Research and practice on coordination assessment system of Yunnan transmission network and power supply construction

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Abstract. Power supply and power grid are both independent and closely related, and they are two parts of the power supply community. Power supply and power grid have their own characteristics and laws, and their interactions are different in different stages of development of power industry. Under the market environment of the new power system reform, some new changes have taken place in the relationship between the two. Firstly, this paper analyses the changes of the related factors of power construction after the reform of power system, and then constructs the coordination evaluation system of Yunnan power transmission network and power construction from the aspects of power development mode, energy policy and new energy access. Finally, taking Yunnan Province as an example, it evaluates the coordination of power transmission network and power construction in 2017, which proves the feasibility and science of the evaluation system.

1. Introduction
The transmission network is an important part of the power system and a key link to ensure the stable development of the power system. Under the new power system reform market environment, the influence factors of power supply construction have changed, and the original coordinated evaluation system of power transmission network and power supply construction is no longer applicable. Therefore, it is necessary to reconstruct the coordinated evaluation system of power transmission network and power supply construction in order to guide the actual power supply planning and construction.

2. Change of influencing factors of power supply construction after the reform of electric power system

2.1. Power development model in electricity market environment
Under the environment of electricity market, the development mode of power supply mainly goes through three stages: monopoly mode, generation competition mode and market competition mode. Among them, the economic efficiency of market competition mode formed after the reform of electric power system is higher than that of monopoly mode and generation competition mode, and resources can be used more effectively. Under the electricity market environment, the decision-making of power generation companies on the location selection of new power sources, the determination of installed capacity, construction cycle and operation time is mainly based on the change of supply and demand relationship, the future electricity price situation and the corresponding regulatory policies. The purpose of grid investment is to maximize the benefits of grid construction and operation. Therefore,
the difference of ultimate purpose between power supply and power grid brings more uncertainties to the coordinated operation and sustainable development of power grid.

2.2. Impact of energy policy
Nowadays, the main energy sources in the world are oil, coal and natural gas. With the increasing demand for energy, the reserves of fossil energy are increasingly exhausted, and these energy sources will produce serious pollution in the use process. It is an urgent need for the development of the world to find new energy sources that can replace limited fossil energy and are environmentally friendly. The power system reform marked by document No. 9 of 2015 and the strong support for clean energy consumption and distributed generation access are also based on this starting point. Therefore, the national energy policy plays a key role in guiding the development of the types of power supply and the proportion of different types of power supply.

2.3. Impact of new energy access
According to the stability of new energy generation in power grid, it can be divided into continuous generation and intermittent generation; according to access mode, it can be divided into centralized access and decentralized (or distributed) access. In the reform of electric power system, the priority is to ensure the reliable absorption of new energy generation, and the policy foothold is also to solve the problem of clean energy on the generation side of the grid. Therefore, the integration of large-scale distributed generation will inevitably make the power structure and planning more complex, and make the safe operation of power grid more difficult.

3. Coordination evaluation system of transmission network and power supply construction in electricity market environment

3.1. Evaluation index system

| Object of evaluation | Main Characteristic Indicators | Corresponding effect index |
|----------------------|-------------------------------|----------------------------|
|                      | First level index             | Second level index         |                          |
| Coordination between | Power supply scale            | Ratio of transformer       |                          |
| Transmission Network | Generation capacity margin    | capacity to installed      |                          |
| and Power Supply     | safety, reliability           | capacity                   |                          |
| Construction         | Ratio of transmission line    | length to power supply     |                          |
|                      | capacity                      | capacity                   |                          |
|                      | Peak shaving power supply     | energy saving, environmental|                          |
|                      | energy saving, environmental  | protection and strong      |                          |
|                      | proportion                    | Percentage of Clean Energy |                          |
|                      | Access Capacity               | adaptability               |                          |
|                      | Proportion of electricity     | discarded                  |                          |
|                      | discarded                     |                            |                          |
|                      | Supply-demand equilibrium     | advanced and efficient     |                          |
|                      | advanced and efficient        | index                      |                          |
|                      | Market Power Level on         | Generation Side            |                          |
|                      | Generation Side               |                            |                          |

In order to ensure the scientificity and rationality of the evaluation, and to fully and objectively reflect the coordination between transmission network and power supply, this paper constructs an evaluation
index system of coordination between transmission network and power supply construction from three aspects: power supply scale, power supply structure and power market construction, as shown in table 1.

3.2. Calculating method and range of indicators
The calculation method and range of each index are described as follows in table 2.

| Object of evaluation | First level index | Second level index | Calculation formula | Index type | Range Ideal range of values |
|----------------------|-------------------|--------------------|---------------------|------------|-----------------------------|
| Coordination between Transmission Network and Power Supply Construction | Power scale | Generation capacity margin | \( u = \frac{S_{\text{available capacity}} - \text{Load}_{\max}}{S_{\text{available capacity}}} \) | Interval index \([0, 1]\) | 16.67%~18.37%[1] |
| | Ratio of transformer capacity to installed capacity | \( r = \frac{\sum \text{Public Transformer Capacity}}{S_{\text{installed capacity}}} \) | Interval index \([0, 1]\) | 1.5~1.6[2] |
| | Ratio of transmission line length to power supply capacity | \( r = \frac{\sum \text{Length of transmission line}}{S_{\text{installed capacity}}} \) | Interval index \([0, 1]\) | 1.6~2 |
| | Peak shaving power supply proportion | \( r = \frac{S_{\text{peaking power}}}{S_{\text{installed capacity}}} \) | Interval index \([0, 1]\) | 1 |
| | Percentage of Clean Energy Access Capacity | \( r = \frac{S_{\text{clean energy}}}{S_{\text{installed capacity}}} \) | Maximum index | 0.1 |
| | Proportion of electricity discarded | \( r = \frac{Q_{\text{power abandoning}}}{Q_{\text{power generation}}} \) | Minimum index | 0 |
| Electricity Supply-demand equilibrium index | Power supply | \( \Gamma_i = \frac{G_i(1-\lambda_i)}{D_i} \) | Interval index >0 | 1 |
| | Market Efficiency Index | \( HHI = \sum_{i=1}^{N} \left( \frac{X_i}{X} \right)^2 = \sum_{i=1}^{N} S_i^2 \) | Interval index \((0, 1]\) | 1/500 |

3.3. Evaluation method and process
Analytic hierarchy process (AHP) and fuzzy comprehensive evaluation method are used to evaluate the coordination between transmission network and power supply. Firstly, the weights of indicators
are determined by analytic hierarchy process, and then the scoring criteria of indicators are determined by the method of fuzzy membership degree. Finally, combined with the analysis conclusion of the current value of indicators, the final evaluation results are substituted into the evaluation method. The specific process is shown in figure 1.

![Evaluation Index System](image)

**Figure 1.** Coordination evaluation process of transmission network and power supply construction.

According to the evaluation score of the coordination between transmission network and power supply, the final conclusion of the coordination between transmission network and power supply can be drawn according to the evaluation grade of the success degree in the table 3.

| Level            | Score  |
|------------------|--------|
| Complete success | 85-100 |
| Basic success    | 70-85  |
| Partial success  | 60-70  |
| Unsuccessful     | 40-60  |
| Fail             | 0-40   |

**Table 3.** Success level of evaluation objects.

4. **Evaluation practice of Yunnan transmission network and power supply construction**

4.1. *Current situation analysis of evaluation indicators*

In order to ensure the scientificity and rationality of the evaluation, and to fully and objectively reflect the coordination between transmission network and power supply, this paper constructs an evaluation index system of coordination between transmission network and power supply construction from three aspects: power supply scale, power supply structure and power market construction.
4.1.1. Power supply scale evaluation index

- Generation capacity margin
  In the traditional energy structure area, thermal power generation is not affected by seasonal climate. The available capacity of power supply in the power generation capacity margin can be expressed by installed capacity. However, for the energy structure area in Yunnan Province, which is dominated by hydropower, there are large hydropower generation in flood season and large thermal power generation in dry season. Therefore, the available capacity of power supply cannot be expressed directly by installed capacity. It is necessary to calculate the available capacity of power generation in high and low periods.

  By the end of 2017, Yunnan Province had a total installed capacity of 89.57 million KW, including 62.81 million kW of hydropower, 16.13 million kW of thermal power, 8.25 million kW of wind power and 2.38 million kW of solar energy. The capacity of the West-to-East power transmission channel is 28.65 million kW, and the maximum load of the whole society is about 25.63 million kW calculated according to the maximum load utilization hour of 6,000 hours. The installed capacity of the Xiangjiaba power plant on the right bank of the State Grid is 3.2 million kW.

  In flood season, Yunnan hydropower output is calculated by 90% of installed capacity, wind power and photovoltaic power generation by 40% of installed capacity, and thermal power output by 70% of installed capacity. After deducting the West-to-East power transmission and merging into the Xiangjiaba section, the available electricity generated by the local power balance is as follows:

  \[(62.81-28.65-3.20)\times90%+16.13\times70%+(8.25+2.38)\times40%=43.41\text{ Million kW}\]  

  That is to say, the capacity margin of Yunnan's power generation during the flood season is as follows:

  \[\frac{43.41-25.63}{43.41}\times100%=40.95\%\]  

  In dry season, Yunnan's hydropower output is calculated by 35% of installed capacity, wind power and photovoltaic power generation by 80% of installed capacity, and thermal power output by 95% of installed capacity. After deducting the West-to-East power transmission and merging into the Xiangjiaba section, the available generating capacity for local power balance is as follows:

  \[(62.81-28.65-3.20)\times35%+16.13\times95%+(8.25+2.38)\times80%=34.66\text{ Million kW}\]  

  The capacity margin of Yunnan in dry season is as follows:

  \[\frac{34.66-25.63}{34.66}\times100%=26.06\%\]  

  When the power generation capacity margin of Yunnan power grid is averaged in both high and low periods, the final value of the index is: \((40.95%+26.06%)/2=33.51\%\).

- Ratio of transformer capacity to installed capacity
  This index refers to the ratio of the capacity of a public step-down transformer of a certain voltage level to the installed capacity of the power supply in the current year or the planned target year. As of the end of 2017, there are 29 500 kV substations in Yunnan, with a capacity of 44.61 million kVA. The installed capacity for local load is 57.72 million kW. The index values are as follows:

  \[\frac{4461}{5772}=0.773\]  

- Ratio of transmission line length to power supply capacity
  This index refers to the ratio of transmission line length (10,000 km) to installed capacity (100 million kW) in transmission network. By the end of 2017, Yunnan power grid had 500 KV transmission lines 12586 km and 220 KV transmission lines 15388 km, with installed capacity of 57.72 million kW for local load. Then the index is:

  \[\frac{1.2586+1.5388}{0.5772}=4.874\]
4.1.2. Evaluation index of power supply structure

- Percentage of clean energy access capacity
  
  This index reflects the coordination of the structure and output characteristics of various types of energy in the region. The changes of power supply structure and installed scale after the reform of Yunnan electric power system are shown in table 4 below.

| Table 4. Power supply structure and installation scale in Yunnan Province (Unit: Million kW). |
|-----------------------------------------------|------------------|------------------|------------------|
| Project                        | 2015 Year | 2016 Year | 2017 Year |
|-----------------------------------------------|------------------|------------------|------------------|
| Total installed capacity                | 79.27       | 84.43         | 89.57         |
| Installed capacity of hydropower           | 57.74       | 60.96         | 62.81         |
| Among them: the main stream of the Three Rivers | 37.18    | 39.58         | 41.26         |
| Medium and small hydropower              | 20.56       | 21.38         | 21.55         |
| Thermal power installation               | 14.22       | 14.59         | 14.62         |
| Wind power                              | 6.14        | 7.37          | 8.25          |
| Photovoltaic                            | 117         | 208           | 2.38          |

In 2017, in the provincial power generation installation, wind power and photovoltaic power generation with obvious stochastic and reverse peak regulation characteristics totaled 10.63 million kilowatts, accounting for 11.87%, and still growing rapidly.

In terms of hydropower, Xiaowan and Nuozhadu power stations ("two reservoirs") were put into operation in 2009 and 2012 respectively. As the total available storage capacity of "two reservoirs" is as high as 212 m³, it has significant effect on improving seasonal contradiction of power generation capacity of the whole network. Since 2013, cascade hydropower groups in the main stream of Jinshaojiang River have taken shape, with an additional generating capacity of 2.06 million kilowatts, and basically no regulation capacity. Taking 2016 as an example, the ratio of flood and dry power generation capacity of Lancang River basin with Xiaowan and Nuozhadu reservoirs is 48:52, and that of Jinsha River middle reaches without leading reservoirs is 73:27. The commissioning of runoff cascade hydropower stations in the middle reaches of Jinsha River results in a continuous decline in the overall regulation capacity of Yunnan power grid. In Yunnan Province, less than 30% [3] of hydropower plants have annual above regulation capacity.

In terms of thermal power, because of the high proportion of hydropower and new energy in Yunnan power grid, thermal power operates in the smallest way in flood season, while in dry season, thermal power generates electricity with load curve and participates in peak shaving.

Therefore, in general, due to the increasing peak-valley gap of Yunnan power grid and the increasing capacity of hydropower and new energy generation, even if thermal power units participate in peak-shaving fully, the overall peak-shaving power supply proportion of Yunnan power grid reaches 45%, the low-valley peak-shaving of power grid is still facing great difficulties.

- Percentage of clean energy access capacity
  
  This index refers to the proportion of regional clean energy access capacity to the installed capacity of all equivalent power sources, and reflects the degree of clean energy acceptance in the process of power grid construction and development. By the end of 2017, the total installed capacity of Yunnan power generation was 89.57 million kilowatts, of which 62.81 million kilowatts were hydropower, 16.13 million kilowatts were thermal power, 8.25 million kilowatts were wind power and 2.38 million kilowatts were solar energy. Water, thermal power and new energy accounted for 70%, 18% and 12% of the total installed capacity respectively.

  The index values are as follows:

  \[ 70\% + 12\% = 82\% \] (6)

- Proportion of electricity discarded
  
  Yunnan Province is rich in water resources, and power abandonment mainly refers to water abandonment. In 2017, Yunnan Province completed a total of 295.8 billion kilowatt-hours of power
generation, 124.22 billion kilowatt-hours of power transmission from west to east, and about 30 billion kilowatt-hours of power abandonment. In 2017, the total social electricity consumption of Yunnan Province was 153.8 billion kilowatt-hours, that is, in 2017, the amount of water discarded in Yunnan exceeded 10% of the total annual electricity generation, accounting for about 20% of the total social electricity consumption in Yunnan Province. It is obvious that the situation is still not optimistic, and it is still necessary to further strengthen the construction of outgoing passages and take effective measures to alleviate the problem of water discarding.

4.1.3. Evaluation index of electricity market construction.
- Supply-demand equilibrium index
  This index represents the situation of power supply and demand. In 2017, Yunnan's installed capacity for local loads was 57.72 million kilowatts. The maximum power load of the whole society was estimated to be about 256.63 million kilowatts according to the maximum load utilization hours of 6,000 hours, and the reserve capacity was 14% (Load reserve is 3%, accident reserve is 10%, overhaul reserve is 1%). The supply-demand equilibrium index was as follows:

\[
5772 \times (1-14\%) / 2536 = 1.96
\]

- Market power level on generation side
  The market power level on the generation side can be characterized by the Herfindahl-Herchmann index (HHI), i.e. the market share of each power producer is examined.
  On the power generation side, taking the hydropower plants in Yunnan Province which have been put into operation since 2004 and connected to the grid with 220 kV and above voltage levels as the analysis object, the installed capacity of Huaneng Lancangjiang Company accounts for 43.67%, and the market concentration index of the five major power generation groups is 2588, greater than 1800, which indicates that the industry is monopolistic. The HHI value ranges from 1/3000 to 1/1000, which belongs to the high oligopoly type. It can be seen from this that even if the access scope of the generation side is greatly expanded, the five power generation groups, especially Huaneng Lancang River Company, can form a clear monopoly by exercising market power on the generation side.

4.2. Comprehensive evaluation and implementation
According to the above analysis of the status quo of the coordination evaluation indicators of Yunnan transmission network and power construction, combined with the comprehensive evaluation method and process proposed in this paper, the coordination evaluation score of Yunnan transmission network and power construction is obtained.

Table 5. Total score of coordination evaluation between transmission network and power supply construction.

| Object of evaluation | First level index | Second level index | Value | Weight | Score |
|----------------------|------------------|--------------------|-------|--------|-------|
| Coordination between Transmission Network and Power Supply Construction | Power scale | Generation capacity margin | 33.51% | 0.5278 | 83.85 |
| | | Ratio of transformer capacity to installed capacity | 0.773 | 0.3325 | 51.8 |
| | | Ratio of transmission line length to power supply capacity | 4.874 | 0.1396 | 61.8 |
| | Power structure | Peak shaving power supply proportion | 45% | 0.5499 | 62 |
| | | Percentage of Clean Energy Access | 82% | 0.2402 | 82 |
From table 5, it can be seen that the evaluation score of Yunnan transmission network and power supply coordination in 2017 is 67.92. Combined with the success evaluation grade, the evaluation conclusion of transmission network and power supply coordination is partial success. The following is a concrete analysis of the advantages and disadvantages of each index combined with radar chart.

The first-level indicators of coordination evaluation between transmission network and power supply construction include power supply scale, power supply structure and power market construction. Radar charts of each index score are as follows in figure 2.

**Figure 2.** Radar Chart of Scoring First-Class Indicators for Coordination Evaluation.

**Figure 3.** Score radar map of secondary indicators for coordination evaluation.
Among the three first-level indicators, only the power supply scale index scored more than 70 points, and the construction conclusion of the index was basically successful; the other two indicators scored between 60 and 70 points, and the construction conclusion of the index was partial success, that is, the completion of the index was poor.

The secondary index radar chart is shown below in figure 3.

Among the secondary indicators of coordination between transmission network and power supply construction, generation capacity margin index has the highest score of 83.85, which indicates that the emergency capacity and the overall level of power exchange generation side of Yunnan power system are better when the load increases.

Secondly, the proportion of clean energy access capacity is 82 points, which indicates that the clean energy development in Yunnan power grid is better.

The rest of the indicators are around 60 points, the indicators score is poor. The main reason is that Yunnan power grid is in the stage of rapid expansion and continuous strengthening of development and construction. The speed of power development in Yunnan Province is much higher than that of load demand growth in the provincial and external electricity markets, and the power generation capacity is much larger than that of electricity demand. At the same time, because the construction of Yunnan electric power market is in its infancy, the generation side and the sale side have not yet formed a benign competitive environment, which leads to the low score of the index of electric power market construction.

5. Conclusions
From the analysis of this paper, it can be seen that Yunnan power grid is generally reasonable in power supply and power grid construction, and the construction effect is good. In terms of power construction, Yunnan actively adjusts and improves the power structure of the whole province, and vigorously develops low-carbon, green and clean energy. With the steady progress of power transmission from west to east, the grid structure has been strengthened and perfected, and the power supply capacity has been enhanced, which basically meets the demand of power consumption and power delivery in Yunnan's economic and social development. However, Yunnan power grid still needs to further improve the role of green platform for resource allocation in order to make full and effective use of existing grid resources.

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