Research on the Application of Distributed Energy in Power System

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Abstract. With the expansion of the installed capacity of distributed power generation in China, especially the increase in the proportion of the installed capacity of distributed power generation in some areas to the system load, some potential technical and management problems, and contradictions in the development of large-scale centralized distributed power generation have become increasingly apparent, mainly including distributed power generation, consumption, and safety. Aiming at the distributed characteristics of new energy, this article adopts a multi-agent system in the distribution network dispatching with distributed energy access. The coordination of the multi-agent system can achieve good distribution network scheduling effects, and a single agent can also use its own autonomy and learning experience to participate in the distribution network scheduling. Designed a distribution network dispatching control system based on multi-agent technology and its implementation process. A distribution network example with distributed energy access is used to verify the effectiveness of smart loads in distribution network dispatching.

Keywords: Distributed energy; power system; power dispatch; intelligent body system.

1. Introduction
Energy Internet is a new type of information and energy integration "wide area network" constructed by the Internet concept. It uses the large power grid as the "backbone network", the microgrid as the "local area network", and the open and equal information and energy integration architecture to truly realize energy Two-way on-demand transmission and dynamic balance use. American futurist Rifkin believes that by combining Internet technology with renewable energy, energy mining, distribution and utilization have changed from traditional centralized to intelligent distributed, thereby turning the global power grid into an energy sharing network. The third industrial revolution promoted by this combination of energy and communication technology will eventually bring about earth-shaking changes in human business models and social models. The distribution of wind energy resources in China presents a significant imbalance. Most land-based wind resources are concentrated in the Three Norths, resulting in a relatively concentrated distribution of distributed power generation in China [1]. Large-scale centralized distributed power generation development has become the main method of...
distributed power generation development in China. However, with the expansion of the scale of installed power generation capacity in China, especially the increase in the proportion of installed capacity of distributed power generation in some areas to the system load, some potential technical and management problems, and contradictions in the development of large-scale centralized distributed power generation have become increasingly apparent. Including distributed power generation, consumption, and safety aspects.

2. The impact of distributed energy generation access on dispatch operations

2.1. The impact of distributed generation on line power flow and network loss

The access capacity of distributed power sources connected to the power grid is closely related to its access location, the load level and distribution characteristics of the connected power grid, the topology and impedance of the connected power grid, and the location of transformer taps [2]. In order to study and demonstrate the decentralized installation of an appropriate number of distributed generators in the distribution network area with relatively abundant wind resources, to reduce the loss of the distribution network and improve the system voltage level, taking a typical 10kV network as an example, the access capacity at different locations was measured Analysis and simulation calculations, through modelling and calculation of the IEEE33 node network, the changes in the network loss with the access to the distributed generation capacity can be obtained. It is shown in Table 1.

| Access node | Active power generation (MW, Mar) | Reactive power generation (MW, Mar) | Active load (MW) | Reactive load (MVAr) | Active loss (MVA) | Reactive loss (MVar) |
|-------------|---------------------------------|-----------------------------------|-----------------|---------------------|------------------|---------------------|
| Not connected | 8.969                           | 6.565                             | 8.711           | 5.859               | 0.258            | 0.706               |
| Node 7      | 8.829                           | 6.181                             | 8.711           | 5.859               | 0.131            | 0.358               |
| Node 12     | 8.812                           | 6.136                             | 8.711           | 5.859               | 0.114            | 0.313               |

2.2. Grid-connection of distributed power generation affects system regulation ability

Due to the volatility of distributed power output, the increased power generation capacity of distributed power generation cannot reduce the reserve capacity of rotating units. On the contrary, the power grid must prepare many rotating reserve units for distributed power plants to solve the problem of output volatility, making conventional the unit is kept at a lower efficiency level. In essence, under the premise of a certain power load, distributed power generation is connected to the grid, which is equivalent to reducing the output of conventional controllable units and using uncontrollable intermittent power sources. In the system power supply, the proportion that can be adjusted is reduced. In the three northeastern provinces where peak shaving is difficult in winter, if the system's regulation capacity remains unchanged, the problem will become more obvious with the integration of distributed power generation.

2.3. The impact of distributed generation on system voltage

The fluctuation of distributed power generation such as wind power and solar power generation and the frequent start and stop of distributed generator sets; power changes will cause the grid frequency to fluctuate within a certain range, affecting the normal operation of frequency-sensitive loads in the grid. The fluctuation of distributed power generation will inevitably cause voltage changes [3]. In addition, if the power electronic control device in the distributed generator set is not properly designed, it will inject harmonic currents into the grid, causing unacceptable distortion of the voltage waveform, and may cause potential problems caused by resonance.
3. Multi-agent system (MAS) control framework

MAS can effectively solve the problem of coordinated control between many distributed power sources and between them and the grid. It can control the microgrid more effectively than traditional centralized control methods. The goal of MAS is to divide large and complex systems into small systems that communicate and coordinate with each other and are easy to manage [4]. They have good autonomy and heuristics, and can respond quickly to changes in the environment. Its advantages are: 1) It can control the operation of components without interference, and can make reasoning and planning through the knowledge system and the external environment to solve various problems in its own field; 2) It can communicate with other entities and coordinate and cooperate to solve complex problems; 3) Have the ability to distribute and quickly handle complex problems.

The MAS proposed in this paper adopts a hybrid structure system, as shown in Figure 1, which is divided into three layers: the upper layer Agent, the central layer Agent and the bottom layer Agent. All bottom-level components in the system (including generators, loads, etc.) operate as independent Agents; the central-level Agent coordinates the management of the bottom-level components in the microgrid according to the information of the bottom-level Agent and the instructions of the upper-level Agent; the upper-level Agent is a higher-level power grid The upper-level grid agent of the Grid, through communication and coordination with the central-level Agent, it solves the task division and the allocation of shared resources between the micro-grid central-level Agents. At the same time, it is also responsible for the coordination and dispatching of the power market and the lower-level grids, and integrates Central Agent information makes important decisions. Different agents also maintain a certain amount of data communication to better ensure the rationality of their respective decisions.

4. Algorithm for minimizing performance index function

The purpose of the performance index function minimization algorithm is to determine the control sequence $U = [u(n), u(n+1), \cdots, u(n+N_w-1)]^T$ to minimize the performance index function $j$ in formula (1), which can be obtained by iteratively using the Newton-Raphson method by setting the Jacobian matrix of formula (1) to zero. In the iterative process, the intermediate value of $j$ is expressed as $J(k)$, and the intermediate value is expressed as

$$U(k) = [u(n), u(n+1), \cdots, u(n+N_w-1)]^T$$

Figure 1. Schematic diagram of MAS structure
Then the iterative formula of $U(k+1)$ is

$$U(k + 1) = U(k) - \left( \frac{\partial^2 J}{\partial U^2}(k) \right)^{-1} \frac{\partial J}{\partial U} (k) \tag{2}$$

Were

$$\frac{\partial J}{\partial U} (k) = \left[ \frac{\partial J}{\partial u(n)} \frac{\partial J}{\partial u(n+1)} \cdots \frac{\partial J}{\partial u(n+N_u-1)} \right]^T \tag{3}$$

Formula (3) is the Jacobian matrix.

$$\frac{\partial^2 J}{\partial U^2} (k) = \begin{bmatrix} \frac{\partial^2 J}{\partial u(n)^2} & \cdots & \frac{\partial^2 J}{\partial u(n)\partial u(n+N_u-1)} \\ \vdots & \ddots & \vdots \\ \frac{\partial^2 J}{\partial u(n+N_u-1)\partial u(n)} & \cdots & \frac{\partial^2 J}{\partial u(n+N_u-1)^2} \end{bmatrix} \tag{4}$$

Equation (4) is the Hessian matrix.

In each iteration of Newton–Raphson, each element of the Jacobian and Hessian matrix needs to be calculated. The h-th element of the Jacobian matrix is

$$\frac{\partial J}{\partial u(n+h)} = -2 \sum_{j=N_1}^{N_2} [y_r(n+j)-y_p(n+j)] \frac{\partial y_m(n+j)}{\partial u(n+h)} + \sum_{j=0}^{N_c-1} \lambda(j) \Delta u(n+j) \frac{\partial \Delta u(n+j)}{\partial u(n+h)} \tag{5}$$

Among them

$$\frac{\partial \Delta u(n+j)}{\partial u(n+h)} = \frac{\partial u(n+j)}{\partial u(n+h)} - \frac{\partial u(n+j-1)}{\partial u(n+h)} = \delta(h, j) - \delta(h, j-1) \quad \tag{6}$$

$$\delta(h, j) = \begin{cases} 1 & h=j \\ 0 & h \neq j \end{cases} \tag{7}$$

Formula (7) is the Kroneck Delta cofunction.

The $m, h$ element of Hessian matrix is

$$\frac{\partial^2 J}{\partial u(n+m)\partial u(n+h)} = 2 \sum_{j=N_1}^{N_2} \left[ y_r(n+j)-y_p(n+j) \right] \frac{\partial^2 y_m(n+j)}{\partial u(n+m)\partial u(n+h)}$$

$$+ \sum_{j=0}^{N_c-1} \lambda(j) \left[ \delta(m, j) - \delta(m, j-1) \right] \left[ \delta(h, j) - \delta(h, j-1) \right]$$

$$h=0, \cdots , N_u-1, m=0, \cdots , N_m-1 \tag{8}$$
To calculate the Jacobian matrix and the Hessian matrix, the first-order and second-order derivatives of the control input vector of the multi-layer forward neural network need to be used, which can be obtained by obtaining the derivative of $u(n + b)$ through equation (7). For each work area $Z_i$, there is a local model $M_i$. To express the effectiveness of the local model $z_k$ at the work point $Z_k$, define the local model effectiveness function

$$\rho_i(z_k) = \exp(-\|z_k - z_i^a\|^2 / 2\sigma^2)$$ \hspace{1cm} (9)

Among them, the norm $\|z_k - z_i^a\|$ represents the spatial distance between the operating point $z_k$ and the nominal operating point $z_i^a$, and $\sigma$ is a constant. In this paper, $\|z_k - z_i^a\|$ is the error $e_{mof}$ between the process output and the output of the predictive model without feedback correction. When performing prediction and optimization without feedback correction, equations (3) and (8) are rewritten as

$$y_{p}(n + j) = y_{m}(n + j)(j = N_1, \ldots, N_2)$$ \hspace{1cm} (10)

$$\text{net}_{j}(n + k) = \sum_{i=1}^{n} w_{ji} y_{m}(n+k-j) + \sum_{i=1}^{n} w_{ji} u_i \left\{ u(n+k-1)k - i < N_u - 1 \right\} + \delta_j$$ \hspace{1cm} (11)

The rest remains unchanged. The control signal applied to the controlled object is synthesized as follows:

$$u(t) = \sum_{i=1}^{N} \beta_i u_i(t)$$ \hspace{1cm} (12)

Where $u_i(t)$ is the output of the $i$ local neural network predictive controller, and $\beta_i$ is the interpolation function, which is defined as

$$\beta_i(z_k) = \rho_i(z_k) / \sum_{j=1}^{N} \rho_j(z_k)$$ \hspace{1cm} (13)

5. Distribution network dispatching based on MAS

5.1. Scheduling basics

Based on maintaining the stable operation of the distribution network, the dispatching of the distribution network will give priority to ensuring the maximum power generation of new energy sources such as photovoltaics and wind power in accordance with the operating characteristics of photovoltaic and wind power generation systems [5]. At the same time, the possible adverse effects of intermittent power generation from new energy sources such as photovoltaics and wind power on the power balance of the distribution network are adjusted by the load, and technically intelligent loads eliminate power fluctuations. In order to achieve the optimal utilization of clean energy, the main goal of MAS control in this paper is to achieve the most economical operation under the conditions of ensuring the safe and stable operation of the entire network. It should be noted that when the microgrid is operating in islands, the safety and stability research of this paper is from the perspective of voltage stability, because in the microgrid where all power sources are connected through inverters (as shown in Figure 2), there is no synchronous model. In distributed power generation, the power angle stability is not the main problem, and the excess or deficiency of active power will directly cause the rise or fall
of the bus voltage; the most economical operation is to make the renewable energy (photovoltaic, wind power) work as much as possible. Maximum power tracking control mode (MPPT), because they do not need to spend such costs as fuel cell fuel to generate electricity.

![Figure 2. MAS application simulation diagram](image)

5.2. Control strategy of each agent in non-grid-connected operation

5.2.1. The central agent's coordinated control strategy for the entire network. In non-grid-connected operation, due to the lack of power support from the upper-level grid, in order to achieve the control objectives of MAS, more rapid and coordinated operation of various components is required. According to the control objectives and constraints of formula (1), the central agent's coordinated control strategy design for the microgrid is shown in Figure 3. The central agent will perform event-driven control on the underlying agent based on the information of the underlying component Agent and the upper-level grid agent. Once there is a new environmental change in the microgrid, the operating status of each agent will be adjusted.

![Figure 3. MAS coordination strategy flowchart](image)

5.2.2. Battery Agent control strategy. The battery agent charges and discharges according to the instructions of the central layer agent. However, in order to avoid command errors caused by
communication problems or sudden changes in the environment, the superior agent does not issue appropriate instructions in time, it still needs to make correct judgments on the central layer agent's instructions according to its own environment. If the environment changes suddenly, it still runs in accordance with the superior instructions, which may aggravate the problem of the power grid. Therefore, the battery agent still has a certain degree of reactivity and adaptability. When the judgment of its own environment is inconsistent with the superior command, it needs to repeatedly query the control command of the central layer agent [6]. And the battery agent also needs to protect the battery. When the terminal voltage exceeds the safe range, the battery is disconnected from the grid, and when the charge and discharge power exceed the safe value, it runs at the safe limit. According to this design, the battery Agent control strategy is shown in Figure 4.

![Flowchart of battery agent control strategy](image)

**Figure 4. Flowchart of battery agent control strategy**

### 5.2.3. Control Strategy of Photovoltaic Agent and Wind Power Agent.
Photovoltaic and wind power, as the most important power generation components in the system, must not only meet economic operation, but also ensure the safety and stability of the system. Therefore, the responsiveness of photovoltaic agents and wind power agents to the environment is particularly important. At the same time, in order to avoid higher-level instruction errors or environmental mutations caused by communication problems, the upper-level Agent does not issue appropriate instructions in time. Photovoltaic and wind power agents need to respond quickly and timely to changes in the environment. Therefore, they not only rely on higher-level instructions to change their operating mode, but also It must be able to change the way according to sudden changes in the environment, that is, it must have a rapid response to the environment [7]. According to this design, the control strategy of photovoltaic agent and wind power agent is shown in figure 5.
5.2.4. Load Agent control strategy. In addition to providing load information to the central layer agent, the load agent also needs to reduce the load according to the central layer agent's command when the power generation of the isolated grid is insufficient. It should be noted that generally there is no primary or secondary level in the microgrid. Load, so almost all can be cut off when necessary. At the same time, in order to avoid command errors caused by communication problems or sudden changes in the environment, the upper-level Agent does not issue appropriate instructions in time, the agent still must make correct judgments on the upper-level Agent's instructions according to its own environment. Therefore, it still has a certain degree of responsiveness and self-adaptability [8]. When the judgment of its own environment is inconsistent with the higher-level instructions, it needs to repeatedly query the control instructions of the upper-level Agent. The load Agent control strategy designed accordingly is shown in Figure 6.

6. Simulation analysis
The Newton-Raphson method is used to calculate the power flow of the example under the MATLAB simulation environment. Regardless of the reverse power limit of DER access, the DER penetration
rate is considered according to 5 levels of 10%, 20%, 50%, 100%, and 120% of the total network load, and the DER injection power of node 2 and node 3 is taken into consideration. The ratio is to analyze the loss and voltage distribution changes under the condition of changing the network structure.

6.1. The impact of network structure changes on network loss

Figure 7 shows the power distribution calculation results of the open-loop, closed-loop and meshed operating conditions of the DC distribution network. The network loss of the DC distribution network decreases from open loop, closed loop to mesh structure. It is particularly worth noting that the slope of the network loss curve decreases successively under the conditions of open loop, closed loop and mesh structure, which indicates that the mesh structure has a significant effect on reducing network loss, and the sensitivity of the mesh structure to DER access is relatively low. Has a strong ability to absorb DER.

![Loss graph](image)

**Figure 7.** The impact of network structure changes on network loss

6.2. The influence of network structure on voltage distribution

Figure 8 shows the calculation results of the unbalanced degree of voltage distribution across the whole network of open-loop, closed-loop, and mesh structures. The unbalanced degree of voltage distribution decreases from open loop, closed loop to mesh network structure, which shows that with the increase of network node interconnection, the voltage distribution of the network gradually improves, indicating that the DC distribution network of the mesh structure has Strong DER absorption capacity.
Figure 8. The influence of network structure on voltage distribution imbalance

7. Conclusion
Most of the distributed power sources are located near the load center, and the installed capacity is small. It is not for the purpose of large-scale and long-distance transmission of electricity. The generated electricity is connected to the local power grid for consumption. The article systematically analyzes the influence of distributed energy on grid dispatching, mainly studies the influence of distributed power generation on dispatching operation, and elaborates on the exploration of distributed power generation dispatch mode, based on the virtual machine hierarchical dispatch structure of four scenarios Explore and analyze the impact of distributed energy island operation.

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