Research on Optimization of independent microgrid based on flexible interconnection technology

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Abstract. In order to solve the problem of interconnected operation control between different independent microgrids, a flexible interconnection method based on bidirectional AC / DC converter is used to connect the independent microgrids. Each microgrid and the AC side of the connected converter form a separate control area. The branch power flow model is adopted in the internal network of the area to optimize the photovoltaic unit, energy storage system, diesel generator unit and other equipment. The active power of the boundary of the adjacent area is coordinated and controlled by the distributed optimization algorithm based on the alternating direction multiplier method. Under normal working conditions, the coordination and complementarity of the devices in the micro grid can be realized through the flexible interconnection device, which can improve the system operation economy; under the condition of equipment failure, based on the flexible control and power support ability of the flexible interconnection device, the power outage range of the fault micro grid can be reduced. Finally, a simulation case is used to verify the effectiveness of the above methods under different operating conditions.

1. Introduction
Micro grid (mg) with high proportion of Distributed Renewable Energy and energy storage system has become one of the important ways of power supply in remote areas [1]. Due to the randomness of renewable energy output and the fluctuation of user load, the reliability of single independent micro grid power supply is low and the cost of power supply is high. If the independent microgrid with close distance is interconnected for operation [2], it can realize the resource complementarity between different microgrids, ensure the consumption of renewable energy in microgrid, increase the reserve capacity of microgrid, and improve the safety and reliability of the overall power supply system operation [3].

The optimal scheduling of interconnected microgrid is an important means to ensure the overall operation economy, which is usually realized by centralized control architecture [4]. However, the scheduling algorithm based on centralized communication may have the following problems in practical application: 1) dimension disaster caused by the large amount of communication and calculation of
central controller; 2) large communication cost investment; 3) insufficient ability to deal with single point failure of communication system, which shows the weak robustness of physical information system [5]. In contrast, the distributed optimization algorithm does not need global information. Each microgrid only needs data interaction with the connected microgrid, and realizes global optimal scheduling through the interaction of boundary information between them. The communication burden of the system is light, and the robustness and adaptability are strong, [6] so it has been widely concerned and developed.

In this paper, the optimal scheduling method of independent micro grid based on flexible interconnection is studied, and the optimal model of interconnected micro grid including flexible interconnection device is established. Each microgrid constitutes a control area, and the internal network of microgrid optimizes the power of photovoltaic unit, diesel generator set, controllable load and other equipment in each optimal power flow calculation process. Based on the alternating direction multiplier method, the coordination of resources in different microgrids can be realized, and finally the global optimal scheduling and reliable economic operation of the system can be realized.

2. Coordinated control of microgrid based on flexible interconnection

The DC side of the flexible interconnection device is used as the boundary to partition the interconnected microgrid, that is, the AC side of each independent microgrid plus the connected flexible interconnection device is a control area, as shown in Figure 1.

Only the consistency constraint of active power balance as shown in equation (1) is required between different regions, so the exchange variable between regions is only the boundary active power. Equation (2) can be rewritten as

Where $P_{\text{link}}$ is the global value of active power at both ends of the flexible interconnection device.

$$P_m^{\text{link}} + P_m^{\text{link,loss}} = P_n^{\text{link}}, \quad P_n^{\text{link}} + P_n^{\text{link,loss}} = -P_n^{\text{link}} \quad (1)$$

In this paper, ADMM is used to realize the distributed coordination optimization among regions. For the flexible interconnected microgrid system shown in Figure 1, take MG1 as an example, $\lambda$ represent the Lagrange multiplier of the region boundary active power consistency constraint, and $\rho$ is a represent the penalty factor, then the augmented Lagrange function of formula (2) can be expressed as

$$L_{MG1}^{\text{ADMM}} = f_{MG1} + \frac{\rho}{2}(P_m^{\text{link}} + P_m^{\text{link,loss}} - P_n^{\text{link}})^2 + \lambda^P(P_m^{\text{link}} + P_m^{\text{link,loss}} - P_n^{\text{link}}) \quad (2)$$

Each independent micro grid carries out independent and parallel optimization according to the internal resources of the micro grid, obtains the optimal solution of the output power of photovoltaic unit and diesel unit, as well as the active power of the area boundary, exchanges the active power information of the area boundary with the adjacent micro grid connected by the flexible interconnection device, and then updates the global value of the area boundary data as shown in formula (3).

$$P^{\text{link}}(K+1) = \left[ P_m^{\text{link}}(k+1) + P_m^{\text{link,loss}}(k+1) - P_n^{\text{link}}(k+1) + P_n^{\text{link,loss}}(k+1) \right] / 2 \quad (3)$$

After the global value of active power on both sides of the flexible interconnection device is obtained, the original residual and dual residual of ADMM can be calculated, and the expression is
\[ r_{1}^{k+1} = \left| P_{\text{link}}^{(k+1)} - P_{m}^{\text{link}(k+1)} - P_{m}^{\text{link,loss}(k+1)} \right| \]  
(4)

\[ s_{1}^{k+1} = \left| P_{\text{link}}^{(K+1)} - P_{\text{link}}^{(K)} \right| \]  
(5)

In the formula, \( r_{1}^{k+1} \) and \( s_{1}^{k+1} \) represent the original and dual residuals of the \( k+1 \) iteration of a respectively, \( k \geq 0 \).

After that, based on the active power information of the region boundary, each region updates the Langerhans multipliers of the region boundary data according to equation (6), i.e.

\[ \lambda^{P(k+1)} = \lambda^{P(k)} + \rho \left( P_{\text{link}}^{(k+1)} - P_{m}^{\text{link}(k+1)} - P_{m}^{\text{link,loss}(k+1)} \right) \]  
(6)

The detailed process of distributed coordination and optimization of flexible interconnected microgrid is as follows:

1) Initialization. Taking the measured data of microgrid operation as the initial value of global variable, \( P_{\text{link}}^{(0)} \) is obtained, and the initial Varangian multiplier is 0, \( k = 0 \).

2) Microgrid autonomy optimization. MG1 and MG2 respectively solve their optimization models, and get decision variables and interaction variables. Thereafter, the area coordination controller 1 sends the virtual active loads \( P_{m}^{\text{link}(k+1)} \) and \( P_{m}^{\text{link,lost}(k+1)} \) to the area coordination controller 2, and receives the area transmission active power \( P_{n}^{\text{link}(k+1)} \) and \( P_{n}^{\text{link,lost}(k+1)} \) sent by the latter at the same time.

3) Global variables and Lagrange multipliers update. Each area controller updates the global variable of the area transmission active power according to equation (5). Then, the corresponding Lagrange multipliers are updated according to equation (6).

4) Residual updating and iteration termination judgment. According to equation 6), the original residual \( r_{1}^{k+1} \) and \( r_{2}^{k+1} \) dual residual \( s_{1}^{k+1} \) \( s_{2}^{k+1} \) of the MG1 and MG2 optimization problems are calculated respectively, and each residual A is sent to the adjacent microgrid area controller. If the infinite norm of the global residual is less than the given convergence threshold, the iteration is stopped and the optimal solution is obtained. Otherwise, let \( k = k + 1 \) and return to step 2).

3. Experiment
In order to verify the effectiveness of the above optimal scheduling method for flexible interconnected microgrid system, the interconnected microgrid is selected as shown in Figure 1. The two independent microgrids are all IEEE 33 node networks, with photovoltaic units, diesel generator sets and energy storage devices installed at different nodes.

The access node of the energy storage device is that node 1 is the balance node. In the interconnection device, the AC / DC at MG2 side adopts the \( V_{d}Q \) control strategy to ensure the DC bus voltage is constant; the AC / DC at MG1 side adopts the PQ control strategy to optimize the active and reactive power output according to the demand.
Select a typical day for scheduling simulation. The load demand and photovoltaic output are shown in Figure 2. The left figure shows the simulation results of MG1, and the right figure shows the simulation results of MG2. The system parameter settings are shown in Table 1. The cost coefficient of photovoltaic unit and energy storage system is converted from the installation cost; the cost coefficient of diesel generator set is approximate with the experimental quadratic curve.
Table 1. Parameter setting of system equipment

| equipment               | (Power range/kW)/(capacity/kVA) | Cost coefficient |
|-------------------------|----------------------------------|------------------|
| PV abatement            | 0~800/800                        | 1.0              |
| DEG                     | 30~540/600                       | 4e-4/0.8/300     |
| Energy storage device   | 0~300/1000                       | 0.5              |
| Flexible interconnection device | 0~500/500                      | 0.014            |

In order to ensure that the diesel generator has a certain reserve in operation, the maximum output power is set as 90% of the rated capacity; the cost coefficient of the flexible interconnection device is selected as the empirical value, and the load cutting cost coefficient is set as 2.0 yuan/kW.

The scheduling results are shown in Figure 3-5 and. Figure 3 shows the transmission power of the flexible interconnection device, figure 4 shows the output of each equipment of the system, Figure 5 shows an example of the residual convergence process, and table 2 shows the total operating cost of the system.

Figure 3. Transmission power of the flexible interconnection device

Figure 4. Active/reactive power output of each devices
In Figure 3, the upper and lower two small figures are the active power and reactive power transmitted by the flexible interconnection device. When the active power is timing, it means the output power from Mg2 to MG1, and when the reactive power is timing, it means the output reactive power. Due to conversion loss, there is active power difference between two sides of the flexible interconnection device. Both sides of the device are used as reactive power sources to provide reactive power support to the system.

In Figure 4, the upper two subgraphs respectively represent the diesel engine output in MG1 and Mg2; the lower two subgraphs respectively represent the reactive output and photovoltaic reactive output of the system diesel engine. It can be seen that the output of diesel unit is basically complementary to photovoltaic output to meet the load demand.

In Figure 5, the left and right graphs show the changes of the original and dual residuals during the 16 h and 19 h optimization iterations, respectively. It can be seen that the ADMM algorithm converges harmoniously after iteration, and the original residual and dual residual of the region boundary active power approach to zero, and the transmission power of the balanced flexible interconnection device is obtained.

By analyzing the scheduling simulation results, it can be found that the following scenarios appear in typical days:

1) Scenario 1. In sunny days, one microgrid has excess photovoltaic output and the other is insufficient. At this time, the flexible interconnection device can transfer the redundant active power of the microgrid on one side to the shortage side to avoid starting the diesel unit, such as 10 h, 11 h and 16 h.

At 16 h, it can be seen from Figure 3 that the photovoltaic output of MG1 is greater than the load demand, and the remaining is about 185.5 kW, while the photovoltaic output of Mg2 is less than the load demand, and the deficiency is about 314.5 kW. If the microgrid operates independently, MG1 needs to store all the remaining power in this scenario, while Mg2 still needs to start the diesel generator set to ensure reliable power supply on the basis of energy storage and discharge. As the cost of photovoltaic power generation is lower than that of diesel generator set, after coordination and optimization of flexible interconnected microgrid system, MG1 will transfer part of its power to Mg2 for energy supply after meeting its internal load demand, as shown in Figure 3. The power transmitted by MG1 is about 176.6 kW, and the power received by Mg2 is about 158.7 kW. The excess energy is consumed in the
AC / DC conversion process inside the flexible interconnection device. In addition, the discharge power of energy storage in Mg2 is about 205.5 kW, to supplement the remaining power shortage.

2) Scenario 2. In sunny days, when the load is small, the photovoltaic output of all micro grids is surplus, and the energy storage device is charged. If the upper limit of energy storage capacity is reached or exceeded, the photovoltaic active power will be reduced, such as 12h, 13h, 14h and 15h.

In 12h, it can be seen from Figure 3 that the photovoltaic output of MG1 and Mg2 is greater than the load demand, and the surplus energy is stored in the local energy storage system, but there is still energy surplus after the internal energy storage of MG1 reaches the maximum charging power, and the charging power of Mg2 has not reached the maximum. Therefore, the remaining energy of MG1 is transmitted to Mg2 through flexible interconnection device with a loss of about 17 kW, as shown in Figure 4.

In Figure 3, in 14h and 15h, the photovoltaic output of Mg2 is 1700 kW and 1600 kW respectively, and the load is 1077.4 kW and 1003.1 kW. At this time, the energy storage device is charged with the maximum charging power of 300 kW, and the power transmitted from Mg2 to MG1 is 84.4 kW and 83.8 kW, but there is still surplus photovoltaic output, so there is about 209.6 kW and 189.1 kW photovoltaic reduction.

3) Scenario 3. In case of no light at night or insufficient photovoltaic output during the day, the diesel generator set of one microgrid cannot operate due to failure, the diesel generator set of the other microgrid will increase its output, and the flexible interconnection device will transfer energy to the maximum capacity to reduce the load cutting power, such as 19 H.

At 19h, the energy storage system in MG1 and Mg2 operates with the maximum discharge power of 300 kW, but it still cannot meet the user's load demand, so it is necessary to start the diesel generator set for power supply. As shown in Figure 5, the diesel units deg11 and deg12 in MG1 are out of operation due to failure, so the diesel units in Mg2 operate with large output, and the surplus part is delivered to Mg2 through flexible interconnection device About 173 kW, as shown in Figure 4. Based on the power support of the interconnection device, the cut-off load of MG1 decreased from 814.5 kW to 662.1 kW. The transmission active power does not reach the maximum capacity of the flexible interconnection device, because the flexible interconnection device needs to compensate the reactive load in MG1 after the diesel generator in MG1 fails to exit, which occupies the total transmission capacity.

4) Scenario 4. In case of no light at night or insufficient photovoltaic output during the day, the internal energy storage device of the microgrid will discharge. If the discharge power is less than the load, the diesel unit will be started for power supply, such as other times.

In 17h, it can be seen from Figure 3 that the photovoltaic output of MG1 and Mg2 is smaller than the load, but the power shortage is smaller, which is 214.5 kW and 154.5 kW respectively, which is smaller than the maximum discharge power of energy storage device, at this time, the discharge of energy storage device can meet the demand; in 18-21h, due to the large power shortage, it is necessary to start the diesel unit and supply power together with the energy storage device; in 1-9h and 22-24h, due to the energy storage device The remaining capacity is insufficient, and the system mainly relies on the power supply of diesel unit, as shown in Table 2.

To sum up, in scenario 1, the microgrid with excess photovoltaic output transmits power through the flexible interconnection device, avoiding the microgrid with insufficient photovoltaic output to start the diesel unit and reducing the operation cost; in scenario 2, the microgrid with excess photovoltaic output transmits power through the flexible interconnection device, although the loss cost is increased. However, the reduction of photovoltaic active power is avoided, and the energy stored in the increased energy storage device can provide power support at other times when the photovoltaic output is low; in scenario 3, the micro grid of diesel unit working normally transmits power through the flexible interconnection device, which can provide support for the micro grid of diesel unit failure, guarantee load power supply, and realize the reduction of total operation cost.
4. Conclusion
In order to improve the reliability and economy of micro grid, this paper uses the flexible interconnection method based on converter to connect the independent micro grid. Each microgrid and the AC side of the connected converter form a separate control area, in which the photovoltaic unit, energy storage system, diesel generator set and other equipment are centralized and optimized by calculating the optimal power flow. The active power at the boundary of the interactive area of the connected microgrid is coordinated and controlled by the distributed optimization algorithm based on the alternating direction multiplier method between the interconnected areas. After finite iterations, the control quantity of each equipment is obtained. The simulation results show that in the normal operation mode, the interconnected micro grid can achieve the economic operation of the whole system through mutual coordination; in the emergency operation mode, based on the voltage and power support capacity of the flexible interconnection device, it can reduce the load cut in the fault area and improve the reliability of power supply.

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