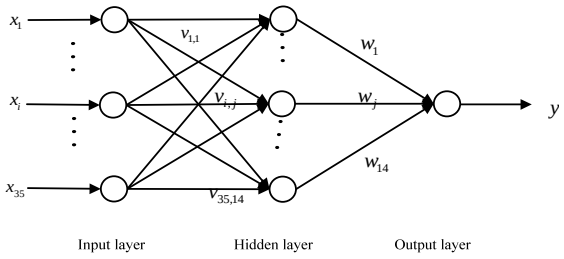


Fig. 2. The topological structure figure of thermal power project benefit evaluation.

2) To determine the activation function.

We can get the evaluation model based on BP algorithm according to Fig. 2.

$$Y=f(W\times[g(V^T\times X)-B_1]-B_2), \quad (2)$$

3) To do the network training.

All of the 35 indexes that this paper selects are quantitative indicators. On the basis of the dimensionless processing, set the maximum training steps for 10000. Set the error precision for e^{-2}. We can train and test the designed evaluation model using the neural network toolbox of matrix laboratory

4) To get the final result.

The output is a value whose data range is between 0 and 5. It can be divided into "excellent, good, medium, bad, worst" five levels of evaluation.

3.3. Combination Evaluation Model Based on the Included Angle Cosine

1. To dispose the evaluation results.

First of all, it is necessary to dispose the result of gray-fuzzy comprehensive evaluation model so that we can make the result of gray-fuzzy model with the result of BP neural network in the same scope and scale.

This paper set the corresponding evaluation score vector of "excellent, good, medium, bad, worst" to $A=(a_1,a_2,a_3,a_4,a_5)=(5,4,3,2,1)$. Then the final evaluation result of grey-fuzzy comprehensive model is $M=A\circ B^T$. Obviously, the final result is a value between 0 and 5 which is the same magnitude in the same area with the result of BP neural network model. It can be coupled in the next step.

2. To determine the coupling function

We can get the final of thermal power project benefit evaluation by coupling function which can combine the grey-fuzzy evaluation model with BP neural network model on the analysis of the a consistent treatment.

The coupling function is as follows:

$$M = W^1 M^1 + W^2 M^2, \quad (3)$$

where M^1 is the result using the grey-fuzzy model. W^1 is the weight of grey-fuzzy model. M^2 is the result using BP neural network model. W^2 is the weight of BP neural network model.

This paper uses the included Angle cosine model to calculate the weights. The principle of included angle cosine is to regard the average value of the two models and the value of the combination evaluation model as two vectors. The average vector and the combination result vector do not overlap because of error. When the angle between combination result vector and the average vector is smaller, that is to say when the angle cosine is greater, the evaluation result is more accurate.

$$MAX\partial = \sum_{t=1}^{n} C_t \bullet A_t \Big/ \sqrt{\sum_{t=1}^{n} C_t^2 \sqrt{\sum_{t=1}^{n} A_t^2}}, \quad (4)$$

where ∂ is the cosine of the angle between the average vector and the combination result vector. C_t is the result of combination model. A_t is the average value of two models.

$$s.t. \begin{cases} e^T W = 1, \\ W \geq 1 \end{cases} \quad (5)$$

where W is the weight vector of the two evaluation methods, $W = (W^1, W^2)^T$, $e = (1,1)^T$.

3. To determine the combination evaluation criterion

The evaluation criterion of combination model (Shown in the Table 1) is same as the criterion of BP neural network model.

Table 1. The criterion of combination model.

Level	Excellent	Good	Medium	Bad	Worst
Criterion	[4.5,5.5]	[3.5,4.5)	[2.5,3.5)	[1.5,2.5)	[0,1.5)

4. The Empirical Research

This paper selects a 2×630 MW air cooling thermal power unit in China, which is named J. Then do the empirical research based on the data of 2010 to 2012 since it put into production since December 2009.

4.1. Grey-Fuzzy Comprehensive Evaluation

1. To determine the weights of evaluation indicators.

The final result is shown in Fig. 3.

2. To determine gray classes.

This paper determines the gray classes based on the actual situation of Project J, the statistical information of China's 600 MW level thermal power air-cooling units, as well as the standard of China and the power industry.

3. To calculate the membership.

$f_j^k(x)$ belonging to the grey class $k(k = 1,2,\cdots,5)$ based on triangular whitenization weight function. On the basis of fuzzy clustering matrix, fuzzy membership degree matrix is determined. We can get the fuzzy evaluation matrix after calculating.

4. Fuzzy comprehensive evaluation.

Finally, we can get the evaluation vector of comprehensive benefit of thermal power project benefit.

$$B = R \circ w = (0.4312, 0.3038, 0.1879, 0.0731, 0.0040), \quad (6)$$

5. The analysis of results.

In the evaluation vector B, 0.4312 is the biggest of all. That is to say, the "excellent" membership degree is biggest. According to the principle of maximum membership degree, we can conclude that the result is "excellent". However, we can find that the membership degree belonging to "good" is 0.3038 which ranks only second to the membership degree of "excellent". Besides, the gap between is small.

4.2. BP Neural Network Comprehensive Evaluation

1. To determine the network structure

In the evaluation of Project J, BP neural network is a mapping of 35 dimensions to 1 dimension. The number of input layer nodes is 35. The number of output layer nodes is 1. The number of hidden layer is 14. The network structure is shown in Fig. 4 using the software of Matlab.

2. To determine the training sample

This paper collects 30 samples of different data sets and determines the mapping relationship of evaluation results.

Then take the 30 sets of data as the training sample to train the BP network.

The 30 samples are all 600 MW and air cooling thermal power projects which are taken from China Datang Corporation.

3. The network training.

Set the largest training step to 10000. Set the error precision to e^{-2}. The BP network training is using the Matlab neural network toolbox.

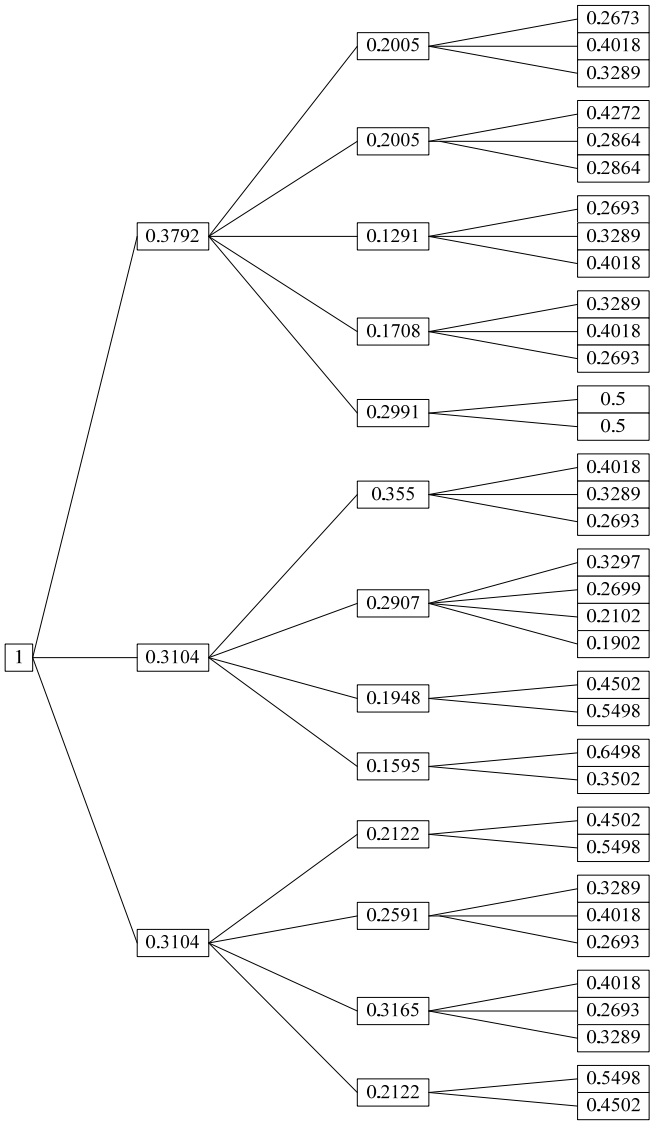


Fig. 3. The weights of four levels in the indicator system

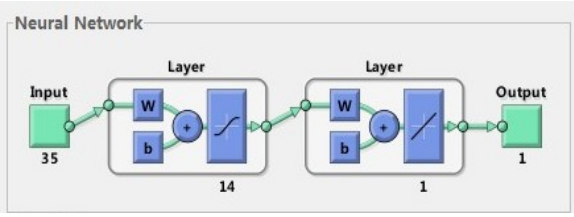


Fig. 4. The structure figure of BP neural network.

Set the sample data which have gone through the process of dimensionless. Import the data in the Matlab artificial neural network model for training and learning. We can achieve the target after 257 times of training and learning sample data. BP neural network learning performance curve is as shown in Fig. 5.

From the training results, we can see the fitting degree of the actual output value compared with the desired output is 0.9975. The fitting degree is high relatively. The model convergence and achieve the required accuracy. The training error is very small. It has good feasibility to use this mode to evaluate the comprehensive benefit.

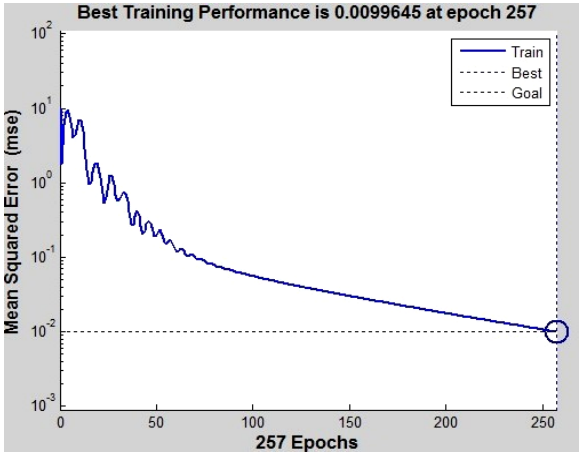


Fig. 5. BP training error approximation process.

4. Get the evaluation results

The processing of raw data is the same as the processing in the grey-fuzzy evaluation model. Then input the processed data to the trained BP neural network model. We can get the output result after the simulation. The final result is 4.1685 which is shown in Fig. 6.

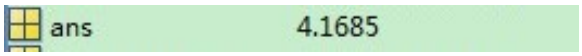


Fig. 6. The evaluation result of BP neural network.

The output value is $y = 4.1685 \in [3.5, 4.5)$. We can find that the evaluation result is "good" according to the output value and the rating criterion.

4.3. Combination Evaluation

The empirical result of grey-fuzzy comprehensive evaluation is "excellent". The empirical result of BP neural network evaluation is "good". We can find that the evaluation results are inconsistent. This paper then uses the combination model to coupling the results.

Firstly, convert the result of grey-fuzzy evaluation model to the same magnitude as the BP neural network evaluation model using the formula ($M^1 = A \circ B^T$).

$$M^1 = (5,4,3,2,1) \circ (0.4312, 0.3038, 0.1879, 0.0731, 0.004)^T, \\ = 4.0851 \quad (7)$$

Secondly, couple the results of the two models using the included angle cosine model. We can get that $W^1 = 0.476, W^2 = 0.524$ according to the included angle cosine model. Then we can get the final result according to the formula (3).

$$M = 4.0851 \times 0.476 + 4.1685 \times 0.524 = 4.1271, \quad (8)$$

Finally, according to the evaluation criterion of combination model we can find that $M \in [3.5, 4.5)$. It can be judged that the final result of Project J is "good".

5. Conclusion

It is a complicated problem to do the evaluation of thermal power project benefit. There were some relevant research results, but to date, it has not formed a more scientific and reasonable index system. And the evaluation methods are casual relatively which are lack of the versatility and standardization. Considering the above defects, this paper constructed an evaluation system including economic benefit, environmental benefit and social benefit under the new background and requirement. Besides, this paper introduced the economic added value and other related indicators innovatively emphasis on the measurement of all the cost of capital of the thermal power enterprises. On the evaluation model, this paper built the grey-fuzzy comprehensive benefit model and BP neural network model respectively. And then the combination model was built based on the angle cosine model to couple the above two models. Finally, based on the algorithm analysis of a 600 MW thermal power project, the rationality and feasibility of the model was verified.

Fuzzy mathematics and grey system theory are two kinds of theories of studying the uncertain systems and commonly used. The mainly research problem of fuzzy mathematics is the "vagueness". The research object is "the connotation clear, and the extension unclear." To the grey theory, it focused on "grey". The object is "the extension unclear, the connotation unclear". It will cause part of the loss of information if only use fuzzy mathematics method. And it will not take the advantage of the fuzziness characteristics if only use the grey theory method. Therefore, this article combined the two methods to build fuzzy-grey comprehensive model. However, this method has some disadvantages such as lack of theoretical basis when giving the weights of indicators, complicated calculation process and a degree of subjectivity. BP neural network has the ability to learn basic features, nonlinear mapping. The evaluation result is more objective. However, the result is instability which is quite different with the change of parameters [8]. Above all, this paper has coupled the two models based on the included angle cosine. The new model not only can solve the complexity problem of thermal power project benefit evaluation, but also can take the vagueness and the grey into consideration. It can combine the subjective with the objective to ensure the scientificity and accuracy of the evaluation results. In conclusion, this paper has significant theory value and application value.

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