Comprehensive Evaluation on Economic Performance of Flexible Substation Power Distribution Technology based on BP Neural Network

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Abstract. With improvement of energy utilization level, the effective way of power distribution becomes a key research focus. The traditional rigid power transformation is featured in low transformation efficiency and serious power loss, while the power distribution technology based on flexible substation could exactly solve this problem. This paper, aiming at technical performance, economic benefits, environment impact, policy factors, selects system suitability, transmission efficiency, operational reliability, system transient characteristics, costs, investment efficiency, natural environment impact, and policy influence as evaluation indexes, designs five technical and economic evaluation grade and establishes fuzzy comprehensive evaluation system in combination with analytic hierarchy process (AHP), fuzzy mathematics and BP neural network to analyze the technical economic performance of AC/DC power transformation technology based on flexible substation, and provide references to subsequent project with example verification.

1. Introduction

With improvement of energy utilization level, the effective way of power distribution becomes a key research focus. At present, the modern intelligent power system requires clean and diversified power source, electronic and information-oriented network power and complex and interactive load characteristics.\textsuperscript{[1,2]} Therefore, more efficient, intelligent, flexible and stable power distribution technology is in urgent demand. The power distribution system based on flexible substation has higher controllability and power transmission efficiency. The study on flexible substation complies with the long-term development trend of the power distribution network in the future in China, and could help improve power transmission efficiency of power distribution network and simplify variety and quantity of substation equipment.\textsuperscript{[3]} With development and promotion of the flexible AC/DC project, an important subject for continuous flexible AC/DC project development is to carry out comprehensive evaluation of technical economic performance of the project, establish scientific and practical technology and economy evaluation mode, improve technical economic performance of project operation and promote reasonable resource configuration. This paper puts
forward a comprehensive evaluation method combining AHP, fuzzy mathematics and BP neural network in accordance with technical characteristics of flexible AC/DC technology.

2. Selection of fuzzy comprehensive evaluation indexes for technical economic performance of flexible AC/DC power transmission based on BP neural network

2.1 Selection of technical and economic indexes

Since there are numerous factors affecting technical economic performance of flexible power distribution, this paper selects indexes which are easy to measure, convenient to collect data and could truly reflect technical economic performance of the project after comprehensively considering various factors. This paper, aiming at secondary indexes including technical performance, economic benefits, environment impact, policy factors, selects system suitability, transmission efficiency, operational reliability, system transient characteristics, costs, investment efficiency, natural environment impact, social environment impact, and policy influence as the third level evaluation indexes. [4] The index system is introduced below.

1) System suitability
   System suitability is mainly used to evaluate the system strain capacity when external environment is changed; abilities in aspects of operation, installation and transformation; it is divided to system flexibility, system expansion capacity, and system function integration level.

2) Transmission efficiency
   The system transmission efficiency is used to evaluate effectiveness of system effective transmission power. It is divided to compensatory loss and other loss.

3) Operational reliability
   The operational reliability mainly refers to the ability of the system to keep stable operation. It contains tide control ability, failure isolation ability, harmonic filtration ability and power quality.

4) System transient characteristics
   The system transient characteristics are mainly used to evaluate the ability of the system to convert from one state to another state rapidly. It contains failure recovery time, overvoltage protection level and short circuit capacity.

5) Costs
   The index of costs is mainly used to evaluate the economic rationality. Its sub-indexes are unit investment, maintenance cost and repair cost.

6) Investment efficiency
   This index is mainly used to evaluate fund use efficiency of the project. It contains net present value, internal rate of return, dynamic investment return period and return on investment.

7) Natural environment
   The natural environment impact contains the impact of the project on nearby environment and resource consumption of the project.

8) Social benefits
   This factor mainly considers the role of innovative demonstration, economic promotion and technology promotion.

9) Policy influence
   The policy influence mainly refers to the support and encouragement degree of national policies.

3. Establishment of fuzzy comprehensive evaluation model for technical economic performance of flexible AC/DC power transmission based on BP neural network

3.1 Calculation steps of BP neural network

BP neural network adopts gradient search technology to minimize the mean square error of actual output and expected output of network. BP neural network system solves the learning problem of hidden unit connection right in multiple layer network. Therefore, this paper also adopts BP algorithm to establish the neural network model. BP neural network is usually divided to three layers, respectively input layer, hidden layer and output layer. There is no connection between the neurons on
the same layer, while neurons on each layer form full connection. When BP algorithm is applied to multi-layer neural network, two stages are contained, respectively forward propagation and back propagation. In forward input, the input information is inputted from the input layer, processed by the hidden layer, and transmitted to the output layer. Each layer of neurons could only affect the status of neurons on the next layer. If the expected output could not be acquired from the output layer, the back propagation process will be started to send the error signal back along original connected path, and minimize the error signal by revising weight of neurons on each layer. The algorithm is as follows:

1. Initialization: to set all weighted coefficient as the minimum random number.
2. Provide training set: to offer input vectors X(1), X(2), ..., X(n) and expected output vectors t(1), t(2), ..., t(n) assigned in sequence.
3. Calculate actual input: to calculate output of neurons on hidden layer and output layer according to formula 1 and 2.

The output of the i-th neuron on the hidden layer can be seen in formula (1).

\[ O_i^p = g \left( \sum_{j=1}^{M} w_{ij} x_j^p - \theta_i \right) \]  

The actual output of the k-th neuron on the output layer can be seen in formula (2).

\[ O_k^p = g \left( \sum_{i=1}^{n} w_{ik} o_i^p - \theta_k \right) \]  

4. Calculate error between expected value and actual output: to calculate according to formula (3):

\[ J_p = \frac{1}{2} \sum_{k=1}^{N} \sum_{l=1}^{L} (t_k^l - o_k^l)^2 \]  

5. Adjust weighted coefficient W_{ki} of output layer according to formula (4):

\[ w_{ki}^{(k+1)} = w_{ki}^{(k)} + \eta \sum_{j=1}^{n} \delta_k^p o_j^p \]  

6. Adjust weighted coefficient W_{ij} of the hidden layer according to formula (5):

\[ w_{ij}^{(k+1)} = w_{ij}^{(k)} + \eta \sum_{p=1}^{n} \delta_i^p o_j^p \]  

7. Calculate step (3) again, till the error meets requirements.

3.2 Establishment of fuzzy comprehensive evaluation system for technical economic performance of flexible AC/DC power transmission based on BP neural network

According to analysis on aforesaid factors, an artificial neural network model for technical-economic index evaluation of flexible AC/DC power transmission is established. In the formula, the indexes are respectively system suitability, transmission efficiency, operational reliability, system transient characteristics, costs, investment efficiency, natural environment impact, social environment impact, and policy influence from the perspectives of technical performance, economic benefits, environment impact and policy factors; W is the weight set of multi-layer neural network. The neural network g(x) is used to simulate nonlinear relationship between each technical-economic index and overall technical-economic performance. The output layers shall be five.
3.3 Quantitative processing of BP neural network model for technical economic index evaluation of flexible AC/DC power transmission

Since many technical economic indexes in flexible AC/DC power transmission technical economic performance evaluation project are fuzzy, this paper adopts the fuzzy comprehensive evaluation in fuzzy mathematics to carry out quantitative processing \(^5\), following the steps shown in the figure:

1. Establish factors set

Factors involved in the problem are listed, and key indexes are selected to form factors set, represented by \(\{u_1, u_2, \ldots, u_n\}^T\).

2. Establish evaluation set \(v=(v_1, v_2, \ldots, v_m)\) and weight set \(w=(w_1, w_2, \ldots, w_n)\), \(\sum w_i = 1\).

3. Solve evaluation matrix \(R = (r_{ij})_{n\times m}\) according to indexes, in which, \(r_{ij}\) means the score of influence factor \(u_i\) in grading is \(v_j\).

4. Carry out fuzzy comprehensive evaluation to form

\[
C = W \times R = (w_1, w_2, \ldots, w_n) \times (r_{ij})_{n\times m} = (c_1, c_2, \ldots, c_m)
\]

\[
V = \sum_{i=1}^{m} c_j v_j / \sum_{i=1}^{m} b_j
\]

5. Solve factor evaluation value

3.4 Confirmation of technical economic performance grade of flexible AC/DC power transmission

When judging technical economic performance grade of flexible AC/DC power transmission with BP neural network, the output results are divided to five grades, respectively unreasonable, reluctantly reasonable, reasonable, comparatively reasonable and very reasonable. The higher the grade is, the more reasonable the overall technical economic indexes will be. As shown in Table 1, when applying neural network training with large sample data, if the error between actual output and allowed error is between \((0.2, 0.2)\) \(^6\), the results are deemed as reliable.

Table 1 Correspondence table between output standard value and output results

| Grade                  | 1       | 2   | 3      | 4      | 5      |
|------------------------|---------|-----|--------|--------|--------|
| Technical economic performance | Unreasonable | Reluctantly reasonable | Reasonable | Comparatively reasonable | Very reasonable |
| Output value           | (1, 0, 0, 0, 0) | (0, 1, 0, 0) | (0, 0,1,0, 0) | (0,0,0,1,0) | (0,0,0,0,1) |

4. Training and test of evaluation model for technical economic index evaluation of flexible AC/DC power transmission

According to actual operation situations of flexible AC/DC power transmission and technical economic performance, this paper selects 6, 8, 10 to apply BP training to ANN \(^7\). The input and output sample value can be seen in Table 2:
The first 12 groups of data in the sheet are selected as training data, and the last 2 groups as test samples to apply repeated learning and training. Findings show the data error turns to stable at the 1146th time.

In order to verify correctness of neural network model established before, the two groups of data without learning are selected to input to network for calculation. The output results are as follows:

Table 3 Checking results table

| No. | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | Result                  |
|-----|-------|-------|-------|-------|-------|-------------------------|
| 14  | 0.0000| 0.0000| 0.2382| 0.0000| 1.0000| Consistent with expectation |
| 15  | 0.9971| 0.0012| 0.0000| 0.0000| 0.0000| Consistent with expectation |

According to Table 3, the results are consistent with expected results, finally proving the neural network model is feasible.

5. Case analysis

This paper takes the flexible substation power distribution project as an example, and refers to domestic and overseas standards concerned and project practices. The voltage grade of this substation project is medium voltage 10kV AC, ±10kV DC and low voltage 750V DC, 380V AC. Total load is 2.5MW, in which, 1.8MW is server load and could be supplied directly by DC. In combination with voltage grade selection and load wheeling requirements, the capacity of the flexible substation shall be 5MVA/5MW/5MW/2.5MVA, and of PV DC booster station shall be 2.5MW. The system components diagram can be seen below. The secondary index score is respectively (0.8, 0.8, 0.8, 0.78, 0.6, 0.5, 0.79, 0.7) according to expert scoring method and AHP. Through network calculation, the output result is (0, 1, 0, 0, 0, 0), i.e., the comprehensive benefits of the project are favorable, and consistent with the actual evaluated results of project.
Fig.1 AC/DC power distribution diagram of certain flexible substation

6. Conclusion
This paper, from five angles of technical performance, economic benefits, environment impact and policy factors, comprehensively analyzes influence factors in each aspect, and establishes comprehensive index system through factor analysis to provide reference for technical economic performance evaluation of power distribution projects based on flexible substation. Moreover, this paper verifies the result with trained BP neural network and proves the method is effective.

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