Analysis of Solar and Wind Power on Access Planning of Multiple Renewable Energy Sources

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Abstract. The scenario generation method suitable for solar and wind power obeying any probability distribution and the concept of cluster was brought up to improve the consumption ability of distribution network of medium and high voltage for renewable energy. The planning model of renewable energy access was established based on cluster partition considering the investments and power generation interests of power producers as well as the power match degree within clusters. The Benders decomposition method was employed to solve the planning problem, and the complicated planning problem of renewable energy generation is decomposed into the decomposed investment operation model. Therefore, the access planning of renewable energy taking account of the solar and wind power was realized.

1. Introduction

In order to achieve the relevant renewable energy cluster access planning, it is necessary to discuss the generation of renewable energy output scenarios. At present, the main renewable energy sources available include solar power and wind power. Because the ability of the cluster to absorb renewable energy largely depends on the matching characteristics between the output and load of renewable energy in the cluster, and the complementary characteristics between solar power and wind power output will affect the matching characteristics between the output and load of renewable energy in the cluster. Therefore, how to describe the degree of complementarity between solar power and wind power and how to generate samples that conform to the distribution of relevant characteristics are the basic problems of planning modeling. The traditional correlation coefficient matrix is applied to generate the wind speed with correlation [1-2], but the traditional correlation coefficient matrix theory has a strong assumption that the random variables obey the normal distribution, which is only suitable for the normal distribution. Wind speed and light are highly random variables. At present, some scholars combine correlation coefficient with time series to establish correlation model [3-4], but they still assume that renewable energy follows the given distribution. Based on Cholesky decomposition, a method for transformation of correlation variable of wind speed with non normal distribution is proposed, and the accuracy of variable transformation with Weibull distribution is verified [5], but the accuracy of random variable with arbitrary distribution is not discussed. Therefore, on the basis of [6], combined with nonparametric estimation method, this paper proposes a correlation sample generation method that can be applied to any distribution.
In this paper, Second Order Conic Relaxation (SOCR) is used to modify the power flow model into a convex optimization model. In terms of solving algorithm, Benders Decomposition Algorithm is applied to decompose complex network planning or distributed generation and energy storage planning problems into investment network operation problems for decomposition and solution, so as to simplify the complexity of each solving problem and speed up the calculation [7]. Therefore, in this paper, Benders Decomposition algorithm is used to solve the planning problem.

2. Cluster of renewable energy planning models

2.1. Distribution network level and its characteristics corresponding to cluster

As shown in Figure 1, a cluster consists of four 35kV power stations and their networks. When power stations 1 and 2 have reverse power from 9:00 to 15:00, the reverse power flow will flow to power stations 3 and 4, but at this time, the output of wind power is small, and it can still absorb the reverse power flow from 1 and 2 power stations. Therefore, it does not affect the wind power consumption of 3 and 4 power stations, and can increase the PV planning capacity of 1 and 2 power stations. Similarly, for 3 and 4 power stations, when 0-5, due to wt there is a reverse power flow to power stations 1 and 2, but PV does not output at this time, so it will not affect the absorption of PV output by 1 and 2 power stations. To sum up, using the complementary characteristics of different renewable energy sources in the cluster can greatly improve the absorption capacity of local renewable energy. However, the reverse power flow mentioned above should not flow in a large-scale network, otherwise it is easy to cause excessive network loss and voltage problems. Therefore, it is necessary to limit the flow range of reverse power flow according to the cluster division results.

2.2. Index and method of planning oriented cluster division

The modularity index based on reactive power and voltage sensitivity is used to measure the degree of close connection between power stations:

\[
\rho_m = \frac{1}{2\Omega} \sum_{i} \sum_{j} (t_{ij} - \frac{K_iK_j}{2\Omega})\phi(i,j)
\]

(1)

The cluster power balance index represents the net power complementary level under the existing DG access level in the cluster:

\[
\varphi_p = \frac{1}{N} \sum_{\tau=1}^{N} \left[ \frac{1}{T} \sum_{t=1}^{T} P_c(t)/\max(P_c(t)) \right]
\]

(2)

Among them, the cluster with high power balance represents that its original DG access level can roughly meet the internal load demand of the cluster, so the DG capacity that can continue to be connected is small; the power stations in the cluster with low power balance can still install distributed renewable energy on a large scale.
The indicators shown in (1) and (2) are combined as cluster comprehensive division index, which is expressed as:

\[ \Phi = \gamma_1 \rho_m + \gamma_2 \phi_p \]  

(3)

2.3. Distributed generation planning model

The objective function of renewable energy planning comprehensively considers the interests of renewable energy generators and network operators:

\[ \text{min} F_s = \sum_{i=1}^{N_s} \left( (C_{PV} S_{PV} + C_{WT} S_{WT}) \sigma (1 + \sigma)^\beta \right) \]  

(4)

\[ \text{min} F_c = (C_{sccl} + C_{sub}) \sum_{t=1}^{T} \sum_{i=1}^{N_s} \left[ (\alpha_{PV} S_{PV} - P_{PV}(t)) + \alpha_{WT} S_{WT} - P_{WT}(t) \right] \]  

(5)

\[ \text{min} F_d = \sum_{t=1}^{T} \sum_{c=1}^{c} P_c(t) \]  

(6)

\[ \text{min} F_e = C_p \sum_{i=1}^{T} \sum_{c=1}^{N_c} \sum_{i,j \in l_{c,i}} P_{ij}(t) \]  

(7)

In order to determine the priority of each objective function, AHP is used to construct the judgment matrix. Firstly, the renewable energy investment and wind / light cost represent the interests of the distributed generation companies, and the grid losses and cluster inflow electricity represent the interests of the grid side. It is assumed that the interests of power generation companies and power grid parties are equally important, in which investment and wind / light cost are equally important; cluster inflow power is slightly more important than grid loss cost. According to the above analysis, the judgment matrix is obtained as shown in Table 1.

| Table 1. Distance and capacity of AC voltage system. |
|----------------------------------------------------|
| Investment          | Power loss | Abandoned energy | Cluster input |
|---------------------|------------|------------------|---------------|
| Investment          | 1          | 3                | 1             | 1             |
| Power loss          | 1          | 3                | 1             | 1/2           |
| Abandoned energy    | 1/3        | 1                | 1/3           | 1             |
| Cluster input       | 1/3        | 1                | 1             | 1/3           |

The consistency was checked according to Table 1:

\[ C_r = \frac{4.1242 - 4}{4 - 1} = 0.414 \]  

(8)

\[ C_p = \frac{C_r}{R_f} = \frac{0.0414}{0.94} = 0.044 < 0.1 \]  

(9)

As shown in (8) and (9), the judgment matrix shown in Table 1 can pass the consistency test.

3. Solution of Benders Decomposition Model

According to the decomposition of the principal subproblem, Benders Decomposition algorithm can be obtained as follows:

Step 1: Solve the MP for the lower bound of primitive problem \( \hat{c}_{lower} \) and \( \hat{x} \).

Step 2: Solve the SP as:
\[
\tilde{z}_{up} = a^T \tilde{x} + b^T \tilde{y}
\]

(10)

\[
\tilde{z}_{up} = a^T \tilde{x} - \sum_{i=1}^{N_1} \tau_i (q_i - E_i^T \tilde{x}_i) - \sum_{i=1}^{N_2} \delta_i g_i^T \tilde{x}_i - \sum_{i=1}^{N_3} \delta_i c_i
\]

(11)

Step 3: Applying the solution to the MP to form a new MP, solve the new MP for the new lower bound of primitive problem \( \hat{c}_{lower} \) and \( \hat{x} \), and goes back to step 2 again.

Therefore, with the solar power and wind power related resources as scenario data and cluster partition results as complementary range of solar power and wind power, the planning scenario input planning model can be established, and Benders Decomposition method is used to solve the planning model.

4. Conclusions

This paper proposes a method to generate solar power and wind power resources that meet the expected complementary relationship accurately. The cluster is regarded as the complementary range of solar power and wind power, and a cluster planning model considering the interests of renewable energy producers and grid parties is established.

Cluster division will affect the distribution of renewable energy. Under the assumption of the same permeability, the renewable energy will be mainly distributed on the nodes with large load when the cluster is not divided, and the distribution of renewable energy within each cluster is more dispersed and uniform after the cluster is divided. In addition, the overall renewable energy consumption capacity of the system will be strengthened during the cluster planning.

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