Regional Coordination Control of Active Distribution Network Based on Bidding Mechanism

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ABSTRACT

In order to improve the control effect and performance of the active distribution network (ADN), based on the control theory of the ADN feeder control error (FCE), the regional coordination control of ADN based on bidding mechanism is proposed. Firstly, the regional coordination autonomy mode of ADN is introduced. The autonomous regions balance the power fluctuations according to the power coordination coefficient issued, and realize the ADN operation in a better state. Then, by adjusting the coordination coefficient in the FCE control equation, the proportion of power fluctuations in different regions is changed. By selecting the "price factor", "deviation tolerance factor" and "optimal distance factor" three bidders in line with the optimization direction, the optimal sharing of real-time power fluctuations in the ADN is realized. At last, a numerical example is given to verify the validity of the control method in this paper.

Key words: active distribution network, feeder control error, power coordination coefficient, bidding factor

I. Introduction

Active distribution network (ADN) is a distribution network with capabilities to combine and control various distributed energy (DER, controllable load, ESSs, demand side management, etc.). One of its characteristics is the control center that realizes coordinated control, which can increase the capacity of the distribution network to accept renewable energy (RE) [1,2]. ADN can be divided into two aspects to absorb the intermittent energy, first, global optimization, to improve the system economy, second, real-time control, to suppress the deviation from the global optimal operating point of ADN operation state caused by intermittent energy real-time fluctuations [3].

[4] proposes the hierarchical distribution control strategy of ADN, which divides the distribution network into three layers, the upper layer is the global optimization of the main station, the middle layer partitions the feeder and performs distributed control, the bottom layer is the local control. This paper mainly studies the control method of the middle layer. In order to represent the difference between the actual operating state in the distribution network and the optimal operating state calculated by the optimization calculation, [5] presents the Feeder Control Error (FCE), and regional coordination control method is produced on this basis. In [6], an optimal scheduling model considering the ADN and DG characteristics is proposed, taking the lowest running cost in a complete scheduling 1period as objective function.

Ancillary service is an important support means to ensure the safety and stable operation of power system, with the large-scale access of distributed energy, the demand for ancillary service is further increased, and the bidding mechanism is a common form to obtain ancillary service [7,8]. In [9], from the perspective of power regulators, the bidding mechanism of franchise right of distribution service in a region is designed to improve the efficiency of power regulators. [10] aims at the power market environment, a multi-objective standby bidding model considering economy, reliability and emission factors is developed. On this basis, a 2-stage solution algorithm is proposed.

In this paper, the bidding mechanism is applied to the regional coordination control of ADN. Based on the FCE, the regional coordination autonomy model of ADN is proposed to realize the ADN running in a better state. On this basis, by modifying the coordination coefficient in the FCE control equation to change the sharing ratio of power fluctuation in different regions. Through the establishment of multi-bidding factor mechanism, the optimal sharing of real-time power fluctuation of ADN is realized, and the simulation of the example is carried out, and the control effect before optimization is compared and analyzed.

II. Regional coordination control mode of ADN

The autonomous areas of ADN is shown in Fig.1. It refers to the minimum control range that can be independently coordinated and controlled between the two global optimizations of the main station according to the actual situation of the power grid [11].

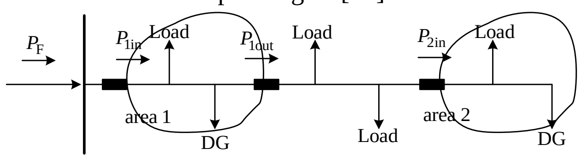

Fig.1 Autonomous Areas of ADN

Based on FCE, the control objective function of area i is expressed as

$$P_{FCE,i} = k_i \times \Delta P_F - \Delta P_{area\text{-}i} = 0 \quad (1)$$

where $P_{FCE,i}$ is the FCE indicator of area i, k_i is the power

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coordination coefficient of area i, ΔP_F is the deviation between the actual exchange power of the feeder and its optimized target value, $\Delta P_F = P_F - P_F^{opt}$, $\Delta P_{area\text{-}i}$ is the deviation between the actual value of the exchanged power of the autonomous region i and its optimization target value, $\Delta P_{area\text{-}i} = P_{area\text{-}i} - P_{area\text{-}i}^{opt}$, $P_{area\text{-}i}$ is set positive outflow and negative inflow, so the area can be equivalent to a DG. k_i, P_F^{opt} and $P_{area\text{-}i}^{opt}$ are control parameters [11] and target values obtained by global optimization algorithm calculation.

The proposal of FCE quantifies the actual working state of the autonomous region and its ability to bear the fluctuations of the power grid. Assuming that at some point, the exchange power of the feeder and the region are the same as the global optimization target values, then P_{FCE}=0; when the exchange power of the feeder and the region are reduced, P_{FCE}<0, and at this point, the energy storage in the area will reduce its output power to adjust the P_{FCE} to 0; on the contrary, when the exchange power of the feeder and the region increase, P_{FCE}>0, and at this point, the energy storage in the area will increase its output power to adjust the P_{FCE} to 0. The control goal in the area is to guarantee P_{FCE}=0 in real time, by adjusting P_{FCE} to control DGs and energy storage devices in coordination in the area, making the actual operation state of the power grid closer to global optimization.

III. Analysis of FCE regional control operation

When the FCE control is in the regional coordination autonomy mode, the intra-area fluctuation will be adjusted by the controllable DGs and energy storage in the control area, so that the regional exchange power remains unchanged. For external power fluctuation, the fluctuation is borne by the feeder outlet (external grid) and all areas on the feeder, and the proportion is:

$$\Delta P_F = \Delta P / (1 + \sum_{i \in N} k_i) \tag{2}$$

$$\Delta P_{area\text{-}k} = -\frac{k_k \cdot \Delta P}{1 + \sum_{i \in N} k_i} \quad (k \in N) \tag{3}$$

When the DG output of a certain area reaches the limit, or the state of energy storage exceeds the limit and the fluctuation cannot be adjusted, this part of the fluctuation will be converted into the fluctuation of the out-of-area, and it is shared by the remaining areas and the feeder outlet still in accordance with the pre-formula ratio.

The types of the load and intermittent energy included in each area of the ADN may be different, and their characteristics may vary. According to the FCE regional control principle, this may cause different trends in the operating states of the controllable DGs on the feeder. However, in the hierarchical partition control method of ADN, the global optimization period for the DG and the energy storage output control is 15 minutes, but due to the regional FCE control, the actual output of DG and energy storage is biased relative to the planned value in these 15 minutes. Based on the deviation between the current DG, energy storage output and the output plan curve value set by the global operational decision system, the DG is divided into three operating states:

1) optimization state S_0, the current DG output as the planned curve value;

2) forward deviation state S_+, the current DG output is greater than the planned curve value;

3) negative deviation state S_-, the current DG output is less than the planned curve value.

Take the feeder example shown in Fig.2. It is assumed that the ESS in the area 1 and 2 belong to the forward deviation state S_+, the MT in the area 3 belongs to the negative deviation state S_-, and the ESS in the area 4 belongs to the optimization state S_0.

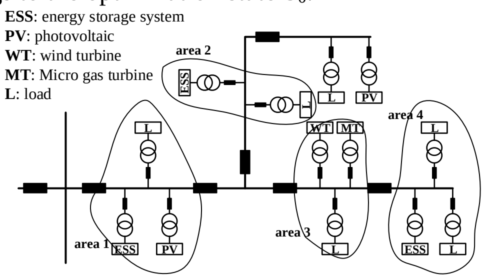
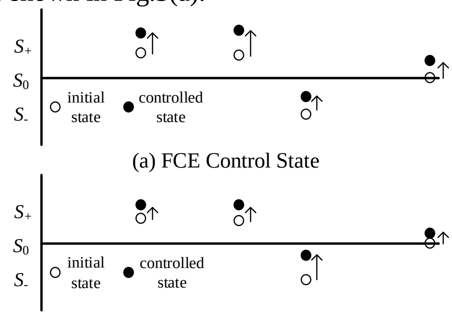


Fig.2 Example of Regional Control

The states of each controllable DG in Fig.2 can be represented by the open circles in Fig.3. If an out-of-region fluctuation occurs ΔP>0, DGs in area 1-4 will shift to the forward state, ESS gradually deviate from its own plan curve as shown in Fig.3(a).



(a) FCE Control State

(b) Optimization State

Fig.3 Comparison of FCE Control Effect and Optimization Effect

If the k_i of area 1, 2 and 4 is reduced at this time, and the k_i of area 3 is increased, the fluctuation adjustment caused by the ΔP will be mainly undertaken by area 3, as shown in Fig.3(b). The MT in area 3 is closer to the planned curve value, and the deviation of the ESS from the planned curve in other regions is also slowed down.

The operating state of ADN is approximated regarded as a fluctuation state composed of the global optimal operating state and the deviation from the global optimal state. For the data of the global optimal operating state, the current DG and energy storage output are the most reasonable and optimized values, and no further optimization is needed. For the fluctuation state, the FCE regional control described in the foregoing, sharing these fluctuation values at a fixed ratio, is obviously not optimal, so we put forward the regional coordination method based on bidding mechanism.

IV. Application of bidding mechanism in regional control of ADN

Through the reasonable setting of the coordination coefficient and the distribution coefficient of each region, the ADN can realize the optimal state in the assumption of the real-time fluctuations on the basis of the global optimization results. In the case of multi-regional participation in bidding, it is necessary to measure the bidding data provided by each region and select bidders who meet the optimization direction. In this paper, 3 factors affecting the optimization direction are selected.

1) price factor *c*

The price factor indicates the cost of power fluctuation of different types of DGs in each region, and its value is mainly based on the power generation costs of various types of DGs and grids. When the output needs to be reduced, the DG with higher price factor should be reduced first. The range is [0, 1].

2) deviation tolerance factor *e*

The deviation tolerance factor describes the degree of which DG's subsequent operation is affected by the current state, and the energy storage system output is affected by the SOC state, so the deviation tolerance factor is relatively low, while the deviation tolerance factor of MT is relatively high.

3) optimal distance factor ω

The optimal distance factor is to evaluate the deviation between the running state and the planned curve of DG, and the greater the difference between the DG real-time output and the global operating decision system setting target value, the larger the optimal distance factor.

$$\omega_{i,\mathrm{t}} = \frac{P_{i,\mathrm{t}} - P_{i,\mathrm{T}}^{\mathrm{opt}}}{P_{i,\mathrm{DG}}} \tag{4}$$

Where $P_{i,\mathrm{t}}$ is the output of the *i*-th DG at time t, $P_{i,\mathrm{T}}^{\mathrm{opt}}$ is the target output of the *i*-th DG in period T, $P_{i,\mathrm{DG}}$ is the installed capacity of the *i*-th DG.

Each region will provide the above three factors when bidding for power deviation. Global optimization will give evaluation weight a_1-a_3 of these three factors in each optimization period, for three factors can be considered in a comprehensive way:

$$y = \begin{cases} a_1(1-c) + a_2 e - a_3\omega, & \Delta P > 0 \\ a_1 c + a_2 e + a_3\omega, & \Delta P < 0 \end{cases} \tag{5}$$

where ΔP represents the power fluctuation value, $a_1 + a_2 + a_3 = 1$. Different weights can achieve different emphasis. When a_1 is larger, the cost factor is mainly considered in deviation suppression of the ADN. When a_2 is larger, the DG type with the least influence by the power fluctuation is more inclined.

In order to reduce the communication pressure of the system and utilize the existing channels between the main station and the coordinated interaction controller, this paper adopts the communication mechanism based on the blackboard system. As the "blackboard", the main station opens up the storage area to provide information interaction medium between hierarchical distributed controllers. Each coordinated interaction controller serves as a "knowledge source" and provides its own bidding information. The coordinated interaction controller will combine the information listed in the "blackboard" with its own state to dynamically adjust the regional coordination coefficient. The region serves as a knowledge source to provide various factors of the DG in the region and related data, in which the feeder outlet (representing the external grid) will be the bidding participant of the fixed factor value, and the global operation decision system will form the control strategy based on all the bidding information, and modifies the coordination coefficient of the coordinated interaction controller. The detailed algorithm flow is shown in Fig.4.

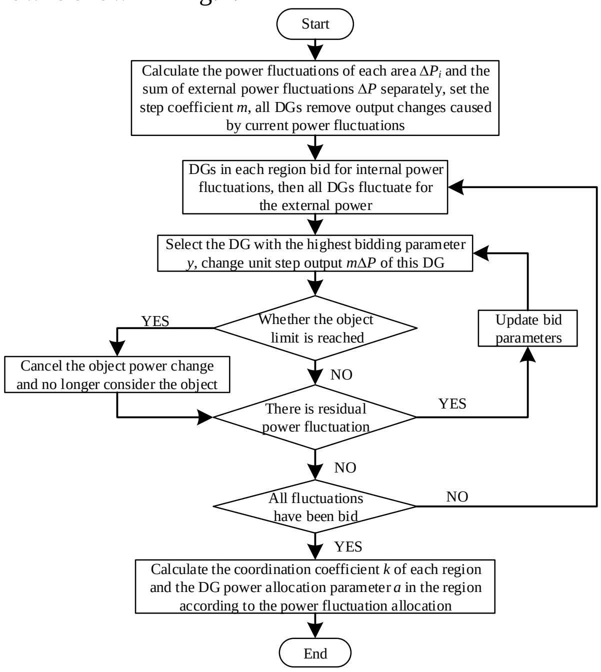


Fig.4 Bidding flow chart

V. Numerical examples

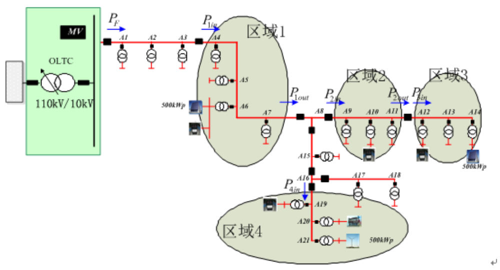


Fig.5 Topology Connection of the Example

The topology connection of the example is shown in Fig. 5. According to the principle of zoning, it is divided into four regions, and the external grid is equivalent to an infinite power supply. The control strategy is simulated by DIgSILENT.

The global operation decision system takes 24 hours as a complete optimization scheduling cycle with a scheduling interval of 15 minutes and a total of 96 optimization periods throughout the day. In order to prove the effectiveness of the ADN regional coordination control strategy, this paper selects a time period for specific analysis. The other types of DG and energy storage configuration in the region are shown in Table 1. During this period, the DG output plan, feeder outlet power, each region exchange power target value and the power coordination coefficient are shown in Table 2.

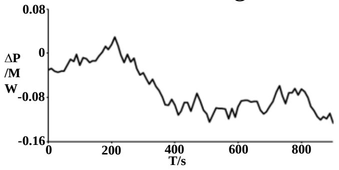
Table 1 Configuration of DG and ESS

Type	Connection Node	Capacity	Type	Connection Node	Capacity
ESS1	A6	250kWh	MT	A20	300kW
ESS2	A10	250kWh	PV1	A6	500kW
ESS3	A12	250kWh	PV2	A14	500kW
ESS4	A19	250kWh	WT	A21	500*2kW

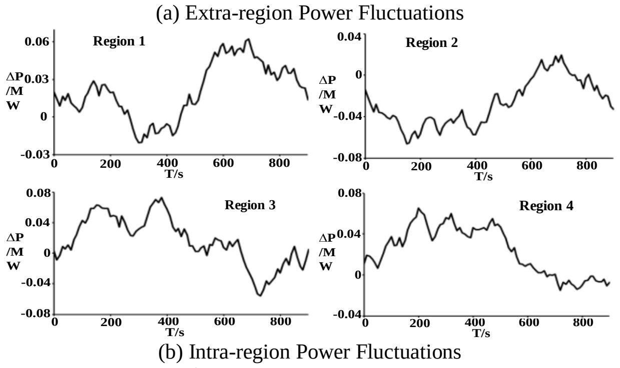
Table 2 Global Optimization Target Value

Object	Target Value/ MW	Coordination Coefficient	Object	Target Value/ MW	Coordination Coefficient
Substation Bus	0.510	\	ESS1	0.097	\
Region 1	0.111	0.253	ESS2	0.065	\
Region 2	0.212	0.249	ESS3	0.129	\
Region 3	0.217	0.249	ESS4	0.021	\
Region 4	-0.638	0.249	MT	0.2	\

The power fluctuations generated by the objects outside the four regions in the example are identified as external power fluctuations, and the total power fluctuations within and outside the region relative to the predicted values are as shown in Fig.6.



(a) Extra-region Power Fluctuations



(b) Intra-region Power Fluctuations

Fig.6 Diagram of Intra- and Extra-region Power Fluctuations

The evaluation factors for various types of DG are shown in Table 3, while the optimal distance factor is calculated according to the real-time DG output and the planned output.

Table 3 Reference Value of DG Factors

Object	Price Factor	Deviation Tolerance Factor
ESS	0.3	0.3
MT	0.6	0.7
Feeder Outlet (External Grid)	0.5	0.9

Taking cost as the primary factor for simulation analysis, and the evaluation weights are: a_1=0.6，a_2=0.2，a_3=0.2. The results are shown in Fig. 7.

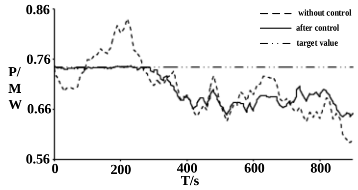


Fig.7 Comparison of Feeder Outlet Power

The solid line after control is closer to the target value of the period than the uncontrolled dotted line. Most of the fluctuations of the first 300s are borne by other DGs. The feeder outlet power and the target value coincide. After 300s, the external grid gradually bears power fluctuations outside the region, which makes feeder outlet power deviate from the planned value. The exchange power fluctuations in four regions have also been reduced to different degrees, and are closer to the global target value.

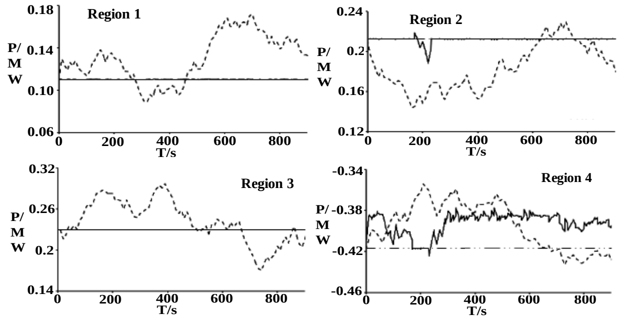


Fig.8 Comparison of Region Exchange Power

The comparison of the four regions' exchange power before and after optimization is shown in Fig.8. Region 1 and Region 3 do not bear the fluctuations outside the region. Therefore, the exchange power after optimization is exactly the same as the global optimization target value. Region 2 and Region 4 bear some fluctuations outside the region, so there's still deviation from the global optimization target after optimization, but the power deviation is reduced compared to the uncontrolled result.

1) Bidding results for power fluctuations in the region

In this example, there are 4 regions, of which Region 4 contains 1 MT and 1 ESS, bid for power fluctuations in the Region 4. The bidding result is shown in Fig.9. Within 15 minutes, the forward power fluctuations occurring in the region are borne by ESS4, while the negative power fluctuations are all borne by MT. The main reason for this phenomenon is that the forward power fluctuation needs to increase the DG output to keep the Region 4 exchange power unchanged. At this time, the evaluation weight takes the price factor as key, and the weight of the deviation tolerance factor is low, so that the ESS bears the forward power fluctuations. For negative power fluctuations, it is necessary to reduce the DG output, while the MT price factor is higher, the output saving cost is more, and the MT's deviation tolerance factor is also higher than the ESS, so this part of the negative power fluctuation is completely borne by MT.

2) Bidding results for power fluctuations outside the region

After each region completes the bidding for power fluctuations in the region, the bidding results for power fluctuations outside the region are shown in Fig.9. Under the evaluation weight of this group, the power fluctuations outside the region is mainly borne by the MT and the external grid. This is mainly because the external fluctuations are mainly negative fluctuations, while the evaluation weight is biased towards the price factor. The price factor of MT and the external grid are higher, and bear the negative fluctuations saves more. The forward power fluctuations outside the region is borne by ESS2, because the power fluctuations in Region 2 is negative during this period, so that the optimal distance factor is larger when ESS2 bids for power fluctuations outside the region, thus ESS2 bears the power fluctuation of the segment, and the deviation between its own output and the planned curve decreases.

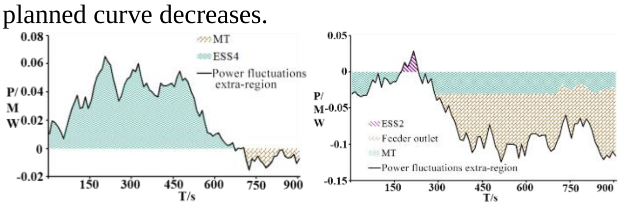


Fig.9 Bidding Result Intra- and Extra-region

Under different evaluation weights, all kinds of DGs will obtain different power fluctuation shares due to their own different evaluation factors. When the evaluation weight is set to a_1=0.1, a_2=0.1, a_3=0.8, the optimal distance factor will be the priority. In this case, the bidding results for power fluctuations intra- and extra-region are shown in Fig.10.

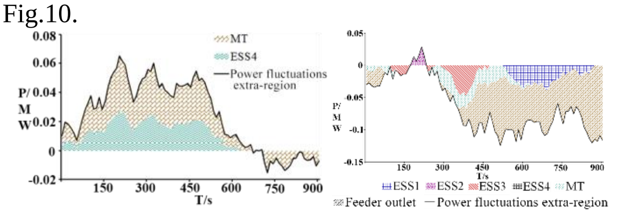


Fig.10 Bidding Result Intra- and Extra-region when the Optimal Distance Factor as the Priority

VI. Conclusion

Based on the regional coordination control mode of ADN, this paper proposes a regional coordination control method for ADN based on bidding mechanism. The regional coordination control mode coordinates the DGs and energy storage devices in the control region by the size of the P_{FCE}, so that the actual operating state of the power grid is closer to the global optimization target, but it is difficult to achieve optimal tracking of real-time power fluctuations. Through the establishment of multi-bidding factor mechanism, regard the region and feeder outlet (external grid) as bidders, so as to modify the coordination coefficient in the FCE control equation and change the sharing proportion of power fluctuations in different regions. The global operation decision system and coordinated interaction controller conduct the real-time interaction of the bidding parameters, which enables the ADN to be in an optimal state on the assumption of real-time fluctuations based on the global optimization results. The simulation analysis of the example shows that this method has good control performance and effect on the power fluctuations of the ADN. The selection principle of the bidding factors will continue to be studied in the future to improve the control system.

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