Comprehensive Evaluation Model of Power Grid Development Potential Considering Inventory and Incremental Equipment

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Abstract. Reasonable evaluation of the development potential of power grid is an important guarantee for power planning and investment. In this paper, the evaluation index system of power grid development potential is constructed, and based on the operation status of the existing equipment of the power grid, as well as the operation capacity of incremental equipment after the projects under construction and planning are put into operation, the evaluation model of power grid development potential considering the existing / incremental equipment is constructed. Finally, through the verification of Tianjin Power Grid, the index system and method mentioned in this paper are easy to implement and can evaluate the development potential of power grid comprehensively and accurately.

1. Introduction

Under the guidance of the “13th Five-Year” development plan and construction goals of the State Grid, the lean management level of the power grid company has been significantly improved. At the same time, building a "one strong, three excellent" modern company in an all-round way puts forward higher requirements for precise investment, efficient operation and management. The development level of power grid has a direct impact on power grid construction and power layout. Only by accurately evaluating the development potential of power grid, can we improve the scientificity and accuracy of the analysis of the future development trend of power grid, and make the power planning and investment more in line with the actual demand of the national economic development for power.

At present, many scholars have conducted research on the evaluation index system of the power grid. Literature [1] has constructed a power grid development evaluation index system from the four aspects of power grid safety and reliability, efficiency and benefit, equipment level, and external environmental impact; Literature [2-3] respectively proposed a comprehensive index system for comprehensive analysis and evaluation of the smart grid; Literature [4-6] proposed the power grid operation evaluation index system from the perspectives of power quality, low carbon and cleanliness; Literature [7] constructed the evaluation index system of the development of power grid enterprises from six aspects of social impact, green environmental protection, grid structure, economic efficiency, intelligence level, and interaction ability.

However, there is no literature on the evaluation index of power grid development potential. Based on the existing literature research, this paper establishes the evaluation index system of power grid development potential, and puts forward the calculation method of power grid development potential,
evaluates the development potential of the future power grid formed after the projects under construction and the planned projects are put into operation, which can help analyze the existing and incremental equipment but not yet been developed. In the end, the rationality of the proposed method is verified by the actual calculation of Tianjin Power Grid. The flow chart of this paper is shown in Figure 1.

**Figure 1.** The flow chart of this paper

### 2. Definition of power grid development potential

The power grid equipment includes two types, one is the existing stock equipment, and the other is the incremental equipment after the project under construction and the planned project are put into operation. At present, the power grid evaluation mainly focuses on the inventory equipment, which is to diagnose and analyze the current performance of the power grid, but does not consider the role of incremental equipment to improve the performance of the power grid.

The performance evaluation of the power grid, which is aimed at the current power grid, is an assessment of the current operating state of the stock equipment. The development potential of the power grid refers to the capabilities that the power grid itself but has not yet realized after considering the stock and incremental equipment. The development potential evaluation is aimed at the current power grid and the power grid formed after the project under construction and planning is put into operation, including both the existing equipment and the incremental equipment. Therefore, to realize a comprehensive assessment of the power grid, the assessment of development potential is an indispensable part.

The grid development potential evaluation model starts from five aspects: power supply capacity, safety, power supply quality, progressiveness and economy, and proposes a calculation method for grid development potential indicators, which integrates the development potential of each index to accurately and comprehensively assess the overall development potential of the power grid.
3. Comprehensive evaluation model of power grid development potential

3.1. Evaluation process
The implementation process of the comprehensive evaluation model of power grid development potential is as follows:

(1) Computing development potential
From the five aspects of power supply capability, security, power supply quality, advanced nature and economy, the evaluation index system of power grid development potential is constructed. According to the calculation formula of each index, the development potential ($X_i$) of each index of power grid is calculated.

(2) Determine the weight
The analytic hierarchy process (AHP) is used to determine the weights, and the weights are assigned according to the importance of each index. Then the first-level index weight $U$ and the second-level index weight $W$ are obtained respectively.

(3) Conduct the comprehensive evaluation
First, according to the calculation formula of each indicator, we can calculate the development potential $X(x_1, x_2, ... x_n)$ of each secondary indicator (where $n$ is the number of indicators); Then, we need to calculate the development potential of each level of indicators; Finally, the comprehensive development potential of the power grid can be evaluated.

The implementation flow chart is shown in Figure 2.

**Figure 2. Implementation flow chart of comprehensive evaluation model of power grid development potential**
3.2. Evaluation index system

According to the principle of index selection, a grid development potential evaluation index system is constructed from five aspects: power supply capacity, safety, power supply quality, progressiveness, and economy, as shown in Table 1.

| First-level indicators | Second-level indicators                                      | Voltage level | Indicator type        |
|-----------------------|-------------------------------------------------------------|---------------|-----------------------|
| **Power supply capacity** | Increased rate of network supply load | /            | Maximum indicator      |
|                       | Proportion of main transformer capacity in substation expansion | 500-35kV     | Maximum indicator      |
|                       | Proportion of line outgoing remaining interval              | 10kV          | Maximum indicator      |
|                       | Increased rate of line maximum load rate                    | 500-10kV      | Maximum indicator      |
|                       | Increased rate of main transformer maximum load rate        | 500-35kV      | Maximum indicator      |
| **Safety**            | Increased rate of line N-1 pass rate                         | 500-10kV      | Maximum indicator      |
|                       | Increased rate of main transformer N-1 pass rate            | 500-35kV      | Maximum indicator      |
|                       | Reduced rate of heavy-duty main (configuration) variable ratio | 500-10kV     | Minimal indicator      |
|                       | Reduced rate of heavy duty line proportion                  | 500-10kV      | Minimal indicator      |
| **Power supply quality** | Increased rate of power supply reliability rate | Urban Network, Rural Network, Comprehensive | Maximum indicator |
|                       | Increased rate of comprehensive voltage pass rate | Urban Network, Rural Network | Minimal indicator |
| **Progressiveness**    | Increased rate of three remote terminals                    | 10kV          | Maximum indicator      |
|                       | Increased rate of line cable rate                            | 10kV          | Maximum indicator      |
|                       | Increased rate of overhead line insulation rate              | 10kV          | Maximum indicator      |
|                       | Increased rate of distributed power supply access capacity   | /             | Maximum indicator      |
| **Economy**           | Reduced rate of line loss                                   | Comprehensive, 500kV, 10kV and below | Minimal indicator |
|                       | Increased rate of line average load rate                     | 500-10kV      | Maximum indicator      |
|                       | Increased rate of main transformer average load rate         | 500-35kV      | Maximum indicator      |

The following is a description of the evaluation indicators:

1. The development potential of maximum indicator refers to the gap between the planned value of the indicator (or the limit value that can be increased) and the current value at a certain point in the future account for the planned value of the indicator (or the limit that can be increased the limit value), reflecting the potential unused capability of the indicator;
(2) The development potential of minimal indicator refers to the ratio of the gap between the current value of the indicator and the planned value (or the limit value that can be reduced) to the current value of the indicator at a certain point in the future, reflecting the potential of this indicator to be optimized;

(3) The overall development potential of the power grid refers to the synthesis of the development potential of each indicator on the basis of considering the importance of each indicator. Among them, the index planning value (or limit value) refers to the state that the performance of this aspect of the power grid is planned to be achieved at a certain point in the future after the construction project and the planned project are put into operation. The current value of the indicator reflects the current performance status of the power grid.

The calculation method of the development potential of each indicator is as follows:

The calculation formula for the development potential of the maximum indicator is

$$ X = \frac{F - P}{F} $$  \hspace{1cm} (1)

The calculation formula for the development potential of the minimal indicator is

$$ X = \frac{P - F}{P} $$  \hspace{1cm} (2)

Where, \( X \) is the development potential of the indicator, \( F \) is the planned value of the indicator (that is, the limit value to which the extremely large indicator can be raised or the limit value to which the extremely small indicator can be reduced), and \( P \) is the current value of the indicator.

3.3. Index weight determination

AHP can treat a complex multi-objective decision problem as a system, and then divide the evaluation object into the target layer, the criterion layer and the plan layer, and then quantify the qualitative indicators through expert evaluation and other methods to calculate the weights and comprehensive Weight [8,9,10]. In this article, AHP is used to determine the index weight.

3.4. Comprehensive assessment

Firstly, according to the development potential calculation formula in 3.2, calculate the development potential of each evaluation index \( X (x_1, x_2, \ldots, x_n) \) (where \( n \) is the number of indicators). Then, calculate the comprehensive development potential of each level indicator. Finally, the comprehensive development potential of power grid is evaluated.

(1) Comprehensive development potential of each level index calculated

$$ R_i = W_i \times X_i^T $$  \hspace{1cm} (3)

Where, \( W_i = (w_{i1}, w_{i2}, \ldots, w_{ij}) \), \( X_i = (x_{i1}, x_{i2}, \ldots, x_{ij}) \)

\( R_i \) is the comprehensive development potential of indicators at all levels; \( W_i \) is the weight of each secondary index obtained by AHP; \( X_i \) is the calculated value of each evaluation index development potential, \( i \) is the first level index number, \( i = 1, 2, 3, 4, 5 \); \( j \) is the number of second-level indicators included in each primary indicator.

(2) Comprehensive development potential of power grid evaluation

$$ F = U \times R^T $$  \hspace{1cm} (4)

Where, \( F \) is the comprehensive development potential of power grid; \( U \) is the first level index weight obtained by AHP; \( R \) is the comprehensive development potential of the first level indicator, \( R = (R_1, R_2, R_3, R_4, R_5) \).

4. Empirical analysis

Taking Tianjin as the empirical analysis object, the model input is the current value and planned value (or limit value) of each indicator. Among them, take the 2018 data as the current value of the indicator and 2020 as the end node of the future planning period. The 2020 power grid is based on the
current power grid, considering the power grid formed before 2020 and under construction and planning projects. The index planning value is the state (or the limit state) that the power grid plan will reach in 2020. The model output is the development potential of each index and the comprehensive development potential of the power grid.

4.1. Calculate the development potential of the power grid various indicators

Collect the data related to the development potential of Tianjin power grid, and calculate the development potential ($x$) of each index according to the calculation method of the index development potential in 3.2.

Table 2. Power grid development potential calculating.

| First-level indicators | Second-level indicators | Voltage level | Weights ($w$) | The current value | Planned value (or limit value) | Development potential ($x$) |
|------------------------|-------------------------|---------------|---------------|-------------------|-------------------------------|---------------------------|
|                        | Increased rate of network supply load | /             | 0.241         | 1489              | 1747                          | 14.77%                    |
|                        | Proportion of main transformer capacity in substation expansion | 500           | 0.069         | 1725.3            | 2835.3                        | 64.33%                    |
|                        |                         | 220           | 0.069         | 2735.6            | 4034.6                        | 47.48%                    |
|                        |                         | 110           | 0.069         | 1591.2            | 2181.1                        | 37.07%                    |
|                        |                         | 35            | 0.034         | 1082.3            | 1326.3                        | 22.77%                    |
|                        | Proportion of line outgoing remaining interval | 10            | 0.034         | 4746              | 7140                          | 33.53%                    |
|                        | Increased rate of line maximum load rate | 500           | 0.069         | 61                | 62                            | 1.61%                     |
|                        |                         | 220           | 0.069         | 56                | 57                            | 1.75%                     |
|                        |                         | 110           | 0.069         | 18.4              | 19.6                          | 6.12%                     |
|                        |                         | 35            | 0.034         | 19.51             | 21.2                          | 7.97%                     |
|                        |                         | 10            | 0.034         | 50.14             | 51.9                          | 3.39%                     |
|                        | Increased rate of main transformer maximum load rate | 500           | 0.069         | 53                | 57                            | 7.02%                     |
|                        |                         | 220           | 0.069         | 55                | 56                            | 1.79%                     |
|                        |                         | 110           | 0.034         | 39.07             | 42.2                          | 7.42%                     |
|                        |                         | 35            | 0.034         | 50.37             | 51.9                          | 2.95%                     |
|                        | Increased rate of line N-1 pass rate | 500           | 0.1           | 100               | 100                           | 0%                        |
|                        |                         | 220           | 0.05          | 100               | 100                           | 0%                        |
|                        |                         | 110           | 0.05          | 100               | 100                           | 0%                        |
|                        |                         | 35            | 0.05          | 95.99             | 99.95                         | 3.96%                     |
|                        | Increased rate of main transformer N-1 pass rate | 500           | 0.05          | 100               | 100                           | 0                        |
|                        |                         | 220           | 0.05          | 100               | 100                           | 0                        |
|                        |                         | 110           | 0.05          | 100               | 100                           | 0                        |
|                        |                         | 35            | 0.05          | 100               | 100                           | 0                        |
|                        | Reduced rate of heavy-duty main (configuration) variable ratio | 500           | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 220           | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 110           | 0.05          | 7.14              | 6.1                           | 14.57%                    |
|                        |                         | 35            | 0.05          | 12.9              | 10.2                          | 20.93%                    |
|                        |                         | 10            | 0.05          | 2.72              | 1.43                          | 47.43%                    |
|                        | Reduced rate of heavy duty line proportion | 500           | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 220           | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 110           | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 35            | 0.05          | 0                 | 0                             | 0                         |
|                        |                         | 10            | 0.05          | 0.39              | 0.23                          | 41.03%                    |
Table 2, cont.

| First-level indicators | Second-level indicators                          | Voltage level | Weights \(w\) | The current value | Planned value (or limit value) | Development potential (x) |
|------------------------|-------------------------------------------------|---------------|----------------|-------------------|-----------------------------|---------------------------|
| Power supply quality   | Increased rate of power supply reliability rate | City Network  | 0.25           | 99.9647          | 99.99                        | 0.03%                     |
|                        |                                                 | Rural Network | 0.125          | 99.8664          | 99.934                       | 0.07%                     |
|                        |                                                 | Comprehensive| 0.25           | 99.9492          | 99.965                       | 0.02%                     |
| Advanced               | Increased rate of three remote terminals        | 10            | 0.25           | 37.47            | 45.23                        | 17.16%                    |
|                        | Increased rate of line cable rate               | 10            | 0.25           | 72.03            | 81.69                        | 11.83%                    |
|                        | Increased rate of overhead line insulation rate  | 10            | 0.25           | 100              | 100                          | 0                         |
|                        | Increased rate of distributed power supply access capacity | /             | 0.25           | 107.97           | 156.9                        | 31.19%                    |
| Economy                | Reduced rate of line loss                       | Comprehensive| 0.1            | 6.72             | 6.41                         | 4.61%                     |
|                        |                                                 | 500           | 0.1            | 0.47             | 0.45                         | 4.26%                     |
|                        |                                                 | 10 and below  | 0.05           | 4.61             | 4.21                         | 8.68%                     |
|                        | Increased rate of line average load rate        | 500           | 0.1            | 38               | 40                           | 5.00%                     |
|                        |                                                 | 220           | 0.1            | 33               | 35                           | 5.71%                     |
|                        |                                                 | 110           | 0.1            | 31.67            | 34.45                        | 8.07%                     |
|                        |                                                 | 35            | 0.05           | 32.45            | 35.26                        | 7.97%                     |
|                        |                                                 | 10            | 0.05           | 40               | 45                           | 11.11%                    |
|                        | Increased rate of main transformer average load rate | 500           | 0.1            | 24               | 26                           | 7.69%                     |
|                        |                                                 | 220           | 0.1            | 25               | 28                           | 10.71%                    |
|                        |                                                 | 110           | 0.1            | 49.07            | 51.3                         | 4.35%                     |
|                        |                                                 | 35            | 0.05           | 40.37            | 42.1                         | 4.11%                     |

4.2. Determine index weight
The first-level index weight \(U\) and the second-level index weight \(w\) are calculated by the analytic hierarchy process.

(1) First-level index weight.
Determine the five first-level indicators—the weight of power supply capacity, safety, power supply quality, advanced and economy is: \(U = (0.2, 0.3, 0.2, 0.15, 0.15)\)
According to the importance of the indicators, the order of importance is: safety, power supply capacity and power supply quality, advanced and economy.

(2) Second-level index weight.
1) The weight of the power supply capacity index is: \(W_1=(0.241, 0.069, 0.069, 0.069, 0.034, 0.034, 0.069, 0.069, 0.069, 0.034, 0.034, 0.069, 0.069, 0.034, 0.034)\)
2) The weight of the security index is: \(W_2=(0.1, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05)\)
3) The weight of the power supply quality index is: \(W_3=(0.25, 0.125, 0.25, 0.125, 0.125)\)
4) The weight of the advanced index is: \(W_4=(0.25, 0.125, 0.25, 0.25)\)
5) The weights of economic indicators are: \(W_5=(0.1, 0.1, 0.05, 0.1, 0.1, 0.1, 0.05, 0.05, 0.1, 0.1, 0.1, 0.1, 0.05)\)

4.3. Comprehensive evaluation of power grid development potential
(1) Based on the development potential value of each indicator, the following calculations are made:
1) Combined with the weight of the indicator layer, the first-level indicators are calculated according to formula (3), that is, power supply capacity, safety, power supply quality, advanced and economic development potential are (17.75%, 6.40%, 0.02%, 15.05%, 6.63%) .

2) The weights of power supply capacity, safety, power supply quality, advanced and economy are $U = (0.2, 0.3, 0.15, 0.15)^T$. According to formula (4), the comprehensive evaluation value of power grid development potential is 8.72%.

(2) Result analysis
The development potential of the first-level indicators from large to small is as follows: power supply capacity, advanced nature, economy, safety and power supply quality. Specifically:

1) In terms of power supply capacity, the development potential of increased rate of network supply load, proportion of main transformer capacity in substation expansion, and proportion of line outgoing remaining interval are all greater than 10%, indicating that the grid has more potential for increased load capacity and dig grid capacity expansion. The potential of the maximum load rate index of 500kV, 220kV and 10kV lines and the maximum load rate index of 220kV and 35kV main transformers is between 0-5%, with poor development potential. The potential of the maximum load rate index of 500kV, 220kV and 10kV lines and the maximum load rate index of 220kV and 35kV main transformers is between 0-5%, with poor development potential. The remaining indicators are between 5% and 10%, and the development potential is acceptable.

2) In terms of safety, the development potential of the 110-10kV reduced rate of heavy-duty main (configuration) variable ratio and the 10kV reduced rate of heavy duty line proportion is greater than 10%, indicating that the heavy-load phenomenon is expected to be greatly improved. The potential of the N-1 pass rate of 500-35kV lines and main transformers can be increased, the percentage of 500-220kV reduced rate of heavy-duty main (configuration) variable ratio, and the potential of 500-35kV reduced rate of heavy duty line proportion by 0%, indicating that these The indicator has reached a very good state at present. The potential for increasing the rate of N-1 pass rate on 10kV lines is between 0-5%, and the development potential is poor.

3) In terms of power supply quality, the potentials of increased rate of power supply reliability rate and increased rate of comprehensive voltage pass rate indicators are both less than 1%, and the development potential is poor, but it also shows that these indicators have reached a relatively good state at present.

4) In terms of Progressiveness, the potentials of three remote terminals, line cable rate and distributed power access capacity increased rate are all greater than 10%, indicating that the rate of three remote terminals, line cable, and distributed power in installed capacity of the network has a larger room for improvement. The potential for increasing the insulation rate of overhead lines is 0%, that is, the current overhead lines have all been insulated.

5) In terms of economy, 10kV increased rate of line average load rate and 220kV increased rate of main transformer average load rate’s potential more than 10%, indicating that the equipment capacity utilization rate has greater room for improvement. Comprehensive reduced rate of line loss, 500kV reduced rate of line loss, and 110-35kV increased rate of main transformer average load rate are between 0-5%, with poor development potential. The remaining indicators are between 5-10%, and the development potential is acceptable.

5. Conclusion
Firstly, this article defines the development potential of the power grid. Secondly, based on the current operation status of the grid's stock equipment and the operating capacity of the incremental equipment after the grid construction projects and planned projects are put into operation. A grid development potential evaluation model considering the stock / incremental equipment is constructed. In addition, the evaluation process is described in detail in the model, constructing the evaluation index system for the development potential of the power grid, determining the calculation methods of each index weight and the comprehensive development potential of the power grid. Finally, with Tianjin as the object of empirical analysis, the potential of its power grid development is calculated and evaluated. The results of power grid development potential assessment can improve the scientific
and accuracy of future power grid development trend analysis, then guiding power effectively planning and investment.

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