Integrated control technology of photovoltaic reactive power with source network coordination based on Multi-Agent Technology

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Abstract. With the rapid development of photovoltaic power generation technology, its participation in reactive power control of distribution network technology has been widely concerned. However, photovoltaic output has great volatility and randomness, which also brings challenges to the security and stability of distribution network reactive power regulation. Firstly, considering the topology of photovoltaic power generation unit and the demand response of the grid point, the reactive power model of distribution network including photovoltaic power generation is established based on source grid coordinated regulation. Then, on the basis of the above research, a source-grid cooperative photovoltaic reactive power double-layer regulation model was established. These include the upper-level control model responding to grid reactive power control demand, and the lower-level control model uses particle swarm optimization algorithms to allocate and control the upper-level demand for each photovoltaic power generation unit. Finally, based on IEEE33 distribution network model, it is verified that the proposed method can effectively solve the impact of photovoltaic output fluctuation on reactive power regulation and control of distribution network.

Keywords: Multi-agent technology, photovoltaic reactive power control, particle swarm optimization algorithm, hierarchical control

1. Introduction

With the development of renewable energy and the continuous reduction of coal and other traditional energy reserves, the global fuel structure has undergone great changes. As a renewable energy, solar energy has the characteristics of rich resources, clean and safe. According to the statistics of national energy administration, the newly added and accumulated installed capacity of photovoltaic power stations in China ranks first in the world. However, the following problem is that the fluctuation and randomness of photovoltaic output will have a certain impact on the grid point voltage of the system, which brings challenges to the safe and stable operation of the power system[1-5].
At present, the research on voltage control of photovoltaic power station is mainly divided into the following two aspects. (1) A constant voltage regulation control method is proposed to stabilize the voltage fluctuation at the paralleling point. The research in this area is mainly focused on the photovoltaic power station level. The voltage of the grid connection point is controlled by PI (proportion integration) tracking control method, sensitivity analysis method, optimization algorithm and other methods. The purpose of auxiliary control of grid voltage stability is to maintain the grid voltage constant. The above methods improve the stability of power grid operation to a certain extent, but the auxiliary control of grid voltage fluctuation cannot achieve significant effect in peak-valley period of system load or period of large fluctuation of photovoltaic output[6-8]. (2) A feedback control method is proposed to suppress the risk of voltage overrun. The goal of this research is to restrain the voltage of the junction point from exceeding the limit. Through the online monitoring system, the voltage at the junction point can be obtained in real time, so as to make emergency control for the situation beyond the voltage control range[9-10]. It solves the problem of voltage overrun at the grid connection point and prevents further deterioration of grid voltage. However, it is still a passive voltage control method, which cannot give full play to the reactive power regulation capacity of photovoltaic power station[11-15].

In this paper, the integrated control technology of source network coordinated photovoltaic reactive power is studied, and a double-layer reactive power optimization model of photovoltaic power station is established. The multi-agent technology is used to carry out hierarchical coordinated control. The upper optimization model is used to respond to the demand of grid voltage control. The lower optimization model optimizes the distribution of the upper optimization results in each group of photovoltaic generation unit PVGU (PV Generation Unit), so as to realize the fine control of source network coordinated photovoltaic reactive power, so as to improve the stability of power system.

2. Ease of Use Source network coordination reactive power control structure

2.1. Multi-agent technology
Multi agent technology is a technology for complex system analysis and simulation. Since it was proposed in 1970s, it has developed very fast and is a new distributed computing technology[16-20]. Compared with the traditional single system application, multi-agent system has the following advantages: autonomy, mobility, initiative, communication, learning ability, responsiveness, planning ability, reasoning ability, longevity, cooperation and negotiation ability. Therefore, the multi-agent system has the following advantages:

(1) The cooperative ability of multi-agent improves the efficiency of task execution;
(2) The redundancy of multi-agent can improve the robustness of task application;
(3) Multi-agent is easy to expand and upgrade;
(4) Multi-agent can complete distributed tasks.
To sum up, the advantages of multi-agent structure can effectively improve the control ability of photovoltaic reactive power, so this paper will design a reactive power optimization control method based on multi-agent structure.

2.2. Source-network coordination reactive power control architecture
At present, a kind of multi-agent structure commonly used is tree structure, as shown in Fig. 1. Among them, agent_U is the upper agent, agents_1~n are the lower agents. The communication link is used to realize the information exchange and instruction transmission between the upper and lower agents. The upper agent coordinates the cooperative operation of all agents according to the real-time information of the lower agents.
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$$Q_{ci} = \begin{cases} Q_{max} (V_i - V_{min}) + Q_{max}, & V_i < V_{min} \\ V_{min} - V_d, & V_{min} \leq V_i \leq V_{dmax} \\ 0, & V_{dmax} \leq V_i \leq V_{imax} \\ \frac{Q_{max} (V_i - V_{imax})}{V_{imax} - V_{max}}, & V_{imax} \leq V_i \leq V_{max} \\ -Q_{max}, & V_i > V_{max} \end{cases}$$

3. Source-grid cooperative photovoltaic reactive power double-layer regulation model

3.1. Upper-level regulatory command model

The upper reactive power optimization model is that the active output of photovoltaics remains unchanged, and the reactive output $Q_{ci}$ is calculated according to the voltage $V_i$ of the photovoltaic
\[
\Delta Q_{\text{order}} = \sum_{i=1}^{\pi} Q_{\text{rt}}
\]

Where, \(\Delta Q_{\text{order}}\) is the total photovoltaic reactive power regulation command, \(V_{\text{max}}\) and \(V_{\text{min}}\) are the upper and lower limits of allowable node voltage, and \(V_{d\text{max}}\) and \(V_{d\text{min}}\) are the upper and lower limits of reactive voltage regulation dead zone.

### 3.2. Lower reactive power optimization layer model

The lower reactive power optimization takes the upper level reactive power optimization result \(\Delta Q_{\text{order}}\) as the known quantity. By optimizing the reactive power output of each group of PVGU and SVG, the voltage distribution inside the photovoltaic power station is more reasonable, and the active power loss inside the photovoltaic power station is reduced as much as possible.

This paper uses PSO algorithm (PSO: Particle swarm optimization) to calculate the control instruction \(\Delta Q_{\text{order}}\) accurately.

If the minimum error value of the total reactive power control command is the target, the objective function is:

\[
\min f_2 = \left| \Delta Q_{\text{order}}(t) - \sum_{i=1}^{n} \Delta Q_i(t) \right|
\]

Where, \(\Delta Q_{\text{order}}(t)\) is the total reactive power regulation command given by the upper level control command layer, \(\Delta Q_i(t)\) is the actual total reactive power regulation quantity, and \(n\) here is the number of photovoltaic reactive power control units. If \(n\) is larger, the optimization precision is higher, then the search space dimension of PSO algorithm is \(n\), and any position in the search space can be expressed as:

\[
x = [m_1, m_2, m_3, ..., m_n]
\]

Where \(m_i\) is the reactive power of photovoltaic reactive power regulation unit at the \(i\)-th time. Any position in the search space corresponds to a possible solution result.

Set the constraint condition of \(\Delta Q_i(t)\) as

\[
\Delta Q_{i\text{min}} \leq \Delta Q_{\text{order}}(t) \leq \Delta Q_{i\text{max}}
\]

Among them, \(\Delta Q_{i\text{min}}\) and \(\Delta Q_{i\text{max}}\) are the lower and upper limit of reactive power regulation of PV reactive power regulation unit.

Assuming that a population with \(j\) particles is searched in an \(n\)-dimensional search space, the starting position of particle \(i\) at the \(t\)-th iteration is

\[
x_i = [x_{i-1}(t), x_{i-2}(t), x_{i-3}(t), ..., x_{i-n}(t)]
\]

The corresponding speed is

\[
v_i = [v_{i-1}(t), v_{i-2}(t), v_{i-3}(t), ..., v_{i-n}(t)]
\]

Among them, all dimensions component meet:

\[
v_{\text{min}} \leq v_{i-d}(t) \leq v_{\text{max}}
\]

In equation (8), \(v_{d\text{f}}(t)\) represents the \(d\)-th dimensional velocity component of the \(i\)th particle at the \(t\)-th iteration.

The specific steps are as follows:

1. The position and velocity of each particle in the population is randomly initialized, where each particle represents the possible initialization reactive power value of each photovoltaic reactive power control unit;

2. According to equation (3), the value \(f\) of the optimization objective function corresponding to each particle will be calculated;

3. The individual optimal position \(Q_{i\text{best}}(t)\) of each particle is updated according to value \(f\);

4. Based on the constraint conditions shown in equation (5), the global optimal position \(Q_{i\text{best}}(t)\) of each particle is updated according to value \(f\);
(5) Judge whether the termination condition is satisfied, that is, whether the iteration has been 100 times. If so, the optimal solution $\Delta Q_i(t)$ of $n$ photovoltaic reactive power regulation units will be output; otherwise, the number of iterations $t$ will be increased once, and return to step (2) for execution;

According to the above steps, the control instructions of each PV reactive power control unit at each time point are determined to realize the real-time reactive power compensation of distribution network.

4. Simulation verification

Based on the research of the above-mentioned source network coordination photovoltaic reactive power regulation technology, the above method is simulated and verified on the basis of IEEE33 node distribution network model. As shown in Fig. 3, on the basis of IEEE33 node distribution network model, two photovoltaic power generation units are considered to be connected into it.

![Fig. 3 Distribution network model considering photovoltaic power generation unit](image)

According to the double-layer control model of source grid coordination and photovoltaic reactive power, the upper control layer proposes the total reactive power regulation command of photovoltaic power generation unit based on source grid coordination, and the lower control layer proposes reactive power regulation command of each photovoltaic power generation unit based on particle swarm optimization algorithm.

Firstly, in the upper control layer, photovoltaic generation units are connected to nodes 4, 10 and 18 respectively. The voltage offset at the end of the main line of the distribution network is shown in Fig. 4. Considering the source network reactive power coordination, the total reactive power regulation command of the photovoltaic power generation unit is given, which can be divided into three stages: zero adjustment stage, fine adjustment stage and multi adjustment stage, as shown in Table 1.

![Fig. 4 Voltage offset at the end of main line in distribution network](image)

**Table 1. Three Scheme comparing**

| Scheme                   | Time          | Voltage offset/var |
|--------------------------|---------------|--------------------|
| zero adjustment phase    | 0–5.5h        | 0                  |
| fine adjustment stage    | 5.5h–8.25h    | 15                 |
| multi adjustment stage   | 8.25h–15h     | 35                 |
According to the three-stage total reactive power regulation, with the help of particle swarm optimization algorithm, as shown in Fig. 5 and Fig. 6, the reactive power regulation amount of three PV units can be obtained, as shown in Fig. 7.

**Fig. 5** Experimental process of particle swarm optimization in fine adjustment stage

**Fig. 6** Experimental process of particle swarm optimization in multi adjustment stage

**Fig. 7** Reactive power regulation of each photovoltaic power generation unit
After the optimization of the photovoltaic reactive power double-layer control model based on source grid cooperation, the voltage offset at the end of the distribution network is shown in Fig. 8.

![Fig. 8 Voltage offset after optimization](image)

Compared with Fig. 4 and Fig. 8, it can be found that through the double-layer control model, the reactive power regulation ability of photovoltaic power generation unit and the reactive power regulation ability of photovoltaic power generation unit are fully considered, and the voltage offset at the end of distribution network is reduced, which verifies the effectiveness of the method in this paper.

5. Summary

In this paper, an integrated reactive power control technology based on multi-agent technology is proposed. Firstly, on the basis of multi-agent technology, the total reactive power regulation instructions of multiple photovoltaic power generation units are proposed; then, the optimization of photovoltaic reactive power regulation instructions is carried out with the minimum voltage offset of photovoltaic power generation unit as the optimization objective by using particle swarm optimization algorithm, and the optimal values of PVGU and SVG are given respectively; finally, the effectiveness of the proposed method is verified by comparing the voltage offset of the PV generation unit before and after optimization. The later research can be applied to the actual distribution network model on the basis of this method to verify the feasibility of the method.

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