Scenario Simplification Strategy Based on Space-time Partition in DPV Planning

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Abstract. Distributed photovoltaics (DPV) are the main form of power supply in active distribution network (ADN). Reasonable planning of DPV is beneficial to voltage quality and power deployment. In order to characterize the operating status of ADN, while considering the randomness of load and power, an hour-level annual time-series scenario model was established. Aiming at the space-time uncertainty of the DPV planning stage, a simplified method based on Space-time partition is proposed, and the planning model is further optimized from the perspective of grid managers. Finally, the effectiveness of the proposed method is verified in a modified IEEE 33-node distribution network system.

1. Introduction

As the energy shortages intensify globally, power systems are increasingly emphasizing the flexibility and initiative of the power grid. In the context of smart grids, the optimization of locations and sizing of distributed generations (DGs) is a key issue related to the reliable and economical operation of active distribution networks (ADN)[2]. Due to the complexity of loads and the randomness of DGs, especially distributed photovoltaics (DPV), researchers in ADN planning problems often need to face complex scenarios, which undoubtedly increases the difficulty of planning. In order to better adapt to the new normal of ADN, the field of DGs planning research has undergone profound changes.

In order to characterize the load and the uncertainty of the DPV, the researchers established different operating scenarios and analyzed them to form a time series or a random model. Ref. [3] uses chance constrained programming (CCP) to solve the problem of random DGs planning, analyzes the actual distribution network operation status, and considers uncertain factors such as load growth and electricity prices. As a further study, in [4], a Latin hypercube random sampling method was proposed, and the author compared the effects of this method with other random sampling. Reference [5] introduced a deviation coefficient to cope with randomness, and regarded the fluctuations caused by external interference as noise. Despite trying different mathematical tools, the problem of DGs and load uncertainty is still very complicated, especially as the system scale increases, the complexity increases significantly. To this end, the author in [6] proposed a scenario reduction technique for ADN planning and applied this method to a three-phase network large-scale system, which proved to be effective. In addition, [7] combined the improved correlation matrix method and Latin hypercube sampling, and processed the correlation of DGs by dividing the period. In summary, although the method of using analog sampling or scene reduction has produced effects to some extent, it is still difficult to overcome the problems of excessive system scale and low accuracy. Reference [8] adopted
the idea of cluster partition to simplify the planning process of ADN, but it was not further applied to scene reduction, that is, there is still a need for further optimization. Therefore, this paper analyzes and provides the logical basis of space-time partitioning by establishing hour-level annual time-series scenario models. The principle of partitioning based on load characteristics under the idea of cluster partitioning is proposed, and a typical scenario reduction method is adopted for further optimization. At the same time, for grid managers, it is more important to be able to effectively control DPV installation capacity. Therefore, this paper improves the planning model to improve capacity controllability.

2. Analysis of time-series model

2.1. Load

At present, in power planning and power industry statistics, loads are often divided into four types: industrial, agricultural, commercial, and municipal. In addition, considering that residential loads are also different from other types of loads, this article chooses 4 types of load mentioned above. In addition to the obvious difference between agricultural load and busy time, various loads show different regularities in spring, summer, autumn, and winter. The time-series characteristic curve is shown in Figure 1.
It can be seen that there is a large gap in the characteristics of different types of loads. Among them, the industrial load is the most stable. This is because the time of industrial power is less affected by factors such as seasons and time periods. In addition, the regularity of commercial loads is also obvious. The business hours are from 8:00 a.m. to 9:00 p.m. (with small fluctuation depending on the season). The demand of agricultural load changes significantly during busy and non-busy periods, and there is little fluctuation in power consumption during non-busy hours, and the overall demand for power increases during busy periods, with peaks in three periods; similarly, municipal loads and residential loads show clear peaks at different times.

2.2. DPV

The output characteristics of DPV are related to the intensity of the light and the control method of the inverter. In actual distribution networks, the form of DPV is mainly small or household. The user’s behavior only seeks to maximize the amount of power generation. Therefore, this article assumes the output of DPV Absolutely affected by light. The annual and typical DPV output curves of a region in Shandong Province are shown in Figure 2.

\[ S_{\text{DPV}}(i) = \text{Floor}(S_{\text{DPV}}(i)) \quad \text{if} \quad S_{\text{DPV}}(i) \geq \frac{S_{\text{lim}}}{n_i} \]
2.3. Time-series Model

The time-series model of DPV and load can also be considered as the time-series model of the operation state of the distribution network. The number of time slots for hour-level scenarios throughout the year is: \( n_t = 365 \times 24 = 8760 \). Let the total number of distribution network nodes be \( n_i \), and the load type corresponding to node \( D_i \) is marked as \( Typ_L(i) \). The corresponding relationship between the values is shown in Table 1.

| Typ_L | 1 | 2 | 3 | 4 | 5 |
|-------|---|---|---|---|---|
| Load  | Industrial | Agricultural | Commercial | Municipal | Residential |

Then the total number of the determined distribution network scenes is \( N_{acc} = n_i n_t \), and the time-series matrix \( S \), which is composed of the total number of scenarios, can be expressed as follows:

\[
S = \{(Typ_L(i), M_{DPV}(i))\}_{n_i \times n_t}
\]  

Among them, the value of \( M_{DPV}(i) \) indicates the flag that the \( i \)-th node is or not installed with DPV. The value of 0 indicates that the node is installed with DPV. Otherwise, the value of 1 indicates that the node has DPV installed.

3. Scenario reduction based on partitioning

3.1. Space Partition

The principle of cluster partition is that the cluster has strong internal connections and the cluster has weak external coupling. Under this principle, the cluster can achieve better autonomy. In the distribution network planning stage, in order to reduce the complexity of the model, this paper puts forward the principle of cluster partition that "the geographical and cultural environment in the cluster area are similar, and the external features are normalized in form." This principle can ensure that: (1) There are relatively consistent cultural and geographic characteristics within each partition of the distribution network, and thus form a relatively consistent distribution of meteorological characteristics and user electricity behavior is achieved, keeping the uncertainty of load and DPV as low as possible; (2) The characteristics of each area of the distribution network can be expressed uniformly, and its form stay constant with the change of the number of nodes in the distribution network, which avoids the analysis problem due to the expansion of the size of the distribution network.

3.2. Time Partition

Observing the timing characteristics of different loads and the DPV in Section II, it can be found that the timing characteristics of the hour level can be further simplified. The following uses the residential load shown in Figure 1 as an example. The fluctuation of the residential load is in line with the behavior habits of residents. It starts to rise at 6:00 a.m. and reaches a peak at about 8:00 a.m. and then drops to a valley at about 10:00 am. Similarly, the peaks of the electricity consumption at noon and evening occurred at 12:00 a.m. and 8:00 p.m. respectively. In addition, since the early morning is at rest time, load consumption is decreasing at about 4:00 a.m. Although the temperature and electricity need to be adjusted in winter and summer, the power consumption characteristics of this type of load have not been changed. Therefore, the residential load can be simplified into 4 characteristic periods, and the peak value is taken as the planning scenario. This is because during the planning process, the adaptability of the power distribution network under extreme scenarios is mainly considered. In general scenarios, the distribution network can use its own inertia and adjustment capabilities to offset fluctuations. Similarly, by analyzing the other four loads, it can be concluded that the characteristic periods of the daily curve are 6 periods of 4:00 a.m., 8:00 a.m., 12:00 p.m., 4:00 p.m., 8:00 p.m., and 10:00 p.m. According to the characteristics of the typical daily curve of photovoltaics, it can be known that such a time-division method can also reflect the output characteristics of DPV.
In addition, the fluctuation of DPV output and load within a year can be followed regularly. The typical weather (clear, rain, and overcast) in four seasons of the year were selected as the characteristic periods. Thereby, the number of time scenes in the year can be obtained after simplification: \( np = 6 \times 4 \times 3 = 72 \).

4. Simulation analysis

According to the work in this paper, the actual situation of a space-time partition scenario reduction technology in a certain place in Shandong Province is analyzed. Further, the annual DPV output data is applied to the IEEE 33-node power distribution system for comparative verification.

The power system topology is shown in Figure 3. It is assumed that the agriculture, commerce, and industry are located and sized well-balanced in the power grid. They are divided into three areas based on the zoning principle. For flexibility, it is assumed that DPV and capacitors can be installed on all nodes. In the DPV planning stage, the number of iterations is set to 150, and the crossover probability and mutation probability are adaptive. The annual maximum load loss hours and utilization hours are 3200 and 5000 respectively. The fine for carbon emissions is 9.75yuan/t, and the maximum allowable distributed power installation capacity is 20% of the total load.

After partitioning according to the correlation between time and space, the simplification effect in this example is shown in Table 2. The calculation time test uses the classic GA algorithm for DPV planning.

As can be seen from the table, it will take a lot of time to analyze the unreduced scenarios, which cannot be afforded by the grid manager. At the same time, the capacity of DPV will decrease due to too many scenarios considered, thus deviating from the principle of low-carbon power generation. By comparing the cluster reduction and space-time partition reduction methods, it can be seen that the analysis time of both is within an acceptable range, and this method of partition reduction can further simplify the complexity of the scenarios. The clustering method is reduced by more than 80%. From the perspective of economic cost, there is no big difference between the three methods. The maximum cost appears in the space-time partition method. Compared with the minimum cost, the difference is less than 1.1%, which is within the allowable range. The DPV capacity is: the cluster analysis method is the largest, followed by the space-time partitioning method, and the capacity without clustering is the smallest. This is because the cluster analysis blurs the extreme scenes, and has a certain tolerance for very few scenes that deviate from the normal operating range. The space-time partitioning has also simplified these scenarios, the difference is that the latter uses a large range of partitions to reduce uncertainty and has a lower tolerance for extreme scenarios.

In order to verify the effectiveness of the DPV capacity constraint, a comparison and analysis of the total capacity of the DPV configuration without the added DPV capacity constraint and the added constraint was performed at each iteration, as shown in Figure 4.

Observing Figure 4, it can be found from the individual analysis that the capacity of each iteration of the DPV changes greatly, the maximum capacity can reach close to 60kW, and the minimum capacity is less than 5kW. In fact, GA is a state of blind search in each iteration. Although the final result shows that the total capacity of DPV is about 50kW, it is still appropriate for GA to deviate from the optimal state during iteration. This may be one of the reasons why efficiency has not been improved. The comparative analysis shows that the DPV capacity tends to be conservative after the constraint, indicating that the addition of the constraint is effective. From the perspective of grid managers, economics is not the ultimate goal pursued, and it is sometimes more important to reasonably limit the appreciation of DPV capacity.

| Reduction Method       | Number of Scenary | Total Cost(CNY) | Size of DPV(kW) | Time Consuming(s) |
|------------------------|-------------------|-----------------|-----------------|-------------------|
| No Reduction           | 289080            | 5.252×10^6      | 397             | 838332            |
| Cluster Reduction      | 1584              | 5.271×10^6      | 417             | 4611              |
| Space-time partition   | 216               | 5.310×10^6      | 412             | 643               |
Figure 3. Zoning result

Figure 4. Loss of each branch after DPV planning
5. Conclution and Future Research

This paper establishes a time series model of load and DPV during the operation of the distribution network, analyzes the space-time distribution characteristics of DPV and load, and determines a method to reasonably partition based on this characteristic to reduce the planning scenario, and optimizes DPV by GA. The configuration adds constraints that can limit the capacity of DPV installations in order to meet the needs of grid managers. The simulation results prove that the scenario reduction method can greatly reduce the computing time cost under the premise of reasonable planning. In view of the rapid development of smart grids, the work in this paper still has room for further research, such as adding time series models of other DGs such as wind power and gas turbines, verifying the effect of scenario reduction in a larger-scale actual distribution network, and even considering social life.

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