Research on power exchange flexibility optimization of urban AC / DC distribution network

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Abstract. After large-scale access to distributed generation of new energy generation in urban AC / DC distribution network, its own randomness and uncertainty affect the supply-demand balance mechanism of distribution network. Therefore, this paper studies the power exchange flexibility optimization method of urban AC / DC distribution network to provide reference for the operation and scheduling of distribution network and main network. First, the active power exchange model of distribution network is established, the extreme value of power exchange of distribution network is obtained, and the flexible range of exchange power is calculated. Next, the flexibility evaluation index is established, and the operation characteristics of energy storage are transformed to complete the research on power exchange flexibility optimization of urban AC / DC distribution network. Through the actual example analysis, the results show that after the optimization of the design method, the net load curve is smoother, the effect of reducing the peak valley difference is more significant, and the overall curve is relatively smooth, which shows that the design method has certain effectiveness.

1. The first section in your paper

With the progress and development of society, energy crisis and environmental pollution have become the problems restricting the development of contemporary society. After many aspects of research and innovation, access to a large number of distributed generation based on new energy generation in urban distribution network has become an effective solution. However, the following questions can not be ignored. With the increase of distributed generation access, its own randomness and uncertainty affect the normal power supply operation of distribution network, increasing the risk factors of power grid. In order to maintain the balance between supply and demand of distribution network, it not only meets the development trend of future distribution network, but also ensures the basic requirements of system operation reliability. It is necessary to make the active distribution network with strong observability and controllability. The operation mode of AC / DC hybrid distribution network also needs to be more flexible and reliable [1]. After the large-scale access of distributed generation based on new energy generation, it can effectively reduce the power in the network transmission, but its own negative impact can not be ignored. Therefore, this paper studies the power exchange flexibility
method of urban AC / DC distribution network, which provides a reference for the operation and scheduling of distribution network and main network.

2. Research on power exchange flexibility optimization of urban AC/DC distribution network

2.1. Establishment of power exchange model

The operation process of urban AC / DC distribution network is mainly to receive the electric energy delivered by the main grid side substation, and complete the power transmission through a series of related power facilities in the distribution network. Therefore, the electric energy carried in the network is distributed to all power users driven by the distribution network [2-3]. The optimization of exchange power flexibility between distribution network and main network mainly refers to changing the flexible adjustment range of active power between distribution network and main network, as shown in Figure 1.

![Figure 1: Schematic diagram of switching power flexibility](image)

In the urban AC / DC distribution network, the number of substations is relatively large in general. In these substations, when one of the substations is less flexible in the process of power exchange, there will be a power shortage of substation transmission, which will further cause the imbalance of supply and demand of the distribution network as a whole. A series of measures can be taken to realize the balance and transmission of power load between multiple substations [4-5]. In the AC / DC hybrid distribution network, AC and DC are connected through voltage source converter. The AC distribution network needs to maintain a radial shape to ensure its safe and stable operation. Compared with AC distribution network, DC distribution network is more flexible and reliable during operation [6-7].

In order to find out the flexible range of the exchange power between the AC / DC hybrid distribution network and the main network, two extreme values of the feasible exchange power between the main network of the distribution network can be obtained.

$$\begin{align*}
\max_{i \in N_{sub,v}} \sum_{i} P_{sub,i} - \Phi_{1} \sum_{j \in L} I_{ij}^{2} r_{ij} \\
\min_{i \in N_{sub,v}} \sum_{i} P_{sub,i} + \Phi_{2} \sum_{j \in L} I_{ij}^{2} r_{ij}
\end{align*}$$

(1)
In the above formula, $N_{sub,n}$ represents all the substation nodes contained in the urban AC / DC distribution network lines. $L$ represents the collection of all the effective transmission lines in the distribution network. $P_{sub,i}$ represents the value of all active power injected into the substation node. $r_{ij}$ represents the resistance present in the line ij. $I_{ij}$ represents current flowing through line ij. $\Phi_1$ and $\Phi_2$ respectively represent the weight coefficient, the value of which determines the accuracy of the second-order cone relaxation. In the actual operation process, the actual loss of the network should not be too large.

2.2. Evaluation of AC / DC flexibility

Due to a large number of renewable energy access, some energy storage devices are also in large-scale application, and they can coordinate with each other to balance. In the process of flexible index evaluation, flexible scheduling resources must take into account the economy and system flexibility, so as to achieve the flexible balance of supply and demand [8-9]. In the urban AC / DC distribution network, flexibility is required in large-scale distributed generation and system load, and the changes of the net load composed of them on a fixed time scale are as follows.

\[
flexR_t = NL_{t+1} - NL_t, t = 1, ..., T
\]  

(2)

In the above formula, $flexR_t$ represents the flexibility requirement of urban AC / DC distribution network system at the time of $t$. $NL_t$ represents the net load at the same time. $T$ represents the number of time periods divided according to certain rules. In order to complete the flexibility evaluation, the supply-demand balance of flexibility needs to be considered. Therefore, a series of evaluation indicators need to be established [10]. Two time-varying indicators are selected to evaluate the volatility of the system supporting uncertainty, that is, the flexibility of time and direction. The real-time flexibility demand rate and the real-time flexibility demand permission rate mainly represent the strength of the flexibility demand and the ability to respond to the flexibility demand.

When flexibility resources are unreasonably allocated, there is often a high instantaneous shortage in the operation process. The relationship between flexibility and vacancy time cannot be reflected in the non-optimized flexibility expectation index.

3. Example analysis

In order to verify the effectiveness of the proposed power exchange flexibility optimization method of urban AC / DC distribution network, corresponding examples need to be selected for verification.

3.1. Example description

The widely used wind power prediction error probability model is selected to fit the error in a certain direction. In order to verify the flexibility optimization method, the advantage of kernel density estimation can be used to compare and analyze the fitting results of normal distribution. The output load probability prediction of a small wind farm in a distribution network is selected as the analysis object, and the topology structure of the distribution network is refined.

The modification results of load parameters are as Table 1:
Table 1 Revised system load parameters

| Node number | Type | Active power | Reactive power | Node number | Type | Active power | Reactive power |
|-------------|------|--------------|----------------|-------------|------|--------------|----------------|
| 1           | 3    | 0            | 0              | 2           | 3    | 0.42         | 0.02           |
| 3           | 3    | 0.1          | 0.06           | 4           | 2    | 0.06         | 0.02           |
| 5           | 3    | 0.06         | 0.04           | 6           | 3    | 0.28         | 0.03           |
| 7           | 3    | 0.2          | 0.06           | 8           | 3    | 0.09         | 0.025          |
| 9           | 3    | 0.04         | 0.08           | 10          | 3    | 0.1          | 0.025          |
| 11          | 3    | 0.15         | 0.03           | 12          | 3    | 0.08         | 0.03           |
| 13          | 2    | 0.25         | 0.02           | 14          | 3    | 0.09         | 0.2            |
| 15          | 3    | 0.09         | 0.1            | 16          | 3    | 0.35         | 0.2            |
| 17          | 3    | 0.14         | 0.1            | 18          | 3    | 0.06         | 0.07           |
| 19          | 3    | 0.35         | 0.02           | 20          | 3    | 0.12         | 0.06           |
| 21          | 3    | 0.06         | 0.03           | 22          | 1    | 0.1          | 0.04           |
| 23          | 3    | 0.12         | 0.025          | 24          | 3    | 0.06         | 0.04           |
| 25          | 1    | 0.06         | 0.15           | 26          | 3    | 0.06         | 0.07           |
| 27          | 3    | 0.045        | 0.35           | 28          | 3    | 0.42         | 0.06           |
| 29          | 2    | 0.06         | 0.07           | 30          | 3    | 0.12         | 0.035          |
| 31          | 3    | 0.12         | 0.06           | 32          | 3    | 0.06         | 0.03           |
| 33          | 1    | 0.08         | -              | -           | -    | -            | -              |

Most of the above-mentioned nodes are residential load, while a small part are industrial load and office load. In the AC network based on the above conditions, it can be seen from the figure that one of the branch 9-10 is connected to OLTC, that is, on load tap changer. The regulation range is 0.95-1.05p.u., and the step size is 0.005p.u. In the flexible economic dispatch model of this paper, the time-of-use power price is adopted to purchase electricity from the superior power grid. The electricity price is 0.89 yuan / kwꞏh in the peak period of 11:00-15:00 and 18:00-21:00. The electricity price is 0.49 yuan / kwꞏh in 7:00-11:00, 15:00-18:00 and 21:00-00:00. And the electricity price is 0.25 yuan / kwꞏh in the valley period of 00:00-7:00. Under the above-mentioned case conditions, the power exchange flexibility optimization method of urban AC / DC distribution network designed in this paper is used for scheduling, and the results are analyzed.

3.2. Experimental results and analysis
Under the above example conditions, the optimal output of flexible resources before and after optimization is shown in Figure 2.
Figure 2 Output of flexible resources before and after optimization

In the above Figure, Figure (1) shows the output of flexible resources before optimization, and Figure (2) shows the result after optimization. It can be seen from the above figure that interruptible load acts at peak load. Energy storage is discharged at peak load and charged at low load. Flexible resources can cut peak load and fill valley significantly. After optimizing the dispatch flexibility resources, it can be seen that the fluctuation of each load curve is improved and the peak valley difference is reduced. In particular, the peaks of 9:00-11:00 and 20:00-23:00 and the troughs from 11:00 to 15:00 are significantly compensated. After optimization, the net load curve is smoother, the effect of reducing peak valley difference is more significant, and the overall curve is relatively smooth, which shows that the method designed in this paper has certain effectiveness.

4. Conclusion

With the development and rise of urban AC / DC distribution network, the research on the practical application of urban AC / DC distribution network in related fields such as power electronics technology is gradually in-depth. In the current distribution network, more distributed generation based on new energy is connected, and the power exchange flexibility adjustment method of AC / DC distribution network is proposed. This paper mainly considers the steady-state operation of AC / DC distribution network, taking into account the uncertainty of distributed generation and the flexible operation of distribution network. The research work of this paper is verified by actual example analysis. The results show that after using the flexible optimization method, the load curve of the
example becomes smoother than before. However, due to the limited level and research time, there are still some defects in this paper, which need to be improved in the future research.

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