Construction of an evaluation index system for power market considering economic-environmental multi-objectives

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Abstract: At present, China's electricity market has been initially built, direct trading of electricity continues to increase, and the mode of "multiple purchase and multiple sale" has emerged in the market, which enables the electricity market to compete effectively and make the optimal allocation of resources. Therefore, it is necessary to evaluate the operation of the electricity market. The article firstly studied the indicators of power market operation from three aspects: economic value, green value and security value; secondly, established a three-level evaluation index system of power system; on this basis, proposed a comprehensive evaluation model of power market based on fuzzy comprehensive evaluation. It provides a reference basis for the evaluation of China's power grid operation and is of great significance to promote the healthy development of China's power market.

1. Introduction

In 2015, the release of the Chinese development [2015] No. 9, the new electricity reform and other related documents showed that the process of China's electricity market reform is accelerating and gradually establishing a fully competitive, open and orderly, healthy development of the electricity market system in the country. The safe, stable, reliable and efficient operation of the market determines the construction of the market and the operation of the market. Therefore, it is imperative to construct a set of electric power market evaluation index system suitable for China's national conditions. In the market scheme design stage, the relatively better market design scheme is evaluated and selected, and in the market operation stage, the market operation and market performance are monitored and evaluated to find out the problems in the market construction and operation. There is not much research work on evaluation system at home and abroad, and the methods and focus of establishing it differ from country to country, and no accepted evaluation system has been formed yet.

Most of the relevant domestic research results focus on the necessity and feasibility analysis of establishing electricity market indicators, improving the market regulation model, and the implementation principles and steps.Indicators such as competitiveness were studied for the European Electricity Market Evaluation System (EEMES) by Taysi et al[1]. Fei Chen et al. started from the international evaluation standards, took into account the construction of the electricity market, the purpose and constraints of government control, and tried to build a set of evaluation index system that meets the actual situation in China[2].Tao Li and Shengyu Wang evaluate the trading in China's electricity market from three perspectives: the fundamentals of the electricity industry, the electricity market setup and the real trading in the electricity market[3].Shuhong Shi et al. established a set of evaluation index system in direct power trading, and a comprehensive evaluation system based on topo cloud theory[4].Bangcan Wang et al. established an evaluation index system for the electricity market trading mechanism from five aspects: market liquidity, stability, economy, development coordination, and openness[5].Guided by the SCP model, Zhixiong Hu constructed indicators for market structure, market operation and market performance to evaluate the new market operation in terms of[6].

Most of the previous researches are still focused on the theoretical support level of index system construction, more inclined to the evaluation model before the operation of the electricity market, but not more applied to the practical operation and effectiveness of the judgment support and feedback regulation. Therefore, in view of the current situation of this kind of research, this paper will establish a set of practical indicators to evaluate the current electricity market mechanism from the perspective of the whole value system of electricity energy, based on the economic value, green value and security value, and make specific evaluation of the indicators based on the fuzzy comprehensive evaluation method, and each province can make market evaluation according to this indicator system and the steps of the evaluation method. In order to provide a basis for the specific investigation of the current electricity market mechanism.

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2. Electricity market evaluation index system considering economic-green-security

A healthy electricity market mechanism should make it possible to: optimize the allocation of market resources under the action of value law, expand the interests of all market subjects under the premise of meeting social needs; promote the formation of a market system and long-term mechanism for green energy production and consumption, and promote the construction of a new power system with new energy as the main body; improve the efficiency of the power system and the level of safe and reliable supply. This is also the core of this paper from this value perspective, from the three major value systems of economic value, green value and security value of the electric power market, and to reflect the effect of decision-making influence, to build an electric power market assessment index system and form a power market assessment model to assist market decision-making.

2.1 Market economic value category indicators

In order to judge whether the current market mechanism design is conducive to the recovery of economic value, we should first consider the legitimacy of the market force manipulation in the electricity market on the general principle of fairness and equity, i.e., the indicators of market health. Only on this basis can we further consider the interests of market members under this market mechanism and measure the economic value of its electricity market by the indicators of market efficiency.

2.1.1 Market Health

(1) Lerner Index

The Lerner Index (LI), which measures the monopoly position of a market player by the degree of deviation between the electricity market clearing tariff and the marginal cost. The following are specific definitions:

$$\mathrm{LI} = \frac{\mathrm{P}-\mathrm{MC}}{\mathrm{P}} \tag{1}$$

In the formula: P is the current market price; MC is the marginal cost of the unit.

(2) Residual Supply Index

The Residual Supply Index (RSI) of a power producer is the sum of the market shares of all units except this one in a given period. It is expressed by the following formula:

$$\mathrm{RSI_i} = \frac{\sum_{j=1}^{k} q_j}{D} - \frac{q_i}{D} = \frac{\sum_{j=1}^{k} q_j - q_i}{D} = \frac{\sum_{j=1, j\neq i}^{k} q_j}{D} \tag{2}$$

In the formula: k is the number of all units in the market; q_j is the capacity of the first j unit; q_i is the capacity of the first i unit; D is the market all load demand.

(3) HHI indicators

The HHI metric is measured by the sum of the squares of the market shares held by each supplier in the market. It is expressed by the following formula:

$$\mathrm{HHI} = \sum_{i=1}^{l} (100 \times t_i)^2 \tag{3}$$

In the formula, t_i indicates the market share of the first i supplier in the market; l indicates the number of suppliers in the market.

2.1.2 Market Benefits

(1) Producer surplus

In terms of the market, the producer surplus is the additional profit that producers receive for the difference between their true costs and the prevailing tariff, i.e., the difference between the actual revenue that generators earn in the market and the minimum profit they can afford to make.

(2) Consumer surplus

For an individual market, consumer surplus is the difference between the maximum price that a power purchaser (including large customers and power sellers) is willing to pay for a particular electricity and the price that they actually pay. Consumer surplus is measured by the additional economic benefits obtained by purchasing the network.

(3) Market Benefit Distribution

Combining the producer surplus with the consumer surplus yields the overall market surplus. In this paper, from the current electricity market reform in China, the concept of market benefit distribution can be defined as the ratio of supply-side benefits to user benefits.

2.2 Market Green Value Category Indicators

In order to judge whether the current market mechanism design is conducive to the recovery of green value, the first should be considered from the perspective of the nature of energy fuels, coal and other thermal energy in power supply compared to renewable clean energy will cause a greater degree of ecological loss; and from the perspective of the results of green value, environmental sustainability indicators are more relevant.

2.2.1 Energy mix

(1) Fuel Diversity Indicators

By simulating the power grid planning for a specific area, it is possible to count different types of power generation in a certain period of time and calculate the different types of power generation with the calculation formula:

$$\mathrm{P} = \frac{\sum_i E_i}{E} \times 100\% \tag{4}$$

In the equation, P is the fuel diversity, E_i represents the amount of electricity generated in a region by other forms of generation besides coal; E represents the total amount of electricity generated in this region during this period.

2.2.2 Environmental Sustainability

(1) CO_2 emission index per unit of power generation

The CO_2 emissions per unit of electricity generated indicator counts the CO_2 emissions per unit of electricity generated and is calculated as follows:

$$Q = \frac{m}{E} \tag{5}$$

In the formula, Q is the CO_2 emission per unit of power generation, m indicates the amount of CO_2 emitted by power generation in a certain region during a certain period of time; E indicates the total amount of power generation in the region within that period of time.

(2) Renewable Energy Efficiency Indicators

Improving the capacity of renewable energy consumption is conducive to reducing environmental pollution and reducing resource consumption. The formula for calculating this indicator is:

$$W = E(Q) \times H \tag{6}$$

In the formula, W indicates the renewable energy benefit, $E(Q)$ indicates the extra electricity generated from renewable energy, and H indicates the environmental benefit per unit of renewable energy electricity.

2.3 Market Safety Value Category Indicators

Real-time balancing of power supply and load of the power system is a prerequisite for ensuring the security and stability of the grid. Therefore, it is important to evaluate whether the current market mechanism design is conducive to the recovery of security value in terms of both capacity value and regulation value. The construction of new power grid with new energy as the core must not be at the cost of ensuring energy security.

2.3.1 Capacity Market

(1) Maximum emergency backup power

Find the sum of the contingency reserve capacity (or contingency reserve capacity set aside for units) in the entire market to find the maximum value of contingency reserves in that market.

(2) Forced out-of-service rate

The forced outage rate is an important indicator of the efficiency of the electricity market operation. Under extreme conditions, the lower the forced outage rate, the lower the price of electricity.

2.3.2 Ancillary Services Market

(1) Active regulation of service costs

The active up or down service cost for the electricity market is the total cost of spinning reserve for the entire market, which includes the operating costs of all spinning reserve units in this area and the opportunity costs borne by units that retain some spinning reserve capacity.

(2) Cost of reactive regulation services

In the electricity market, the cost of reactive services is mainly composed of reactive energy supply and reactive accidental backup.

(3) Up or down service price and FM mileage

Using the U.S. PJM market as a benchmark, the maximum, average and minimum values of daily (monthly) up and down prices and FM miles were selected as indicators for analysis.

3. Comprehensive Electricity Market Evaluation Methodology

Power market evaluation has the characteristic of fuzzy, based on this characteristic, this paper adopts the fuzzy comprehensive evaluation method as the method of power market operation evaluation.

3.1 Overview of fuzzy integrated evaluation method

Fuzzy comprehensive evaluation is a combination of fuzzy mathematics and fuzzy statistics, taking into account various influencing factors, so as to make scientific judgments.

The basic idea of fuzzy comprehensive evaluation is to incorporate various influencing factors into the assessment of the assessment object based on the principle of maximum subordination in fuzzy mathematics. The method combines qualitative and quantitative aspects, and provides objective qualitative analysis of fuzzy attributes that are difficult to analyze quantitatively, thus closely combining qualitative description with quantitative analysis. Thus, it is a more appropriate method for comprehensive evaluation of the electricity market[7].

3.2 Mathematical model of fuzzy comprehensive evaluation method

(1) Determine the set of indicators and evaluation set

First, determine the set of evaluation indicators, that is, which indicators are selected for evaluation. If there are m indicators selected for evaluation, then these m evaluation indicators constitute a finite set of evaluation indicators X:

$$X = [x_1, x_2, \dots, x_m] \tag{7}$$

Then finally, the set of assessments for the goal is determined, that is, the various possible assessments for the goal are assessed. If the scoring criteria are divided into n levels according to the actual needs, it represents a finite set of scoring criteria Y:

$$Y = [y_1, y_2, \dots, y_n] \tag{8}$$

(2) Determine the fuzzy matrix R

Determine the relational affiliation r_{ij} of each ordered pair $(x_i, y_j) \in X \times Y$.

r_{ij} is the affiliation degree of element x_i in X for rank y_j in Y (i=1, 2, ..., m; j=1, 2, ..., n), from which the fuzzy relation matrix $R = [r_{ij}]$ is obtained.

(3) Determine the weight of each indicator

The importance of each indicator x_i in the evaluation index set $X = [x_1, x_2, \dots, x_m]$ to the evaluation objective varies, and each indicator can be assigned a weighting coefficient $a_i(i = 1, 2, \dots, m)$ and satisfy $0 \le a_i \le 1$, $\sum_{i=1}^{m} a_i = 1$.

Evaluation index weights:

$$A = [a_1, a_2, \dots, a_m] \quad (9)$$

In fuzzy comprehensive evaluation, establishing the fuzzy relationship matrix of each factor and determining the weights of each indicator are two important tasks, which can usually be determined by expert evaluation and statistical analysis methods.

(4) Determine the fuzzy integrated evaluation vector B

The fuzzy comprehensive evaluation vector B is based on the weights of the evaluation indexes, and the fuzzy relationship matrix R is synthesized to obtain the comprehensive affiliation degree of each evaluation level.

The fuzzy relationship matrix R is synthesized and calculated on the basis of the evaluation indexes to obtain the comprehensive affiliation degree of the evaluation object on each evaluation level.

$$B = A \cdot R = [a_1, a_2, \dots, a_m] \cdot \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} = [b_1, b, \dots, b_n] \quad (10)$$

(5) Determine the final comprehensive evaluation grade of the evaluation object

In the comprehensive evaluation vector B, the level of the assessment target can be determined based on the principle of maximum affiliation. And to finalize the level of the assessment target, it is necessary to quantify the individual rubrics in $Y = [y_1, y_2, \dots, y_n]$.

4. Conclusion

With the implementation of the new round of electricity reform, the speed of market-oriented reform of China's power grid has also been accelerated. Electricity is an important part of the national economy, and the reform of the power market inevitably requires safe, stable and reliable operation of the power system, thus improving the operational efficiency of each link of power generation, transmission and sale. Therefore, it is particularly necessary to construct a complete evaluation system for the electric power market. Based on the research on the evaluation methods of electric power market, this paper constructs the evaluation indexes of electric power market from three aspects: economic value, green value and safety value. On this basis, an evaluation method based on fuzzy comprehensive evaluation is proposed to reflect the overall situation of the electric power market. The market evaluation based on the index system and evaluation method in this paper can effectively judge whether the operation of the current electricity market is economically beneficial to maximize, environmentally sustainable, and safe, and provide a judgment basis for the healthy development of the electricity market. It provides new ideas for the future exploration of electric power market mechanism in each province of China, and also lays a solid foundation for the future construction and development of electric power market.

References

1. Z. C. Taysi, G. Biricik. Evaluation of Price forecast systems for Turkish Electric Market [C].2015.
2. Chen, F., Liu, J., Zhang,Y. (2017) Objectives 、 constraints and evaluation criteria of power market construction.J.Price Theory and Practice.,12:38-43.
3. Li, T.,Wang, S. (2018) Research on the evaluation system of China's power market transactions based on gray correlation degree and fuzzy comprehensive evaluation method.J.Industrial Technology and Economics.,09:130-137.
4. Shi, S.,Wang, L.,Zhang, Q.,Liu, D.,Yang, T.,Liu,Z. (2018) A Comprehensive Assessment of Electricity Direct Trading Market Efficiency - An Analysis Based on Topo Cloud Theory.J.Price Theory and Practice.,06:146-150.
5. Wang, B.,Zhang, M.,Xu, J.,Xu, Y.,Ying, L.,Cui, X.,Huang, S. (2019) Research on comprehensive evaluation model of electricity market trading mechanism.J.Yunnan Power Technology.,01:80-88.
6. Hu, Z. (2020) Research on Electricity Market Operation Evaluation Indexes and Evaluation Methods under the New Electricity Reform.D.North China Electric Power University (Beijing).
7. P.Kumar,S.K.Singh. A comprehensive evaluation of aspect-oriented software quality (AOSQ) model using analytic hierarchy process (AHP) technique[C]. 2016