Reactive power optimization of distributed photovoltaic access distribution network based on improved multi-objective particle swarm optimization

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Abstract. With the widespread development of distributed power generation technology, photovoltaic power generation has been widely used. Aiming at the past, the reactive power optimization algorithm with distributed photovoltaic access distribution network needs to convert the multi-objective problem into a single-objective solution process where the weight setting is not objective. This paper proposes a multi-objective optimization algorithm based on improved particle swarm optimization algorithm. The multi-objective model based on Pareto optimal solution is used to obtain the Pareto optimal solution set, and the optimal solution is selected from it. At the same time, the algorithm is improved, the external file is used to update the optimal position of the particle, the population diversity is increased to avoid premature problems, and the performance of the algorithm is improved by analyzing the test function. Through modeling, the influence of distributed photovoltaic power generation on the power grid is studied, and simulation is performed in the IEEE-33 node system. The simulation results prove the feasibility of the improved algorithm in this paper.

1. Introduction
In recent years, the emergence of intelligent algorithms such as genetic algorithms and particle swarm optimization (PSO) algorithms has made up for the deficiencies of traditional algorithms, and has been widely used in the field of reactive power optimization[1,2]. For example, the literature [3] uses fuzzy clustering theory and learning automata. The method transforms the multi-objective problem into a single-objective problem. Although the optimization of multiple objectives is fully considered, it is essentially a single-objective optimization method. This paper proposes an improved particle swarm optimization algorithm. In the process of applying particle swarm optimization to solve the multi-objective Pareto optimal solution, in order to save the Pareto optimal solution that has been found in the evolution process, an external file storage mechanism is established and the External file maintenance is combined with updating the optimal position of the group to maintain the diversity and uniformity of the solution and prevent premature convergence.

2. Analysis of operating characteristics of photovoltaic power generation
The principle of photovoltaic power generation is to convert light energy into electrical energy through the photovoltaic effect. Its structure mainly includes solar cell array, inverter, controller and power grid[4]. The typical structure of photovoltaic power generation is shown in Figure 1.
The diode equivalent circuit of an ideal photovoltaic cell is shown in Figure 2.

Figure.2 Equivalent circuit of photovoltaic cell module

The calculation formula of I is as follows:

$$I = I_{ph} - I_o \left[ e^{\frac{q(U+IR_s)}{AmkT}} - 1 \right]$$ (1)

In the formula: q is the Coulomb constant and the value is 1.6×10^{-19}C. U is the photovoltaic cell voltage, V. A is the ideal constant of the diode and 1.5. T is the temperature of the photovoltaic cell, °C. m is the number of cells connected in series; k is Boltzmann constant, with a value of 1.38×10^{-23}J/K. I_{ph}、I_o and T are calculated as follows:

$$I_{ph} = \frac{G_{sc}G_{ref}}{G_{sc}}[1 + \alpha_T(T - T_{ref})]$$

$$I_o = \frac{G_{sc}}{G_{ref}} \left( \frac{T}{T_{ref}} \right)^3 e^{\frac{qE_g}{kT_{ref}} - \frac{1}{kA}}$$ (2)

$$T = T_{am} + I_{bet} \frac{(NOCT - 20)}{0.8}$$ (3)

In the formula: ISC is the short-circuit current of photovoltaic cells under standard test conditions, A; Go is the actual irradiation intensity of photovoltaic cells, W/m2; Gref is the irradiation intensity under standard test conditions, and the value is 1000W/m2; αT is the short-circuit current Temperature coefficient, %/°C; Tref is the temperature under standard test conditions, which is 25 °C; UOC is the open circuit voltage under standard test conditions, V; Tam is the atmospheric temperature, °C; NOCT is the nominal operating temperature of the photovoltaic cell, °C ; Eg is the forbidden band width, eV;

Eg is calculated as follows:

$$E_g = 1.16 - 7.02 \times 10^{-4} \frac{T^2}{T - 1108}$$ (4)
3. Multi-objective particle swarm optimization based on external files

PSO cannot directly solve the multi-objective optimization problem\(^{[5,6]}\). Improve PSO to get multi-objective particle swarm optimization (MOPSO). The multi-objective particle swarm optimization algorithm should focus on external file maintenance and gbest selection, maintain diversity of populations, and prevent premature convergence. Aiming at the above problems, this paper uses Pareto Archive Multi-objective Particle Swarm Optimization (PAMOPSO) to solve the multi-objective reactive power optimization problem of distribution network. The hybrid process of external file maintenance and gbest selection is as follows:

(1) For each newly generated non-inferior solution \(x\), if \(x\) dominates the original solution in the external file \(P\), then delete these dominated solutions and save \(x\) in the external file. If there are particles that previously selected the deleted and dominated solution as gbest, then \(x\) is now used as the gbest of these particles.

(2) For the remaining new non-inferior solutions, if ,\(x\) is added to \(P\), determine a solution \(x\). For all solutions \(x\), the particles of the previous generation think gbest choose \(x\) as gbest and delete it from the external file ; otherwise, new generation The non-inferior solution is not added to external files.

The flow chart of PAMOPSO is as follows.

![Figure.3 PAMOPSO algorithm flow chart](image_url)

This article selects standard test functions ZDT1, ZDT2 to test PANOPSO respectively.

| ZDT1 | ZDT2 |
|------|------|
| \(\min f_1(x) = x_i,\) \(\min f_2(x) = g(x)h(f_1(x), g(x))\) \(g(x) = 1 + \frac{9}{29} \sum_{i=1}^{30} x_i\) \(h(f_1(x), g(x)) = 1 - \left(\frac{f_1(x)}{g(x)}\right)^{1/2}\) \(0 \leq x_i \leq 1, 1 \leq i \leq 30\) | \(\min f_1(x) = x_i,\) \(\min f_2(x) = g(x)h(f_1(x), g(x))\) \(g(x) = 1 + \frac{9}{29} \sum_{i=1}^{30} x_i\) \(h(f_1(x), g(x)) = 1 - \left(\frac{f_1(x)}{g(x)}\right)\left(\frac{f_1(x)}{g(x)}\right)^{\sin(10\pi f_1(x))}\) \(0 \leq x_i \leq 1, 1 \leq i \leq 30\) |
The solution result of the PAMOPSO test function ZDT1 is compared with the real Pareto frontier. Figures 4 is the comparison between PAMOPSO's solution to the test function ZDT2 and the real Pareto frontier. The area formed by the points is the solution result of PAMOPSO, and the curve is the true Pareto optimal frontier of the test function.

Fig. 4 Comparison between PAMOPSO's solution to ZDT1, ZDT2 and the real result Pareto frontier

From the above analysis, we can see that the algorithm proposed in this paper has better convergence, and the optimal solution can be better distributed on the optimal frontier.

4. Analysis of example
The following studies the impact of distributed photovoltaic access distribution network on voltage and network loss in the IEEE33 node distribution network system\cite{7,8}, as shown in Figure 7, where node 1 is a balanced node and the other nodes are PQ nodes. Each distributed photovoltaic power generation is regarded as a PQ node, which is equivalent to a negative load, and the forward and backward generation method is used to calculate the power flow.

Use MATLAB software at node 10 and node 16 to connect to distributed photovoltaic, PV1 (500 + j242kVA), and distributed PV2 (1000 + j484kVA). Carry out modeling and simulation to obtain the voltage distribution of each node. The simulation data is shown in the figure below.

Figures 6 and 7 reflect the voltages when nodes 10 and 16 are connected to photovoltaics of different capacities. Comparing Figures 6 and 7, it can be obtained that the closer the photovoltaic access point is to the end of the line, the greater the voltage change rate of the access point and other nodes of the feeder, and the greater the increase, the voltage overrun may occur.
Table 2 shows the network loss values when distributed photovoltaics with different capacities are connected. The connection of distributed photovoltaics with different capacities to the distribution network will cause different levels of network loss. In Table 1, when the capacity of the same node access increases from PV1 to PV2, the network loss decreases. When the distributed photovoltaic capacity is fixed and the location of the access point is different, the impact on the network loss is also different. The closer to the middle end, the smaller the network loss.

Table.2 Values of network losses for photovoltaics with different capacities

| Aims               | Node number | No distributed photovoltaic | Connect to PV1 | Connect to PV2 |
|--------------------|-------------|-----------------------------|----------------|---------------|
| Network loss       | Node 10     | 208.5                       | 141.4          | 104.6         |
| /kW                | Node 16     | 136.7                       | 112.3          |               |

5. Conclusion
Aiming at the problem of reactive power optimization of distributed photovoltaic access distribution network, an improved multi-objective particle swarm optimization algorithm is proposed. First, the characteristics of distributed photovoltaic power generation are analyzed, and the distributed photovoltaic power generation system is modeled and analyzed. Aiming at the problems of the previous multi-objective particle swarm optimization algorithm, a multi-objective particle swarm optimization algorithm based on Pareto optimal solution is proposed. On this basis, the algorithm is improved, and the external file storage mechanism is established. The selection of the optimal location and the selection of external files are combined. The performance of the improved algorithm is analyzed through the test function. The improved algorithm has better population diversity and effectively solves the problem of premature algorithm. Finally, an IEEE33 node system simulation model is established, and the distributed photovoltaic access distribution network is simulated and
analyzed. The simulation results show that the algorithm has a good optimization effect on reactive power optimization of the distribution network containing photovoltaic power generation.

Acknowledgments
This paper was supported by the Key Project of Shaanxi Provincial Education Department (18JS094), Xi’an Shiyou University, Graduate Innovation and Practice Ability Training Project.

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