Comprehensive Evaluation of Electricity Market Based on Analytic Hierarchy Process and Evidential Reasoning Methods

Z X Jing¹, J H Shi¹-², Z Y Luo¹, D P Chen¹ and Z Y Chen¹

¹School of Electric Power Engineering, South China University of Technology, Guangzhou 510640, Guangdong Province, China

E-mail: 18979792721@163.com

Abstract. Based on the analysis of the current domestic and international methods of power market evaluation, this paper combines the actual situation of Guangdong power market to construct an evaluation index system suitable for Guangdong power market, and proposes a comprehensive evaluation method model of electricity market based on analytic hierarchy process and evidence reasoning method. The model uses the fuzzy method to evaluate the confidence of each index, the analytic hierarchy process to determine the weight of each index, and the evidence reasoning method to integrate the indexes to obtain the comprehensive evaluation results. The example analysis uses this method to evaluate the fairness of the monthly competitive market in Guangdong in the second half of 2018, and verifies the applicability of the evaluation method model.

1. Introduction

Evaluation work is an important part of scientific management, and evaluation results are the main basis for scientific decision-making. From the aspects of operational efficiency, welfare fairness, user choice freedom and environmental protection, the analysis and comprehensive evaluation of the electricity market can predict the market development trend and judge the market power, thus guiding market participants and operational regulators to make market decisions. The optimization of rules will ultimately help improve the performance of the electricity market and promote the construction of the electricity market.

Comprehensive evaluation evaluates different aspects of the object through the establishment of a comprehensive evaluation of a number of indexes. According to the determination of the evaluation indexes, the comprehensive evaluation methods can be divided into two categories: one for deterministic indexes, such as Conventional Comprehensive Evaluation, Principal Component Analysis and Factor Analysis, Cluster Analysis and Discriminant Analysis, and Distance Comprehensive Evaluation, Grey Relational Analysis, Data Envelopment Analysis, etc.; another type for non-deterministic indexes, such as Fuzzy Evaluation, Multidimensional Scaling, BP Neural Network Analysis, etc. [1].

The power market evaluation has the following characteristics: 1) There are ambiguities and uncertainties in the evaluation indexes themselves, and there is a correlation between the indexes; 2) Due to the limitations of the evaluators' understanding of the evaluation indexes, the fuzzy language may be used in the evaluation, leading to subjective judgment uncertainty, and evaluation information often is incomplete; 3) for a same specific index, due to the different interests or cognitive, different
evaluators' evaluation result may be conflict; 4) different indexes may also be conflict, such as market efficiency and market risk. Therefore, the power market evaluation should adopt a comprehensive evaluation method for non-deterministic indexes. At the same time, the overall process of fuzzy judgment and valuation of uncertainty of Indexes, is a typical uncertain Multiple Attribute Decision Making (MADM) problem.

The application background of Uncertain MADM is very extensive, and it is an important direction in the research of decision theory in recent years. The research focus is concentrated on the Analytic Hierarchy Process [2-4], Fuzzy Evaluation [5-9], and Evidence Reasoning [10-22] and other methods. Reference [23] introduced almost all of the uncertainty types and the relevant approaches used in the field of MADM, then presented a novel Interval-based Uncertain MADM approach and examined it in Supplier Selection problem at last.

In the current large number of studies on power market evaluation, the methods of Analytic Hierarchy Process and Fuzzy Evaluation are mainly used to deal with uncertainty. Reference [24] uses the fuzzy comprehensive evaluation model to conduct risk assessment for a power generation enterprise from three processes: planning, construction and operation. Reference [25-28] using the method and hierarchical fuzzy evaluation analysis, market research and evaluation of the overall performance of the power and incentive effects or specifications, reliability of the electricity market electricity market rules attainment of electricity market performance. Reference [29] used fuzzy evaluation and grey correlation degree method to evaluate the efficiency of power market operation and compare the results. Reference [30] Comprehensive Application of time series analysis, DEA and fuzzy evaluation method, the effectiveness of the electricity market for a simple evaluation. Reference [31] combines the analytic hierarchy process and the entropy weight method to calculate the comprehensive weight of the index, and then uses the approximation ideal point method to comprehensively evaluate the power balance scheme. Reference [32-35] uses the theory of self-organization synergy to make the electricity market a large and complex system. By identifying the key factors affecting the state of the system, the author uses the idea of system evolution to conduct an in-depth study on the performance of the electricity market.

The common method combination above provides a way to solve the problem of handling uncertainty MADA in the evaluation of the power market, but throughout the current evaluation research of power market, evidential reasoning method is rarely used. Evidence reasoning, as an effective method to solve the problem of Uncertain MADM [18], can deal with the uncertainty in quantitative and qualitative attributes well. So, this paper attempts to comprehensively evaluate the electricity market by combining AHP and evidence reasoning.

2. Establish a power market evaluation index system

2.1. The process of constructing the electricity market evaluation index system

As an evaluation question, electricity market evaluation must involve some basic elements such as evaluator, evaluation object, evaluation index and evaluation method model. A complete evaluation system is composed of the above basic elements. As an index of the evaluation system, the evaluation index system is the basis for conducting evaluation work. In order to evaluate the market in a multi-dimensional and hierarchical way, indexes should not only be done but also try to refine a comprehensive independent of each other. Meanwhile, indexes should distinguish different markets, different times. Therefore, the establishment of the electricity market evaluation index system is a dynamic development of system engineering. The development process is shown in figure 1.

The first is the establishment of the evaluation platform: relying on the internal supervision departments of the market operation agencies or external regulatory agencies, joint research institutions or expert groups to conduct extensive market research and system analysis, establish an evaluation index system, determine qualitative or quantitative evaluation criteria, and develop comprehensive evaluation methods and technical support system. The second is the development of the evaluation work: monitoring, investigation and comprehensive evaluation of the electricity market.
by means of the coordination of the regulatory agencies or departments, the analysis of the specific organization of the analysts, and the participation of market participants, especially power users. The third is the feedback of the evaluation results: the main purpose of the evaluation work is to find problems and improve them in time, analyze the evaluation results, and disclose the analysis results and other information to the market, guide the market participants to make response decisions, through this feedback mechanism, gradually improve and form an applicable evaluation system.

---

**Figure 1.** Schematic diagram of the dynamic development of the evaluation index system

### 2.2. The basic principle of constructing the evaluation index system of electricity market

The composition of the evaluation index system must be closely related to the evaluation object, depending on the specific evaluation object. It should follow the following principles: (1) Representativeness. The index should be determined by its importance in the evaluation process, each index can reflect the characteristics of a particular area to be evaluated; (2) Independence. Indices should not cross with each other. Index system should be structured, concise; (3) Feasibility. There is a stable source of data and be easy to operate. Evaluation meaning must be clear, the data must be standardized; (4) Comparability. The formulation of evaluation indexes and evaluation criteria should be objective and practical for comparison.

### 2.3. Constructing electricity market evaluation index system

In the process of constructing the evaluation index system, the key issues are to establish evaluation indexes, determine evaluation criteria, and select evaluation methods. In the following, based on the basic principles of index selection, take the Guangdong power market as an example, this paper attempts to establish an evaluation index system suitable for the Guangdong power market from the aspects of establishing evaluation indexes and selecting evaluation methods.

According to the construction market electricity target [36] and the Guangdong power market [37] characteristics, the evaluation system will be divided into equity, benefits and risks of the three major categories, each category are provided a number of secondary indexes, shown in figure 2.

In the market fairness category, including market structure and market behavior. Market supply-demand ratio, power generation/consumption side HHI and residual supply rate(RSI) are market structure (market power) indexes, and Lerner index is market behavior (exercising market power) indexes. In the 2017 market rules of Guangdong [37], the degree of bilateral competition was adjusted by the supply-demand ratio. Therefore, the market supply-demand ratio was added as an important index. The Lerner Index indicates the proportion of profit in electricity prices, which can well reflect the extent to which market players exercise market power. Therefore, the market fairness index reflects whether the market entity has potential market power and whether it has exercised market power.

In the market efficiency category, in addition to the usual indexes such as volume, price, energy conservation, transmission capacity utilization and satisfaction of participants, increase the purchased
power accounting. As an important consumptive province of clean energy from southwest, Guangdong need to rely on expanding inter-provincial trade. Outsourcing power share may reflect the level of inter-provincial trade.

Figure 2. Hierarchy structure of Guangdong Electric Power Market Evaluation Index System

The index system above has the following characteristics: (1) There are correlations between some indexes, need correlation test and weight adjustment. Causal relationship in theory exists in HHI, RSI and Lerner index, but in practice, due to the restrictions of market participants market rules, regulatory measures or other factors, the causal link between having market power and exercising market power may not be very obvious. The market supply-demand ratio is negatively correlated with the market electricity price. The lower the market supply-demand ratio is, the higher the market uniform clearing spread is, resulting in the higher final settlement price. Energy conservation indicates the decline of power generation cost to a certain extent, and there is a certain positive correlation with market electricity price. The increase of market electricity price volatility will lead to the rise of market credit risk. There is also a positive correlation between the two. (2) Qualitative indexes and quantitative indexes exist at the same time. After obtaining the evaluation value of individual indexes, they need to be unified in order to facilitate the comprehensive evaluation of the next step. (3) Qualitative indexes are ambiguous and can only be qualitatively described.

According to the above analysis, this paper uses the analytic hierarchy process and the evidence reasoning method to establish a power market evaluation model to evaluate the Guangdong power market.

3. Overview of Analytic Hierarchy Process and Evidence Reasoning

3.1. Analytic Hierarchy Process (AHP)

AHP is a simple and practical method for decision-making multi-target program, proposed by the University of Pittsburgh Professor Saaty in the early 1970s [38]. The method comprehensively considers qualitative and quantitative factors, is flexible and convenient to use, and is rapidly and widely applied in various fields such as system analysis, economic management, traffic planning, and
scientific research evaluation. The key step of AHP is to compare the importance of each index in the index layer and construct a judgment matrix. By judging the matrix, the index weights can be easily calculated. However, because of the two-two comparison method to establish the judgment matrix, AHP has its inherent shortcomings. When the indexes are compared, the subjectivity is strong, leading to the uncertainty of the judgment results and consistency issues of the judgment matrix. Moreover, the actual problem generally has its own ambiguity or the ambiguity caused by the limitation of understanding, which leads to the fuzzy language of the evaluation result, and has incompleteness. AHP is not suitable to solve this case and needs to be used together with other methods.

3.2. Evidence Reasoning Approach (ERA)
ERA is an uncertainty evaluation method, proposed by the University of Manchester Yang Jianbo et al. in the 1990s [39-47]. The method combines fuzzy mathematics, DS evidence theory, information fusion, utility theory and other advanced evaluation decision-making theories [48], which can effectively solve the evaluation of quantitative and qualitative indexes under the premise of uncertain factors. The key step of ERA is: fuzzy evaluate all underlying indexes, then use evidential reasoning to integrate evaluation results. In the evaluation process, both qualitative and quantitative indexes with uncertainty are involved, which need to be treated as a vague form that can participate in the fusion of evidence. The ERA provides a good integration of all the indexes evaluation information without losing all the premise of fuzzy information. However, the weight of the indexes used in the integration process needs to be determined by means of AHP.

4. Empirical Analysis of Guangdong Market
The basic data are mainly for the operating environment of Guangdong Power Market and related data for long-term transactions, from the periodic statistical report of the National Bureau of Statistics, the National Energy Bureau, China Electricity Council, the Guangdong Information Network statistics, Guangdong Power Grid Corporation and Guangdong Electric Power Trading Center etc. [49-50]. According to the index system and evaluation methods established, we analyze the fairness indexes of Guangdong electric power monthly centralized trading market based on the analysis of Guangdong power market trading data.

4.1. Guangdong power market monthly concentrated trading results
The monthly trading in the Guangdong market is uniformly cleared, and the average value of the bid spreads between the buyers and sellers of the last transaction is taken as the clear spread. According to the integrity and timeliness of the available data collected currently, this paper chooses data from July to December 2018 for the monthly centralized trading analysis.

| Table 1. Guangdong Electric Power Market monthly trading results (2018.07-2018.12) |
|-----------------|-----|-----|-----|-----|-----|-----|
| Transaction volume | GWh | 4250.3 | 4322.9 | 4418.9 | 4117.9 | 4154.3 | 3696.1 |
| Average spread | ¥ /MWh | -67.01 | -66.14 | -66.03 | -64.92 | -63.83 | -64.96 |
| Transaction spread | ¥ /MWh | -43.35 | -41.05 | -42.00 | -37.00 | -34.75 | -34.50 |
| Demand side | | | | | | |
| Total tendered volume | GWh | 4252.8 | 4322.9 | 4418.9 | 4117.9 | 4154.3 | 3697.5 |
| Number of participants | / | 138 | 144 | 143 | 144 | 140 | 140 |
| Number of transactions | / | 137 | 144 | 143 | 144 | 140 | 139 |
| Maximum tendered spread | ¥ /MWh | 0 | 0 | 0 | 0 | 0 | 0 |
| Minimum tendered spread | ¥ /MWh | -39.8 | -38.0 | -39.0 | -35.0 | -32.0 | -34.0 |
Average tendered spread  ¥/MWh  -0.8065  -0.522  -0.8999  -0.5685  -0.5844  -0.7679

Supply side
Total tendered volume  GWh  4586.5  4454.8  4605.0  4257.2  4508.7  4022.1
Number of participants  /  63  65  62  54  57  56
Number of transactions  /  61  64  61  52  55  55
Maximum tendered spread  ¥/MWh  -46.9  -44.1  -45.0  -39.0  -37.5  -35.0
Minimum tendered spread  ¥/MWh  -450  -450  -450  -450  -450  -450
Average tendered spread  ¥/MWh  -248.5736  -226.8552  -223.3394  -201.3738  -219.2993  -222.6545

Convert the transaction results in table 1 into a chart form to get figure 3. It can be seen from the figure that in addition to certain fluctuations in the volume of electricity sold, the changes of tendered spreads are not obvious. Wherein the supply side presents a large range spread, while the demand side presents a small range spread, which tend to spread 0, so the demand elasticity is much larger than the supply elasticity, means that the market supply-demand ratio is small. The supply side can always maximize the turnover of volume and price to maximize profit by market analysis and game.

4.2. Estimation of fairness index of monthly centralized trading in Guangdong power market
In the market fairness index, the actual supply-demand ratio can be calculated by using the total tendered volume of the supplier and the demander, and the HHI data of the power generation/consumption side can be obtained by querying the market public information.

Since the collected data does not include the tendered spread curve, the RSI index can’t be obtained by calculating the market share.

In the Lerner index calculation, it is necessary to know the final transaction price and the marginal cost of power generation companies. As the Guangdong market uses spread mode currently, so the final transaction price equal to the transaction spread plus the benchmark price. Guangdong thermal
power generation benchmark price is 450.5 ¥/MWh. Actual marginal costs is difficult to obtain. It can be assumed that in six months, the marginal cost of electricity generation remained unchanged to simplify the analysis. Here takes 400 ¥/MWh. Therefore, the Lerner index is calculated as follows:

\[
LI = \frac{P - M}{P} = 1 - \frac{400}{450.5 + P_c}
\]

Where \( P \) represents the transaction price, \( M \) represents the marginal cost of power generation, and \( P_c \) represents the clear spread.

According to the above analysis, the calculation results of relevant indexes are shown in table 2.

| Table 2. Transaction-related metrics measure |
|-------------------------------------------|
| Jul | Aug | Sep | Oct | Nov | Dec |
|-------------------------------------------|
| Market supply-demand ratio | 1.08 | 1.03 | 1.04 | 1.03 | 1.08 | 1.08 |
| Power generation side HHI | 1277 | 1533 | 1647 | 1172 | 1284 | 1447 |
| Power consumption side HHI | 469 | 453 | 445 | 432 | 438 | 449 |
| Lerner Index | 0.0176 | 0.0231 | 0.0208 | 0.0326 | 0.0385 | 0.0385 |

4.3. Analysis of the results of the evaluation indexes

The indexes analysis and integration steps using comprehensive evaluation model based on AHP and ERA are as follows: (1) Convert the results of all months in each index in table 2 to a confidence evaluation vector; (2) Fuse confidence vectors of monthly market supply-demand ratio, power generation/consumption side HHI and Lerner index; (3) Fuse confidence vectors of different months to a final single fairness confidence vector, then perform utility analysis.

4.3.1. Convert quantitative indexes into confidence evaluation vectors. Assume that the evaluation level \( N \) equals 5 and the level set is \{very poor, poor, general, good, excellent\}. The following is an example of the calculation of the confidence evaluation vector of the market supply-demand ratio, HHI and Lerner index.

The market supply-demand ratio is a the-closer-to-the-middle-the-better index, if which is too small, the supply side may exercise market power, or too large may cause the transaction price not cover the variable cost of power generation, resulting in irrational tender. Assuming ideal supply-demand ratio is 1.25, then the value range is \([0, 2.5]\). If the supply-demand ratio is 1.08, the center level is 5, which is excellent. The confidence vector is \([0, 0, 1/11, 4/11, 6/11]\).

HHI belongs to the-smaller-the-better type, and its value range is \([0, 10000]\). If the HHI on the power generation side is 1277, the enter level is 5, which is excellent. The confidence vector is \([0, 0, 1/11, 4/11, 6/11]\).

The Lerner index belongs to the-smaller-the-better type, which has a value range of \([0, 1]\). If the index value is 0.0176, the center level is 5, which is excellent. The confidence vector is \([0, 0, 1/11, 4/11, 6/11]\).

4.3.2. Fusion of each index confidence vector. Suppose the weight calculation of the market supply-demand ratio, generation side HHI, consumption side HHI and Lerner is \([1/3, 2/9, 1/9, 1/3]\). Then for each month, the results of the integration of the four indexes are shown as table 3:
### Table 3. Using evidence reasoning to fuse confidence vector of each index

|          | Jul | Aug | Sep | Oct | Nov | Dec |
|----------|-----|-----|-----|-----|-----|-----|
| very poor| 0   | 0   | 0   | 0   | 0   | 0   |
| poor     | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 |
| general  | 0.3520 | 0.3520 | 0.3520 | 0.3520 | 0.3520 | 0.3520 |
| good     | 0.5696 | 0.5696 | 0.5696 | 0.5696 | 0.5696 | 0.5696 |

#### 4.3.3. Fusion of each month’s confidence vector.
Assuming that the weight of each month is allocated according to its transaction volume of electricity, then the result is [0.170, 0.173, 0.177, 0.165, 0.166, 0.149]. Then the result of the fusion of the six-month confidence vector is [0, 0.0669, 0.3364, 0.5967].

Levels in set {very poor, poor, general, good, excellent} respectively assigned to each of the utility values {0, 0.25, 0.5, 0.75, 1}.

The final utility is 0.8825, between 0.75 and 1, so the evaluation result is excellent, indicating market fairness can be well guaranteed.

### 5. Reliability Testing of Model

In order to consider the impact of index changes on the comprehensive evaluation results, the reliability tests of AHP and ERA algorithms involved in the model were carried out. This paper mainly tests the impact on the final evaluation results when the weight calculated by AHP changes.

Now, suppose the weight calculation of the market supply-demand ratio, generation side HHI, consumption side HHI and Lerner changes to [1/4, 1/4, 1/4, 1/4]. Then for each month, the results of the integration of the four indexes are shown as table 4:

### Table 4. Using evidence reasoning to fuse confidence vector of each index

|          | Jul | Aug | Sep | Oct | Nov | Dec |
|----------|-----|-----|-----|-----|-----|-----|
| very poor| 0   | 0   | 0   | 0   | 0   | 0   |
| poor     | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 |
| general  | 0.3521 | 0.3521 | 0.3521 | 0.3521 | 0.3521 | 0.3521 |
| good     | 0.5692 | 0.5692 | 0.5692 | 0.5692 | 0.5692 | 0.5692 |

The weight of each month is still allocated according to the transaction volume of electricity, that is [0.170, 0.173, 0.177, 0.165, 0.166, 0.149]. Then the result of the fusion of the six-month confidence vector is [0, 0.0671, 0.3366, 0.5963].

Comparing with the previous value [0, 0, 0.0669, 0.3364, 0.5967], we find that there was no significant difference between the two results. The fundamental reason is that the calculation method is not precise enough in the process of converting index values into confidence vectors, where binomial distribution is used.

### 6. Conclusions

This paper attempts to analyze and construct an evaluation system suitable for the Guangdong power market, and to propose a comprehensive evaluation model based on AHP and electricity markets evidential reasoning method, finally, in conjunction with the second half of the year 2018’s actual data.
of the Guangdong monthly market, case study of fairness index is carried out. The results show that
the evaluation methods have good applicability in dealing with the uncertainty of data.

Of course, during the progress of obtaining the confidence index in each evaluation level by a
binomial distribution, the distinction is not enough. In the case where the original evaluation index
values differ greatly, the obtained confidence vectors are identical. Therefore, the model need to be
further improved.

In addition, the current Guangdong spot market has already started trial settlement. We can explore
to use the evaluation method in this paper to carry out comparative analysis of the market operation
results between the monthly transaction opened in 2017 and the spot transaction currently starting trial
operation, to further verify and improve the evaluation method model proposed in this paper.

References
[1] Hu Y H, He S H 2000 Comprehensive Evaluation Method (Beijing, China: Science Press) 2-90
[2] Fan L, Zuo F 2008 Research on Multi-Attribute Decision-Making Method Based on AHP and
Outranking Relation Workshop on Power Electronics & Intelligent Transportation System.
IEEE Washington, DC, USA
[3] DagDeviren M 2008 Decision making in equipment selection: an integrated approach with AHP
and PROMETHEE J. Intelligent Manufacturing 19 397-406
[4] Fallahpour A, Olugu E U, Musa S N 2017 A hybrid model for supplier selection: integration of
AHP and multi expression programming (MEP) Neural Computing and Applications 28 499-504
[5] Kulak O, Kahraman C 2005 Fuzzy multi-attribute selection among transportation companies
using axiomatic design and analytic hierarchy process Information Sciences 170 191-210
[6] Kulak O 2005 A decision support system for fuzzy multi-attribute selection of material handling
equipments Expert Systems with Applications 29 310-9
[7] Gu X, Zhu Q 2006 Fuzzy multi-attribute decision-making method based on eigenvector of
fuzzy attribute evaluation space Decision Support Systems 41 400-10
[8] Lin J 2007 Fuzzy multi-attribute decision making based on the distance of Hausdauff J. Syst.
Engin. 22 367-72
[9] Kahraman C , Sel?uk ?eb? 2009 A new multi-attribute decision making method: Hierarchical
fuzzy axiomatic decision Expert Systems with Applications 36 4848-61
[10] Wang J Q, He B 2005 MCDM Method Based on Evidence Reasoning for Incomplete
Determination of Information System Engineering and Electronics 27 659-61
[11] Fu Y H, Tang J F, Zhang H G 2005 Evaluation and investment decision making evidence-based
reasoning Northeastern University (Natural Science) 26 840-3
[12] Liao X W, Li Y, Dong G M 2005 A kind of multi-attribute decision making under uncertainty
information (Xi'an, China: Xi'an Jiaotong University) 39
[13] He B, Ren M M, Wang J Q 2006 Evidence of an information reasoning with incomplete
multiple criteria decision making method Based on Mathematical Practice and Theory 36
58-62
[14] Wang J Q 2006 Multi-criteria ranking approach based on evidential reasoning with incomplete
certain information J. Syst. Engin. 21 419-23
[15] He J F, Xu J C, Wu W D 2006 ER method Uncertain Multiple Attribute Decision improvement
Control and Decision 21 385-90
[16] Gao B, Zhou L, Ni M F 2007 ER algorithm improvements in Uncertain Syst. Engin. 25 105-7
[17] Hua Z, Gong B, Xu X 2008 A DS-AHP approach for multi-attribute decision making problem
with incomplete information (Tarrytown, NY, USA: Pergamon Press, Inc.) 2221-7
[18] Guo K H, Li W L 2012 Evidential Reasoning-Based Approach for Multiple Attribute Decision
Making Problems under Uncertainty J. Manage. Engin. 26 94-100
[19] Zhang L, Liu Y W, Wang R C et al 2013 Trust evaluation model based on improved D-S
evidence theory Journal on Communications 7 167-73
[20] Jin L Q, Xu Y 2016 Method for uncertain multi-attribute decision making based on evidential reasoning and third-generation prospect theory Control and Decision 31 105-13
[21] Jin L Q 2016 Research on Uncertain Multi-attribute Decision Making Method Based on Confidence Evidence Reasoning (Sichuan, China: Southwest Jiaotong University)
[22] Xiong N X, Wang Y M 2018 Multi-attribute decision making method based on improved fuzzy entropy and evidence reasoning Computer Applications 38 55-60
[23] H^ eris, Golpira 2018 A novel Multiple Attribute Decision Making approach based on interval data using U2P-Miner algorithm Data & Knowledge Engineering 115 116-28
[24] Li H F 2008 Research on Performance Evaluation Index System and Evaluation Model of China's Power Market (Beijing, China: North China Electric Power University)
[25] Shi X 2009 Research on Evaluation Index System and Comprehensive Evaluation Method of Electricity Market Operation Rules (Beijing, China: North China Electric Power University)
[26] Dong J, Guo F Y, Tian K 2009 Research on Reliability Comprehensive Evaluation of Electricity Market Operation Rules Modern Electricity 26 79-83
[27] Wang Q, Wen F S, Liu M et al 2009 Combined Use of Fuzzy Set Theory and Analytic Hierarchy Process for Comprehensive Assessment of Electricity Markets Autom. Electr. Power Syst. 33 32-7
[28] Li X 2017 Research on Evaluation Indexes and Methods of Electricity Market in China (Beijing, China:North China Electric Power University)
[29] Cheng C 2011 Research on Indices System and Evaluating Method of Electricity Market Operational Efficiency (Beijing, China: North China Electric Power University)
[30] Cui H R, Yang L 2011 The Analysis of Power Market Efficiency andIts Evaluation Model in China Electr. Power Engin. 26 399-405
[31] Pu T J, Chen N S, Ge X J et al 2015 Research on Evaluation Index System and Synthetical Evaluation Method for Balance of Electric Power and Energy Power Syst. Technol. 39 250-6
[32] Zhang P Y, Li C J, Yang L 2010 Study on Operational Efficiency of Electricity Market Based on Synergetic Theory East China Electric Power 38 1659-62
[33] Sun J Q, Leng Y, Li C J 2012 Identification of Operational Status of ElectricityMarket Based on System Complexity Management Science 25 111-9
[34] Yan L 2012 The Self-Organization Phenomenon of the ElectricityMarket and the Operational Efficiency Evaluation (Beijing, China: North China Electric Power University)
[35] Sun J Q, Yan L, Li C J 2013 Dynamic Evaluation of Electricity Market Operational Efficiency Basedon Self-organizing Co-evolution East China Power 41 1305-10
[36] Central Committee of the Communist Party of China, State Council. Some Opinions on Further Deepening the Reform of Electric Power System http://news.ncepu.edu.cn/xxyd/lxzx/52826. htm.
[37] Southern Energy Regulatory Authority, Guangdong Economic and Information Commission, Guangdong Development and Reform Commission. Basic Rules of Transaction in Guangdong Electricity Market 2017.
[38] Saaty T L 1980 The Analytic Hierarchy Process (New York, NY, USA: McGraw-Hill Inc)
[39] Yang J B, Singh M G 1994. An evidential reasoning approach for multiple-attribute decision making with uncertainty IEEE T. Systems, Man and Cybernetics 24 1-18
[40] Yang J B, Sen P 1994 A general multi-level evaluation process for hybrid MADM with uncertainty IEEE T. Systems, Man and Cybernetics 24 1458-73
[41] Yang J B 2001 Rule and utility based evidential reasoning approach for multiattribute decision analysis under uncertainties European J. Operational Res. 131 31-61
[42] Yang J B, Xu D L 2002 On the evidential reasoning algorithm for multiple attribute decision analysis under uncertainty IEEE T. Syst. Man and Cybernetics - Part A Systems and Humans 32 289-304
[43] Wang Y M, Yang J B, Xu D L 2006 Environmental impact assessment using the evidential reasoning approach European J. Operational Research 174 1885-1913
[44] Yang J B, Liu J, Wang J et al 2006 Belief rule-base inference methodology using the evidential reasoning Approach-RIMER IEEE T. Syst. Man and Cybernetics - Part A Systems and Humans 36 266-85

[45] Yang J B, Wang Y M, Xu D L et al 2006 The evidential reasoning approach for MADA under both probabilistic and fuzzy uncertainties European J. Operational Res. 171 309-43

[46] Guo M, Yang J B, Chin K S et al 2009 The Evidential Reasoning Approach for Multi-attribute Decision Analysis under Both Fuzzy and Interval Uncertainty IEEE T. Fuzzy Syst. 17 683-97

[47] Yang J B, Xu D L 2013 Evidential reasoning rule for evidence combination Artificial Intelligence 205 1-29

[48] Huo W W 2012 Comparative Analysis of Analytic Hierarchy Process and Evidence Reasoning Economic Research Guide 8 10-11

[49] Guangdong Electric Power Trading Center. Guangdong Electricity Market Annual Report https://mp.weixin.qq.com/s/LzbRpC3umFdrPSygnVMFpA.

[50] Guangdong Electric Power Trading Center. Guangdong Electricity Market Annual Report https://mp.weixin.qq.com/s?__biz=MzI3NDY4NzE2Ng.