Research on the Mechanism and Forecast of Power Grid Regulation Policy under the Background of New Electricity Reform in China

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Abstract. This paper introduces the Network Analytic Hierarchy Process (ANP), constructs the internal relationship model of the policy, and determines the relationship between the indicators. On this basis, it quantifies the regulatory policies since the new power reform, and uses the weight of subjective and objective to determine the weight. The method determines the indicator weights of each indicator to determine the focus of the regulatory policy; then uses the Markov method to analyze the future trends of the policy, and establish a comprehensive scenario to simulate changes in the regulatory focus under the possible policy environment in the future. Look for the development strategy of power grid enterprises under this condition. The grid regulatory policy correlation model established in this paper effectively fits the complex relationship between the current policies. Based on the changes in the regulatory policies, a comprehensive scenario analysis model is constructed to comprehensively predict the regulatory policies in the next few years. It provides a useful reference for formulating policies and grid enterprise development strategies.

1. Introduction

Since the end of 2013, China's economic development has entered the "new normal" of medium and high-speed growth, and the power industry has begun to experience overcapacity. The government's "inappropriateness" for power grid regulation has become more apparent. In March 2015, the State Council issued the "Several Opinions on Further Deepening the Reform of the Power System" and launched a new round of power system reform. Among them, a series of policies on power grid regulation are the specificizations of new power reforms, and propose new directions and constraints for the development of power grids and power grid enterprises.

First, while emphasizing traditional security, it has increased the importance of renewable energy consumption. The pace of energy transformation characterized by “re-electrification” is accelerating, and the development of power grids should serve the construction of a clean, low-carbon, safe and efficient modern energy system. As the central link and fundamental way for the implementation of the energy revolution and power system reform, the power grid is becoming more and more important,
strengthening the grid infrastructure construction to meet the needs of economic development and environmental protection in the new era, and realizing the grid to a wider and higher level. Interoperability to meet the deep participation of users in the context of large markets

Second, the in-depth implementation of power system reform requires that the power grid first meet the needs of power market construction and development, and at the same time improve its operational efficiency. Based on the effective assets of the grid, the government verifies the transmission and distribution price of the grid, and at the same time speeds up the liberalization of the electricity distribution business and promotes the marketization of electricity in an orderly manner. The cost of power grid enterprises is subject to strict regulation and market competition is facing severe challenges.

In this process, it is important to correctly define the boundaries between the government and the market and accurately grasp the positioning of the government and enterprises. Among them, how to correctly understand the relationship between grid investment, planning, operation and government regulation is one of the necessary prerequisites to achieve "management of the middle and release of the two ends".

2. Literature review
The regulatory policies and government reforms of the power grid are closely related to the vitality of the power grid enterprises. All scholars in the field have conducted extensive and in-depth research on this, and the research direction can be divided into three parts.

Some scholars began to study the effectiveness of the "electrical reform" policy from the internal mechanism of policy. Ngan, H. W. reviewed the three main stages of China's power reform, and proposed a legal system and power regulation form to protect market competition and promote efficiency incentives [1]. Mah et al. used Japan as an example to discuss the key regulatory changes in the Japanese government. The limitations of regulatory policies have limited the deployment of smart grids from advancing to higher-order smart grids [2]. Shen et al. provide a comprehensive overview of US and other national policies and regulations, how electricity market reforms and technological advancements can play a role in demand response, become a viable demand side resource for addressing energy and environmental challenges, and capture potential for untapped demand. Specific recommendations were provided [3]. Cambini et al. focused on market and regulatory factors based on a review of European regulatory status and the use of data sets from 459 innovative SG projects [4].

Another part of the scholars began to provide decision support for grid regulation from policy simulation. Meeus and Saguan analyzed the grid companies' negative impact on innovation under the traditional regulatory framework and conducted empirical analysis from three successful cases of incentive grid innovation under the regulatory framework [5]. He, YX et al. studied the impact of transmission and distribution price policy on cash flow of power grid enterprises, and established a decision model of enterprise investment optimization using system dynamics theory to provide suggestions for power grid enterprise investment decision after China's power market reform [6].

Other scholars study the grid evaluation index system from the grid itself. LUO et al. established an evaluation index system for investment returns of power grid enterprises under the background of power system reform. According to the characteristics of power grid enterprises, a comprehensive evaluation method was formed and empirical research was carried out to verify the correctness of the model [7]. Liu, Guo et al. used the analytic hierarchy process to establish the evaluation index system of power grid economic benefits, and evaluated the economic benefits of the power grid during the “Twelfth Five-Year Plan” period in a certain province of China, and summarized the economic benefits of the power grid in 2013-2015. Operating conditions [8]. Han et al. established a comprehensive evaluation index system for the evaluation of grid development level, and used PCA to obtain comprehensive indicators to reduce the variable dimension and determine the development level by calculating the comprehensive score based on ANFIS [9].

3. Construction of network regulation policy relationship network
From the perspective of purchasing (benefit) electricity regulation, since the release of the two ends of the power sale is not complete at this stage, most of the areas are mainly sold by the power grid after
the unified procurement, and the retail is sold to the users. The main content of time government regulatory policy. According to the statistical results, the indicators under the regulation of purchasing (benefit) electricity are mostly based on traditional price regulation, safety regulation and market regulation; and with the change of government regulation policies, operation regulation, service regulation, sustainable development regulation, Institutional regulation and so on will also become the main aspects of government regulation.

From the point of view of transmission and distribution regulation, the regulation of power grid enterprises at this stage is mainly based on grasping the middle, that is, two dimensions of transmission and distribution. According to the statistical results, the indicators under the transmission regulation dimension are mostly based on safety regulation, price (benefit) regulation, operation regulation and service regulation; and sustainable development regulation, institutional regulation, provincial and regional regulation are also the main aspects of government regulation. The indicators under the power distribution regulation are mainly based on safety regulation, market regulation, operation regulation and service regulation; and price (benefit) regulation, sustainable development regulation, institutional regulation, provincial and regional regulation are also the main aspects of government regulation.

From the perspective of power sales regulation, the power sales regulation mainly faces the user side, mainly including large users and urban and rural residents. According to the statistical results, the indicators under the power sales regulation are mainly market regulation, service regulation, information regulation, and credit regulation; and price (benefit) regulation, sustainable development regulation, institutional regulation, provincial and regional regulation are also government regulation. The more important aspect.

4. Simulation of grid supervision policy based on improved ANP

4.1. Hierarchical construction of indicators
According to the above research on the policy indicator system, the indicators are hierarchically divided and determined, as shown in Table 1. At the same time, based on the results of policy statistics, the multi-expert group comprehensive evaluation method is used to determine the correlation of each indicator and construct the ANP network level relationship, as shown in Figure 1.

4.2. Improve the weight of evaluation index of ANP
Through the combing of the policy documents, it is found that the regulatory indicators are intricate and complex, and there is a high correlation. The indicators of the grid supervision index evaluation model constructed as the entry point must have vertical and horizontal relationships. Therefore, the network level analysis method is used to calculate the weight of evaluation indicators.

Compared with the traditional Delphi method to determine the weight, this paper improves the weight determination method. By referring to the specific frequency of relevant policy indicators and combining the Delphi method, the importance degree between each index is compared, and the nine-level gradient method is used. A judgment matrix is constructed by comparing the importance value of one index with another. Through calculation, the weights of each index of the grid supervision index evaluation system are obtained, and the final weights are shown in Table 1.
| Regulatory indicators                                      | indicator number | level | intra-group weight | objective weight |
|-----------------------------------------------------------|------------------|-------|--------------------|------------------|
| Purchase regulation                                       | C11              | 1     | 25.00%             | 2.20%            |
| Transmission regulation                                   | C12              | 1     | 25.00%             | 2.20%            |
| Distribution regulation                                   | C13              | 1     | 25.00%             | 2.20%            |
| Sales regulation                                           | C14              | 1     | 25.00%             | 2.20%            |
| Price (benefit) regulation                                 | C21              | 2     | 9.41%              | 2.42%            |
| Innovation regulation                                     | C22              | 2     | 6.22%              | 1.60%            |
| Sustainable development regulation                         | C23              | 2     | 9.31%              | 2.39%            |
| Safety regulation                                          | C24              | 2     | 31.74%             | 8.15%            |
| Market regulation                                          | C25              | 2     | 8.80%              | 2.26%            |
| Service regulation                                         | C26              | 2     | 9.23%              | 2.37%            |
| Institutional regulation                                   | C27              | 2     | 5.00%              | 1.29%            |
| Provincial and regional regulation                         | C28              | 2     | 6.48%              | 1.66%            |
| Operation regulation                                       | C29              | 2     | 13.81%             | 3.54%            |
| Other innovation indicator                                 | C31              | 3     | 1.73%              | 0.27%            |
| Power plant grid coordination                              | C32              | 3     | 4.86%              | 0.75%            |
| Value-added services                                      | C33              | 3     | 3.47%              | 0.53%            |
| Grid-connected services                                    | C34              | 3     | 7.30%              | 1.13%            |
| Electricity statistics                                     | C35              | 3     | 5.43%              | 0.84%            |
| Power grid construction safety                             | C36              | 3     | 28.36%             | 4.37%            |
| Grid construction safety                                   | C37              | 3     | 23.24%             | 3.59%            |
| Electric energy alternative to other energy sources        | C38              | 3     | 1.94%              | 0.30%            |
| Management innovation                                     | C39              | 3     | 4.24%              | 0.66%            |
| Energy efficiency                                          | C310             | 3     | 7.55%              | 1.16%            |
| Metering fee service                                      | C311             | 3     | 4.53%              | 0.70%            |
| Inter-provincial cross-regional power grid                 | C312             | 3     | 7.36%              | 1.14%            |
| Electric power emergency                                   | C41              | 4     | 10.00%             | 1.71%            |
| On-grid price                                              | C51              | 5     | 0.94%              | 0.32%            |
| Cross subsidy                                              | C52              | 5     | 0.48%              | 0.16%            |
| Power supply service                                       | C53              | 5     | 3.12%              | 1.05%            |
| Guaranteed power supply                                    | C54              | 5     | 0.99%              | 0.33%            |
| Information security                                       | C55              | 5     | 5.57%              | 1.88%            |
| Information regulation                                    | C56              | 5     | 14.87%             | 5.02%            |
| Credit regulation                                          | C57              | 5     | 2.49%              | 0.84%            |
| Renewable energy consumption                               | C58              | 5     | 4.99%              | 1.68%            |
| Renewable energy tariff subsidy                            | C59              | 5     | 0.31%              | 0.11%            |
| Basic electricity price                                    | C510             | 5     | 1.31%              | 0.45%            |
| Safe production                                            | C511             | 5     | 11.20%             | 3.78%            |
| Customer service                                           | C512             | 5     | 0.94%              | 0.32%            |
| Market price                                               | C513             | 5     | 1.42%              | 0.48%            |
| Market access                                              | C514             | 5     | 1.70%              | 0.57%            |
| Cost                                                       | C515             | 5     | 1.51%              | 0.51%            |
| Universal service                                          | C516             | 5     | 3.50%              | 1.18%            |
| Electricity trading                                        | C517             | 5     | 4.53%              | 1.53%            |
| Electric trading institution                                | C518             | 5     | 2.12%              | 0.71%            |
| Power dispatch                                             | C519             | 5     | 6.52%              | 2.20%            |
| Power dispatching institution                              | C520             | 5     | 3.73%              | 1.26%            |
| Power grid construction                                    | C521             | 5     | 3.87%              | 1.31%            |
| Grid access                                                | C522             | 5     | 0.98%              | 0.33%            |
| Power grid planning                                       | C523             | 5     | 1.64%              | 0.55%            |
| Grid operation safety                                      | C524             | 5     | 4.19%              | 1.42%            |
| Inter-provincial cross-regional power market trading       | C525             | 5     | 1.66%              | 0.56%            |
| Cross-provincial transmission and reception                | C526             | 5     | 1.95%              | 0.66%            |
| Transmission and distribution price                        | C527             | 5     | 5.27%              | 1.78%            |
| Transmission and distribution assets                       | C528             | 5     | 1.09%              | 0.37%            |
| Sales price                                               | C529             | 5     | 0.78%              | 0.27%            |
| Ladder price                                              | C530             | 5     | 1.24%              | 0.42%            |
| Risk management (risk warning)                             | C531             | 5     | 5.11%              | 1.72%            |
| Business training                                         | C61              | 6     | 7.12%              | 0.79%            |
| Safety training                                           | C62              | 6     | 38.67%             | 4.30%            |
| Market order                                               | C63              | 6     | 8.02%              | 0.89%            |
| Technology innovation                                     | C64              | 6     | 13.43%             | 1.49%            |
| Power demand side management                               | C65              | 6     | 8.75%              | 0.97%            |
| Provincial power grid comprehensive line loss rate         | C66              | 6     | 6.76%              | 0.76%            |
| Energy in situ consumption                                 | C67              | 6     | 17.24%             | 1.92%            |
4.3. Simulation results
Through calculation, the proportion of each level of grid regulation indicators is 33.15% for the fifth layer, 25.21% for the second layer, 15.13% for the third layer, 12.77% for the sixth layer, 8.66% for the first layer, and 5.08% for the fourth layer. The ratio between the levels can better reflect the difference in the number of indicators between the levels, and the proportion of the indicators with a large number of indicators is also large, indicating that the weight distribution has good objectivity and can reflect the pertinence of the policy.

According to the calculation results, the indicators of each level are sorted. The results show that the safety supervision, operation supervision, price supervision and sustainable development supervision are the main regulatory aspects at the current stage, which are also in line with the results of the previous policy statistics, indicating the improvement. The ANP method can effectively model the policy and get satisfactory results.

5. Policy scenario analysis model based on Markov

5.1. Markov model
The Markov process is a special kind of stochastic process with so-called Markov property, which is suitable for both time series and space sequences. The basic feature is that there is no aftereffect, that is, when the state of the system at a certain time \( t_i \) is known, the state of the system at time \( t \), \( t > t_i \) is only related to the state of the system at time \( t_i \), and the time of the system has nothing to do with the state before \( t_i \).

The Markov process is called the Markov chain. An \( n \)-th order Markov chain is determined by \( n \) state sets \( \{E_1, E_2, ..., E_n\} \) and a set of transition probabilities \( P_{ij} \) \( \{i, j=1, 2, ..., n\} \). The transition probability \( P_{ij} \) \( \{i, j=1, 2, ..., n\} \) reflects the degree of influence of various random factors.

In this paper, the policy scenario analysis model will be analyzed and modeled based on this model, and the policy will be combined with the operation of the grid enterprise to determine the development strategy of the grid enterprise under different policy scenarios.

5.2. Improvements in the construction of Markov models
(1) Because there are many regulatory factors affecting the strategy formulation of power grid enterprises, but not all factors are the key factors affecting the formulation of enterprise strategy. Therefore, based on the research of relevant planning policies, several key factors affecting the formulation of enterprise strategy are selected as Scenario hypothesis factor; at the same time, according to the research results of ANP, the construction of Markov state transition probability matrix factor is carried out.

(2) The corporate strategy is aimed at the future. Many regulatory factors are also uncertain factors. This requires assumptions about the state transition probability between indicators under each scenario hypothesis. According to the normal distribution, about 69.27% of the samples fall between \( (\mu-\sigma, \mu+\sigma) \), based on which the state transition probability \( P_{ij} \) is determined, and the probability of self-transition in a single context is 69.27%. The transition probability is 30.63%. At the same time, according to the frequency of policy statistics, the probability of transition between indicators in a single scenario is determined.

(3) According to the scenario hypothesis weight and adjustment weight, the specific formula is as follows:

The control level weight adjustment formula under the integrated scenario:

\[
W'_j = \begin{cases} 
  P_g \times W_g & , j \text{ is the integrated scenario} \\
  (1 - P_g) \times \sum_{j=1}^{n} mW_{gj} & , j \text{ is not the integrated scenario} \\
  \sum_{j=1}^{n} M_wW_{gj} &
\end{cases}
\]

(1)

The network level weight adjustment formula under the integrated scenario:
Among them, $W_{ij}$ is the intra-group weight of the $j$th indicator in the $i$-th layer of the ANP result, $P_{ij}$ is the weight of a scenario hypothesis to which the $j$th indicator in the $i$-th layer belongs, $w_j$ is the intra-group weight of the $j$th indicator in the $i$-th layer, $m$ is the total number of indicators under a certain scenario within the different indicators of the first layer, $M$ is the total number of indicators under a scenario assumed in the $i$th layer.

5.3. Case Analysis

According to the “13th Five-Year” power industry development plan issued by China, the pilot of spot trading will be launched before the end of 2018; the competition of the main players in the market for power-sales will be completed before the end of 2018, and the market-selling market participants with full competition will be basically formed; in 2020, the proportion of non-fossil energy consumption will reach about 15%; in 2020, the spot market will be fully launched to study the risk hedging mechanism; the non-regulated power generation plan other than the priority power generation will be basically eliminated by 2020; and the “West-to-East power transmission capacity” in 2020 will be It reached 270 million kilowatts.

5.4. Comprehensive policy scenario dynamic analysis model

Dynamic analysis of the first layer of indicators The first layer of regulatory elements is dynamically predicted as follows:

| YEAR | C11  | C12  | C13  | C14  |
|------|------|------|------|------|
| 2018 | 0.2320 | 0.2620 | 0.2715 | 0.2348 |
| 2019 | 0.2212 | 0.2695 | 0.2840 | 0.2258 |
| 2020 | 0.2148 | 0.2742 | 0.2912 | 0.2205 |

Dynamic analysis of other layer indicators Under the comprehensive regulatory scenario, the third-tier indicators for 2017-2020 are tracked and reordered. The three indicators involved (Energy efficiency, Electric energy alternative to other energy sources, and Inter-provincial cross-regional power grid) are sorted as follows:

| YEAR | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|
| Energy efficiency | 3 | 3 | 3 | 1 |
| Inter-provincial cross-regional power grid | 4 | 4 | 4 | 2 |
| Electric energy alternative to other energy sources | 11 | 5 | 5 | 3 |

(1) Under the comprehensive regulatory scenario, the fifth-tier indicators for 2017-2020 will be tracked and re-sorted, including fifteen indicators (On-grid price, Cross-subsidies, Renewable energy consumption, Renewable energy tariff subsidy, Basic electricity prices, Market price, Market access, Cost, Electricity trading, Inter-provincial cross-regional power market trading, Cross-provincial transmission and reception, Transmission and distribution price, Transmission and distribution assets, Sales electricity prices, Ladder electricity prices) are sorted as follows:
Table 4: The Fifth Layer of Regulatory Elements Dynamic Forecasting Rank

| YEAR | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|
| Transmission and distribution price | 5    | 3    | 3    | 2    |
| Renewable energy consumption       | 7    | 4    | 4    | 3    |
| Cross-provincial transmission and reception | 16   | 11   | 5    | 5    |
| Inter-provincial cross-regional power market trading | 18   | 13   | 7    | 6    |
| Cost                             | 20   | 15   | 8    | 7    |
| Basic electricity prices          | 22   | 16   | 10   | 8    |
| Ladder electricity prices         | 23   | 17   | 11   | 9    |
| Transmission and distribution assets | 24   | 19   | 12   | 10   |
| On-grid price                    | 27   | 20   | 13   | 11   |
| Sales electricity prices          | 29   | 21   | 15   | 12   |
| Cross-subsidies                  | 30   | 23   | 16   | 13   |
| Renewable energy tariff subsidy   | 31   | 25   | 18   | 14   |
| Electricity trading              | 8    | 7    | 9    | 15   |
| Market access                    | 17   | 24   | 23   | 19   |
| Market price                     | 21   | 27   | 25   | 20   |

(2) Under the comprehensive supervision scenario, the sixth-level indicators for 2017-2020 are tracked and re-sorted. The three indicators involved (Market order, Provincial-level grid comprehensive line loss rate, Energy in-situ consumption) are sorted as follows:

Table 5: The Sixth Layer of Regulatory Elements Dynamic Forecasting Rank

| YEAR | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|
| Energy in-situ consumption | 2    | 2    | 1    | 1    |
| Provincial-level grid comprehensive line loss rate | 9    | 3    | 3    | 2    |
| Market order | 6    | 5    | 4    | 4    |

6. Conclusion

After statistical analysis, it was found that:

1) Under the comprehensive supervision scenario, more attention has been paid to the regulation of transmission and distribution prices. After the “new electricity reform” proposed the reform of transmission and distribution price, the grid profit model will change from earning electricity price difference to “permitted cost + reasonable income”, effectively releasing electricity reform dividends. The separate verification of transmission and distribution prices, the expansion of the distribution side and the power-selling side have had a profound impact on the grid's profit margin. From the perspective of the composition of total income, the future grid companies should start from the reasonable regulation of the licensing costs and ensure the permitted revenue to increase the permitted income, thereby promoting the efficient development of its own power grid, while completing the "new electricity reform" requirements with high quality and high volume.

2) Under the comprehensive supervision scenario, the status of the market order in the future has been significantly improved, and its indicators have changed by more than one-third. The “new electricity reform” pointed out that doing a good job in market order supervision, regulating market behavior, and maintaining market order is the reform of power market. The inevitable requirement is the inevitable requirement of protecting the legitimate rights and interests of market entities, promoting coordinated and harmonious development of the industry, and promoting the power industry to better serve economic and social development. Therefore, this also promotes the power market reform of this "new power reform". The road is very long, and the supervision of the market order will also have a profound impact on the entire power industry along with the “new electricity reform”.  

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References
[1] H.W. Ngan, Electricity regulation and electricity market reforms in China, Energy Policy, Volume 38, Issue 5, 2010, Pages 2142-2148
[2] Daphne Ngar-yin Mah, Yun-Ying Wu, Jasper Chi-man Ip, Peter Ronald Hills, The role of the state in sustainable energy transitions: A case study of large smart grid demonstration projects in Japan, Energy Policy, Volume 63, 2013, Pages 726-737
[3] Bo Shen, Girish Ghatikar, Zeng Lei, Jinkai Li, Greg Wikler, Phil Martin, The role of regulatory reforms, market changes, and technology development to make demand response a viable resource in meeting energy challenges, Applied Energy, Volume 130, 2014, Pages 814-823
[4] Carlo Cambini, Alexis Meletiou, Ettore Bompad, Marcelo Masera, Market and regulatory factors influencing smart-grid investment in Europe: Evidence from pilot projects and implications for reform, Utilities Policy, Volume 40, 2016, Pages 36-47
[5] Leonardo Meeus, Marcelo Saguan, Innovating grid regulation to regulate grid innovation: From the Orkney Isles to Kriegers Flak via Italy, Renewable Energy, Volume 36, Issue 6, 2011, Pages 1761-1765
[6] Y.X. He, J. Jiao, R.J. Chen, H. Shu, The optimization of Chinese power grid investment based on transmission and distribution tariff policy: A system dynamics approach, Energy Policy, Volume 113, 2018, Pages 112-122
[7] W. Strunk Jr., E.B. White, The Elements of Style, third ed., Macmillan, New York, 1979.
[8] Luo Guoliang, Yuan Xiaohong, Zhang Xinying, Evaluating Power Grid Enterprise's Investment Returns, Energy Procedia, Volume 5, 2011, Pages 224-228
[9] Liu Daoxin, Guo Lijie, Wang Shengyi, Zhang Qili, Liang Fuxing, Research on Multi-level Comprehensive Evaluation Model of Power Grid Efficiency, Procedia Computer Science, Volume 107, 2017, Pages 325-331
[10] Han Wu, Dongxiao Niu, Weidong Liu, Ke Sun, Power Grid Development Level Evaluation Based on Adaptive Neural-fuzzy Inference System, Procedia Engineering, Volume 174, 2017, Pages 850-857