A Multi-Weight Optimization Based Prediction Method for Distributed Generation

Yushu Zhang¹, Hua Deng¹, Bing Qin¹, Jingyan Liu¹, Pu Zhang¹ and Bi-bin Huang²

¹Beijing Electric Power Economic Research Institute Co., Ltd, Beijing, China
²State Grid Energy Research Institute Co., LTD, Beijing, China

E-mail: hhbbibl@163.com

Abstract. The development of distributed generation will be affected by the policy, and become more market-oriented. The impact factors of the future layout are various. In order to accurately predict the future layout of distributed generation and guide the planning, this paper presents a layout prediction method for distributed generation by multi-weight optimization. The method takes different impact factors into consideration and use the historical data to determine the weights of the factors with optimization method. The method can predict distributed generation layout in the target year accurately. The case of the distributed photovoltaic development in Shandong shows that the central region will become the main development region.

1. Introduction
The objectives of distributed generation development are clearly put forward in China, and a series of policies and measures to support the development are also issued.

At present, the annual increase of photovoltaic generation in various provinces is regulated by government[1]. And some research institutions have carried out development layout analysis [2] of distributed photovoltaic power generation. In terms of research methods, most of the existing studies initially allocate in proportion based on the analysis of resource and economy. Then, the preliminary allocation is artificially adjusted considering local policies and initiatives. The result is lack of accuracy because the less scientific method and model. In terms of impact factors, most of the studies ignore the condition of power grid. But the distributed generation only can present its technological and economic advantages after it is integrated in power grid. So the existing research is still in the preliminary stage, and its guidance should be improved.

In order to solve the problems of incomplete application types and considerations, imprecise methods and result artificial adjustment in existing distributed generation layout prediction, this paper proposes a layout prediction method for distributed generation by means of multiple-factors weights optimization, which takes a variety of factors into consideration, such as resource potential, project economy, power grid condition and etc. Based on the historical data, the weights of the factors are determined using optimization. So the development scale of distributed generation in each province is predicted based on the national development goal.

2. Impact Factors of Distributed Generation Development Layout
The following requirements should be taken into account in selecting the impact factors for distributed generation development layout:

1) Importance. There are many factors impacting the development layout of distributed generation. But it cannot take all factors into consideration. So the important factors should be selected.

2) Independence. In order to ensure the validity of layout prediction result, the selected impact factors should be independent of each other, without any coupling.

3) Quantification. The impact factors should be quantifiable in order to improve the quantification of analysis method.

Considering the above requirements, the prediction method of distributed generation development layout proposed in this paper focuses on four factors: resource potential, project economy, power grid condition and local government willingness.

2.1. Resource Potential

The development potential of distributed generation includes resources development potential, technological development potential and economics development potential, each of them varies widely at the data level. The development potential of distributed power has different influencing factors in different technology types, and needs to be evaluated in combination with power supply characteristics. The resource potential in the paper is technological development.

For different types of distributed generation, the resource potential needs to be addressed differently. Because the delivery of light resource is not constrained, the potential for development of distributed photovoltaic technology is primarily limited by the size of the site or facility where the distributed photovoltaic can be installed [3]-[5]. The research that has been carried out currently focuses on agricultural greenhouses, barren hills and slopes, railways and other site facilities. While the resource potential of distributed natural gas generation should pay attention not only to the natural gas supply capacity, but also to the constraints of natural gas pipeline network construction[6].

According to calculations, China's distributed photovoltaic technology development potential is 1.3 billion kilowatts. As shown in table 1, the development potential of rural/urban housing and mining plants, 14 billion kilowatts, accounts for 88% of the total distributed photovoltaic potential.

Table 1. China's distributed photovoltaic development potential

| Technological development | Urban housing | Rural housing | mining plants | Railway mileage | Highway mileage | Reservoir | Fish pond surface | Beach | Agricultural greenhouse |
|---------------------------|---------------|---------------|---------------|----------------|----------------|-----------|-------------------|-------|------------------------|
| 2.23                      | 7.50          | 1.64          | 0.07          | 0.08           | 0.06           | 0.22      | 1.05              | 0.09  |                        |

2.2. Power Grid Condition

With the increase of distributed generation capacity, the operating risks will become significant [7]. Considering the safe operation and reliable power supply, there is an upper limit for the distributed generation capacity integrated in distribution network. It is commonly called the allowable capacity by distribution network to quantify the power grid condition for the distributed generation development.

In order to determine the allowable capacity of distributed generation by distribution network, the concept of penetration is introduced. Penetration refers to the ratio of the capacity of distributed generation to the maximum power load in distribution network. The maximum permissible penetration is called allowable penetration. The United States, Europe, Canada and other countries have carried out research on the allowable penetration. The research result shows that when allowable penetration is less than 15%, it has little effect on the distribution network. Therefore, from the view of quantification and operability, allowable penetration of 15% is regards as a conservative value to calculate the allowable capacity in China. And the current and future situation of allowable capacity is also analyzed in this paper.

2.3. Local Governments Willingness

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Usually, the willingness of local governments is affected by many factors, including demands of industry support, employment-driven, financial capacity, and etc. It is difficult to quantify. In order to solve this problem, this paper summarizes the development planning objectives of distributed generation in all provinces, partly from official documents, and partly from investigation or prediction. The planning objectives of each province can directly reflect the willingness to develop distributed generation.

2.4. Project Economy
The project economy directly determines the enthusiasm of investors, and also has an important impact on the development of distributed generation. The project economy is mainly affected by initial investment cost per unit capacity, annual operation and maintenance cost, electricity/heat/cold revenue and annual equivalent utilization hours.

Affected by light condition, the output of distributed photovoltaic generation is parabolic. Its peak output occurs between 12 and 14 o’clock. Therefore, the impact of peak-valley tariff should be considered when calculating electricity sale income. The average tariff can be calculated by typical output curve and peak-valley tariff weighting, and then the total income can be calculated. While distributed natural gas generation consumes natural gas, and generate electricity, heat and cold at the same time. So the project economy calculation needs to be considered comprehensively. In addition, distributed natural gas generation usually operates with full capacity, and its output is not adjusted frequently, which makes the calculation of average tariff relatively simple.

3. A Layout Prediction Method based on Multi-Weights Optimization

3.1. General Idea of Layout Prediction
The basic idea of distributed generation development layout prediction is shown as followed. Based on the national development prediction of a certain type of distributed generation technology, the development scale of each impact factor is decomposed, considering the factors of resource condition, project economy, power grid condition and etc. On this basis, combined the quantitative value of each impact factor in each province, the scale of each province under each factor can be obtained. Then the certain type of distributed generation development scale of each province can be obtained by accumulating for different factors, that is, the national development layout of distributed generation.

The following problems need to be solved in development layout prediction of distributed generation [8][9]:

(1) How to determine the weights of impact factors. At present, the weights of impact factors are usually determined by expert evaluation method, which needs to invite a large number of experts in the field to score. However, this method is difficult to ensure accuracy because of the subjectivity. The optimization method to calculate the factor weights which are closest to the actual layout data of historical years is proposed in this paper. It can solve the accuracy problem of expert evaluation method to a certain extent. In the short and medium term, the constraints on distributed generation development will not change fundamentally, and the weights of impact factors will remain within a reasonable fluctuation range. Therefore, it can be assumed that the weights of impact factors keep the same between the historical years and the target year.

(2) The relationship between the new scale of distributed generation and its impact factors. The development of distributed generation is still in its early stage, with a small scale and great potential. In addition to the project economy, other factors are all the main constraints. Therefore, it can be assumed that the new scale has a non-linear correlation with project economy, while linear correlation with other factors. Moreover, considering that the prediction method will calculate the weights through historical data fitting, the error under the linear relationship can be controlled within a reasonable range.
(3) How to obtain the impact factors and actual historical layout year by year. The distributed generation layout prediction method proposed in this paper needs the impact factors of past years and future. The amount of data is large and difficult to obtain.

(4) How to calculate, to calculate the target year directly or year by year from now to the target year. Distributed generation layout prediction can be directly based on impact factor data and development scale in target year (such as 2020). However, since the impact factors are not identical between present and the target year, it is necessary to calculate year by year. Of course, it is necessary to assume that the annual national growth is the same between present and the target year. Considering the effect of policy implementation, it is also necessary to maintain stable annual growth in order to guarantee the quality of distributed generation development and promote upstream enterprises.

3.2. Flow of Layout Prediction Method

The detailed steps of distributed generation layout prediction are as follows:

(1) Determine the national development scale $C_{plan}$ of a type of distributed generation in the target year. Then according to the national development current situation $C_{status}$, divide the difference between the current situation and the target according to the years equally. So the yearly increasing scale $C_{dec}$ in the future can be determined.

\[ C_{dec} = \left( C_{plan} - C_{status} \right) / n \]  

Where, $n$ is the number of years between present and the target year.

(2) Calculate each impact factor value of each province in historical years based on optimization, making the predicted data and the actual development data are the closest using the weights of optimization result. The decision variables, constraints and objective formulas are shown in section 2.2.

(3) Combined the new scale obtained in step (1) and the impact factor weights obtained in step (2), calculate the increasing scale of each impact factor in each province year by year. The calculation formula is similar to 2.2.

(4) The increasing scale and current situation of each province should be accumulated yearly to obtain the distributed generation development layout in the target year.

\[ C_{plan,j} = \sum_{i \in m} C_{i,j,all} + C_{status,j} \]  

Where, $C_{i,j,all}$ is the total increasing scale of the $j^{th}$ province in the $i^{th}$ year, $C_{status,j}$ is the distributed generation current situation of the $j^{th}$ province, $C_{plan,j}$ is the distributed generation scale of the $j^{th}$ province in the target year.

3.3. Weight Optimization Based On Historical Data

3.3.1. Decision variables and constraints. The variables of multi-factor weight optimization are the weights of resource condition, project economy, power grid condition and local government willingness. The constraints are:

\[ k_{res} + k_{eco} + k_{grid} + k_{obj} = 1 \]  

In addition, the constraints also need to fulfil the weight range of each impact factor determined by expert evaluation method.

3.3.2. Objective. The objective of multi-factor weight optimization is that the predictive scale and actual scale of each province in historical years are the closest. The sum of squares of the difference between the predictive value and actual value is taken as the objective function, which is as follows:

\[ \min \sum_{i=0}^{m} \sum_{j=0}^{n} \left( C_{status,n,j} + \sum_{k=0}^{n} C_{i,j,all} - C_{status,j} \right)^2 \]
Where, \( m \) is the number of historical years, which is negative, and counts from the latest historical year, such as -1 last year and -2 the previous year; \( j \) is the index of provinces in China; \( C_{\text{status,}m,j} \) is the actual development scale of the \( j \)th province in the \( m \)th year; \( C_{\text{status,}i,j} \) is the actual development scale of the \( j \)th province in the \( i \)th year; \( \sum_{k=i}^{m} C_{k,j,\text{obj}} \) is the sum of predictive scale from the \( i \)th year to the \( m \)th year.

3.3.3. Quantitative Analysis of Impact Factors. The increasing scale of each province is divided into four parts according to the impact factors. The calculation formula of \( \sum_{k=i}^{m} C_{k,j,\text{all}} \) is as follows:

\[
C_{k,j,\text{all}} = C_{k,j,\text{res}} + C_{k,j,\text{eco}} + C_{k,j,\text{grid}} + C_{k,j,\text{obj}}
\]  

(5)

Where, \( C_{k,j,\text{res}} \), \( C_{k,j,\text{eco}} \), \( C_{k,j,\text{grid}} \) and \( C_{k,j,\text{obj}} \) are the increasing scale of the \( j \)th province in the \( k \)th year related to resource condition, project economy, power grid condition and local government willingness, respectively.

1) Increasing scale of provinces related to resource condition

Under the resource condition, the proportion of scale in each province can be calculated directly according to the proportion of resource in each province.

\[
C_{k,j,\text{res}} = k_{\text{res}} \times \frac{\text{Res}_j}{\sum_j \text{Res}_j}
\]  

(6)

Where, \( k_{\text{dec}} \) is the actual increasing scale of the whole country in the \( k \)th year and \( \text{Res}_j \) is the resource of the \( j \)th province.

2) Increasing scale of provinces related to network condition

The provincial scale analysis related to network condition is similar with that related to resource condition. The formula is as follows:

\[
C_{k,j,\text{grid}} = k_{\text{grid}} \times C_{k,j,\text{dec}} \times \frac{\text{Grid}_j}{\sum_j \text{Grid}_j}
\]  

(7)

Where, \( \text{Grid}_j \) is the network condition of the \( j \)th province. According to the analysis mentioned above, the product of load (35 kV and below) and penetration (15%) in each province is adopted as the allowable capacity. It should be calculated year by year.

3) Increasing scale of provinces related to local government willingness

The provincial scale analysis related to local government willingness is similar with that related to resource condition. The formula is as follows:

\[
C_{k,j,\text{obj}} = k_{\text{obj}} \times C_{k,j,\text{dec}} \times \frac{\text{OBJ}_j}{\sum_j \text{OBJ}_j}
\]  

(8)

Where, \( \text{OBJ}_j \) is the development goal of the \( j \)th province.

4) Increasing scale of provinces related to project economy

The project economy is mainly measured by the project return rate. It is difficult to adopt the similar method as resource condition. Therefore, this paper proposes to convert the project return rate into an adjusted proportion. In this paper, a piecewise linear method for determining the adjustment coefficient is proposed, as follows:
Where, \( \text{ecoAdjust}_j \) is the adjustment coefficient of the \( j \)th province.

Then, the preliminary economic decomposition scale of each province is calculated by adjustment coefficient. The formula is as follows:

\[
C_{k,j,\text{eco,adjust}} = (1 + \text{ecoAdjust}_j) \times C_{\text{status},j}
\]

(10)

Where, \( C_{k,j,\text{eco,adjust}} \) is the preliminary decomposition scale related to the project economy.

Finally, it is necessary to revise the scale of each province. The revised formula is as follows:

\[
C_{k,j,\text{eco}} = k_{\text{eco}} \times C_{k,\text{dev}} \times \frac{C_{k,j,\text{eco,adjust}}}{\sum_{j=1}^{31} C_{k,j,\text{eco,adjust}}}
\]

(11)

4. Prediction of Distributed Photovoltaic Development Layout in Shandong Province

Distributed photovoltaic generation develops rapidly under a series of national support policies in China. This paper focuses on the prediction of distributed photovoltaic generation.

By the end of 2018, Shandong Province has the first installed capacity of photovoltaic power generation in China, of which the installed capacity of distributed photovoltaic power generation reached 7 million kilowatts. According to the development goal of distributed photovoltaic in Shandong Province and the allowable capacity, it is predicted that the distributed photovoltaic in Shandong Province will reach 37 million kilowatts by 2030. The average annual growth is expected to be 2.5 million kW.

According to the expert evaluation method, the impact factor weights of resource condition, project economy, power grid condition, and local government willingness are 0.1~0.3, 0.2~0.5, 0~0.3, 0~0.3, respectively.

According to the existing historical annual increasing scale, the impact factor weights are optimized to minimize the sum of squares of the difference between the prediction value and the actual value of annual increasing scale in each province. The impact factor weights of resource condition, project economy, power grid condition and local government willingness are 0.24, 0.38, 0.26, 0.12, respectively.

Based on the impact factor weights, the increasing scale from 2019 to 2030 is calculated year by year, and the results of distributed photovoltaic generation in 2030 are obtained. Take the layout prediction of distributed photovoltaic generation in Shandong Province as an example, the results are shown in table 2.

**Table. 2 The layout prediction of distributed photovoltaic generation in Shandong Province**

| region      | capacity (MW) | region      | capacity (MW) | region      | capacity (MW) |
|-------------|---------------|-------------|---------------|-------------|---------------|
| Weifang     | 5030          | Liaocheng   | 3230          | Binzhou     | 1900          |
| Jining      | 4370          | Dezhou      | 2430          | Taian       | 1800          |
| Linyi       | 4160          | Zibo        | 1920          | Zaozhuang   | 1650          |
| Qingdao     | 3270          | Donying     | 1900          | Rizhao      | 1320          |

5. Conclusion

A distributed generation layout prediction method based on multi-factor weight optimization is proposed in this paper. The factors such as resource condition, project economy, power grid condition and local government willingness are considered comprehensively. The weight of each factor is determined by optimization using historical data. This method realizes the comprehensive and
accurate analysis of impact factors and the development layout of distributed generation in the future target year.

In the future, with the accumulation and enrichment of data, this method can be further improved on the prediction accuracy. For example, with the increase of the historical data, the optimization results of impact factor weights can be calculated more accurate and more impact factors can be considered.

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