Dynamic regulation method of distributed generation in
distribution network under 5G network

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Abstract. Aiming at the problem of uneven power flow distribution caused by distributed power supply access, which leads to high voltage deviation and active network loss, a dynamic control method of distributed power supply in 5G network is proposed. The distributed topology structure of the distribution network under 5G network is generated, and the static topology information is extracted to establish the power partition. The distribution network in each area is connected to its own bus through different feeders. The distribution network reconstruction period is divided in the partition, and the network reconstruction period and the corresponding switch action scheme are determined. The state of distributed power supply was estimated according to reconstruction period and active/reactive power balance index, and the stability of dynamic control was determined. Based on the stability control, the dynamic control model of distributed power supply is established, and the network voltage can reach the preset target by adjusting the power of power switch. The simulation results show that the average voltage deviation of the proposed control method is 1.976, which is 4.431 and 3.783 lower than those based on data drive and flexible load regulation, respectively. The active power network loss of the control method in this paper is 0.342 MW, which is 0.385 MW and 0.346 MW lower than that of the control method based on data drive and flexible load regulation, respectively. Therefore, this method can improve the absorption capacity of distributed power supply and promote the power flow reciprocity of distribution network.

1. Introduction
The development of energy technology drives the progress of human society, promotes the innovation of industrial technology, and is the cornerstone of global economic development. In the past few decades, the rapid progress of the energy industry has provided a strong guarantee for China's industrial upgrading and helped China's economy achieve leapfrog development. The traditional distribution network lags in construction, has limited control means and unreasonable structure, which restrict the flexibility of distribution network operation control [1]. With the massive access of distributed power supply, the urban power distribution network has been transformed from single-
terminal power supply to multi-terminal power supply, making the urban power grid topology undergoing fundamental changes, further affecting the size and direction of fault current in the network, and bringing severe challenges to the protection and control methods of the existing urban power grid [2]. In addition, the increase of permeability of new energy and the increase of the proportion of nonlinear and impact loads put forward higher requirements for the related technologies to ensure the reliability of power supply and improve power quality [3-4]. Large-scale grid integration of new energy generation will profoundly change the dispatching control pattern of the main network[5]. Therefore, this paper proposes a dynamic control method of distributed power supply in the distribution network under 5G network to coordinate distribution network layout and capacity allocation with regional planning. Through coordination with active management and other means, the distributed power supply of the distribution network under 5G network is optimized and planned to improve users' economic benefits and social environmental benefits, so as to promote the construction of smart grid.

2. Dynamic regulation method of distributed generation in distribution network under 5G network

2.1. Generate the distributed topology of the distribution network under 5G network

Because there is no centralized master station to collect information, the network topology information in the distributed system is stored in the monitoring nodes of the urban distribution network. On the basis of static information, more abundant dynamic network topology information is identified through effective coordination among distributed generators in distribution network, and then these information are used to complete advanced automation functions such as fault recovery and island detection. The set composed of sections is called section set. In order to improve the feeder load balance, this paper solves the specific zoning scheme. The objective function of distribution network zoning method is:

\[
\alpha_{\text{max}} = 1 - \frac{\sum_{x=1}^{s_1} \sum_{y=1}^{s_2} (p_{xy} - \bar{p})^2 / s_2}{s_1}
\] (1)

In formula (1), \(\alpha_{\text{max}}\) represents the maximum feeder load balancing degree; \(s_1\) and \(s_2\) represent the number of feeders and the number of calculation points of feeder load balance respectively; \(x\) and \(y\) represent two different moments respectively; \(p_{xy}\) is the feeder load rate at a certain time; \(\bar{p}\) is the average feeder load rate. When a distributed generation partition receives the switch number sent from two adjacent areas or the power side receives the switch number information sent from the downstream direction, and one of the switches controlled by itself is in the off state, it is determined to be the contact node position.

2.2. Division of distribution network reconfiguration period

After being put into operation for the first time, the distributed generation partition can independently obtain and update the dynamic topology information according to the changes of static topology information and system operation state. In order to complete the dynamic regulation function of power supply, the intelligent distribution terminals shall be able to complete information exchange through peer-to-peer communication network. Because the number of switch actions is related to the amount of load cut-off and the number of node cut-off, one of them can be selected as one of the power supply restoration objectives. When the reactive power adjustable capacity is insufficient, the active power cutting strategy is carried out. The update method of the set value can be expressed as:

\[
\lambda(a+1) = \frac{\lambda(a) m_1 \delta}{m_2}
\] (2)
In formula (2), \( \lambda(a) \) and \( \lambda(a+1) \) correspond to the maximum values of range and standard deviation before and after updating respectively; \( m_1 \) and \( m_2 \) represent the number of iteration and expected reconstruction periods; \( \delta \) is the random number conforming to the normal distribution with mean value of 1 and standard deviation of 0.1. Based on the division results of reconstruction period, network reconstruction can be divided into the following two steps.

2.3. Estimating distributed power status
The distribution network system is generally composed of distributed generation, load and energy storage devices. Each distributed generation transmits energy to the load through the power line. In order to adapt to the characteristics of decentralized structure and plug and play, a small signal model of distribution network is established based on the droop control principle. The expression of the active power injected into the microgrid AC bus by each distributed power converter in the distribution network is as follows:

\[
W_1 = \frac{uv \sin \theta}{r} \tag{3}
\]

In formula (3), \( W_1 \) represents active power; \( u \) represents the output voltage of distribution network converter; \( v \) represents common bus voltage; \( \theta \) indicates phase difference; \( r \) is the equivalent output impedance. When the active power is constant, the unit amount of reactive power is injected, and the change of voltage amplitude is only related to the reactive power sensitivity matrix. Similarly, the reactive power injected into the microgrid AC bus by the distributed generation converter can be expressed as:

\[
W_2 = \frac{uv \cos \theta - v^2}{r} \tag{4}
\]

In formula (4), \( W_2 \) is reactive power. When the reactive power is constant, the unit amount of active power is injected, and the change of voltage amplitude is only related to the active power sensitivity matrix. Since the line impedance is usually much smaller than the load impedance, it is considered that the phase difference is very small. If the communication delay is less than the system sampling interval, it will not affect the data transmission; Otherwise, it will lead to packet loss. The data packet loss model of communication link is established based on Beili model, as follows:

\[
\beta'(n) = \eta \beta(n) + (1 - \eta) \beta(n-1) \tag{5}
\]

In formula (5), \( \beta' \) represents the latest data value; \( \beta \) represents the initial data value; \( \eta \) is a random variable, taking values between 0 and 1; \( n \) indicates time. Bring the communication link data into the Kalman filter estimation equation to obtain the state estimation value at the sampling time, which can be expressed as:

\[
\theta(n) = k \theta'(n-1) + h e(n-1) \tag{6}
\]

In formula (6), \( \theta(n) \) represents the state estimation value at the current time; \( \theta'(n-1) \) is the next forecast estimate; \( e \) represents Kalman filter gain matrix; \( k \) and \( h \) are the estimation coefficients, respectively. If there is only one boundary section in the island area, it is impossible to directly connect with the pure load branch outside the island, and there are no other nodes downstream of the island.

2.4. Design the dynamic regulation model of distributed generation
The connection of distributed generation to distribution network will change the single source radial structure of traditional distribution network and change the voltage of each node in the distribution network. In order to solve the related power flow and voltage problems caused by distributed generation access, a dynamic regulation model for maximizing the consumption of distributed
generation is proposed in this paper, so as to enhance the consumption ability of distribution network to distributed generation. The dynamic regulation model of distributed generation is shown in Figure 1.

![Dynamic regulation model](image)

**Figure 1 Dynamic regulation model**

The inverter of distribution network works in constant power control, and the distributed generation is equivalent to a special load with negative power. The fluctuation of load rate on feeder is defined as:

$$\Delta \tau = \frac{q_1 - q_2}{c}$$  \hspace{1cm} (7)

In formula (7), $\Delta \tau$ represents the load rate wave momentum; $q_1$ represents the power flowing through the feeder; $q_2$ represents the power flowing through the feeder when there is no load or new energy fluctuation; $c$ is the feeder capacity. Generally, the new energy access node or feeder end node can be regarded as the key node of voltage control. The objective function of voltage adaptive control is:

$$y = \min \sum_{j=1}^{o} (F_j - E)^2$$  \hspace{1cm} (8)

In formula (8), $y$ represents the objective function; $o$ is the total number of voltage control key nodes; $j$ is the key node; $F$ is the actual voltage; $E$ is the desired voltage. The expected voltage is calculated by the consistency algorithm to achieve the consistency of voltage changes of all key nodes. The input of dynamic regulation of distributed generation is the reactive power of flexible multi state switch, and the output is the actual voltage of key nodes of voltage control. Reactive power control can make the actual voltage of the key node of voltage control track the expected voltage well, so as to realize the distributed adaptive control of voltage. So far, the design of dynamic regulation method of distributed generation in distribution network under 5G network is completed.

### 3. Example analysis and verification

#### 3.1. Simulation example

In order to verify the performance of the dynamic regulation method of distributed generation in distribution network under 5G network designed in this paper, simulation analysis is carried out based on IEEE 33 node distribution system to verify the consumption capacity of distributed generation. System parameters and power switch parameters are shown in Table 1.

| Parameter                  | Numerical value | Parameter                  | Numerical value |
|----------------------------|-----------------|-----------------------------|-----------------|
| System rated voltage       | 15kV            | Node load size             | 100 kVA         |
| Line impedance of adjacent nodes | 2Ω              | Distributed power capacity | 2000 kVA        |
| Switching capacity         | 1500 kVA        | Upper limit of charge and discharge power | 1MW             |
In the IEEE 33 node distribution system, the distributed power supply connected to nodes 9 and 10 is wind power generation, and the maximum active power output is 0.8MVA. The distributed power supply connected to nodes 13, 14, 16, and 18 is photovoltaic, and the maximum active power output is 1.1MVA. It is assumed that except for the adjustable load, the load power of other nodes remains unchanged during the whole recovery process, and the constraint on the coverage of fluctuation range of each node is set to 100%. The power switch connects to the 10kV distribution network from the end of the feeder, and sets the power factor of the distributed power supply connecting to the power grid to 1. The feeder switch operates for a maximum of 4 times, and the minimum state transition interval is 2.

3.2. Results and analysis
Based on the above simulation examples, the consumption capacity of the distributed generation dynamic regulation method designed in this paper is tested. This method is taken as an experimental group to compare with the dynamic regulation methods of distributed generation in distribution network based on data-driven and flexible load regulation. In order to evaluate the maximum consumption capacity of distributed generation, voltage deviation and active network loss are selected as evaluation indexes for test in this example analysis. The voltage offset reflects the system voltage deviation caused by the access of distributed generation. Therefore, the smaller the voltage deviation index, the better. The minimum active network loss is usually the daily scale function of reactive power optimization power flow. Taking the minimum network loss as the objective function can reduce the system active power loss. Therefore, the smaller the active network loss index, the better.

The comparison results of voltage deviation and active network loss of each distributed power generation dynamic regulation method are shown in Table 2 and table 3.

| Number of tests | The dynamic regulation method of distributed generation in this paper | Dynamic regulation method of distributed generation based on data drive | Dynamic regulation method of distributed generation based on flexible load regulation |
|-----------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 1               | 2.156                                          | 7.042                                          | 6.804                                          |
| 2               | 2.208                                          | 6.018                                          | 5.069                                          |
| 3               | 2.062                                          | 7.214                                          | 6.087                                          |
| 4               | 1.139                                          | 5.125                                          | 5.362                                          |
| 5               | 2.315                                          | 6.637                                          | 5.475                                          |

| Number of tests | The dynamic regulation method of distributed generation in this paper | Dynamic regulation method of distributed generation based on data drive | Dynamic regulation method of distributed generation based on flexible load regulation |
|-----------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 1               | 0.315                                          | 0.704                                          | 0.744                                          |
| 2               | 0.328                                          | 0.618                                          | 0.618                                          |
| 3               | 0.362                                          | 0.763                                          | 0.626                                          |
| 4               | 0.338                                          | 0.802                                          | 0.782                                          |
| 5               | 0.365                                          | 0.748                                          | 0.669                                          |

When the system voltage deviation is too large due to the excessive output of distributed power generation, the safe and stable operation margin of the system will be reduced. When the system is disturbed, it is easy to produce the problem of excessive local voltage deviation and cause damage to electrical equipment. According to the comparison results in Table 2, the average voltage deviation of the regulation method in this paper is 1.976, which is 4.431 and 3.783 lower than the regulation methods based on data drive and flexible load regulation respectively. Therefore, the regulation
method in this paper has more stable operation ability. The distribution network has low active power network loss, which can not only increase the economy of system operation, but also improve the voltage quality of the system. According to the comparison results in Table 3, the active power network loss of the regulation method in this paper is 0.342 MW, which is 0.385 MW and 0.346 MW lower than the regulation methods based on data drive and flexible load regulation respectively. The regulation method in this paper has lower network loss. Based on the above results, the dynamic regulation method of distributed generation designed in this paper can suppress or reduce voltage deviation and active power network loss, improve the consumption capacity of distributed generation, and has strong engineering practicability.

4. Conclusion
The development trend of distribution network in the future is the modernization and automation of distribution system. It not only includes advanced power equipment, monitoring, regulation, communication technology and large-scale distributed energy access, but also represents the transformation of distribution mode and operation management mechanism. After the application of 5G network technology, a peer-to-peer communication network is established between intelligent distribution terminals to analyze and judge the fault situation and restore the power supply in non-fault sections. Under the above background, this paper proposes a dynamic regulation method of distributed generation in distribution network under 5G network. Using the distributed control mode, the whole power supply process can be completed by the coordination between intelligent terminals. This method can suppress or reduce voltage deviation and active power network loss and improve the consumption capacity of distributed generation. In addition, the method of robust optimization can be considered, and the operation scheme obtained can be compared with the operation scheme obtained based on probability theory, so as to achieve a better balance in the applicability and economy of the operation scheme.

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