Research on Distributed Grid Connected Capacity Optimization Method for Power System Pre Dispatch

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Abstract. The particle swarm optimization algorithm with adaptive weight and Newton-Raphson method are studied to connect the distributed energy to the grid in this paper. We will discuss the research status of the current stage of the project. The basic principles and processes of particle swarm optimization algorithm and Newton-Raphson method are expounded, and their improvement and combination are made (as well as their improvement and combination) so that they can optimize reactive power for networks with distributed energy better. Then the improved algorithm is applied to the IEEE-14 and IEEE-30 models and the reconstruction results are analyzed. The network loss and reactive power of the reconstruction network are declined, the voltage quality is improved. The SIMULARTOR software is used to establish and calculate the power flow of original model and reconstruction model of IEEE-14 and IEEE-30 respectively. The economic factors with grid supply point and connected capacity are analyzed to obtain the best ratio of power system at the same time. Compared with the above results, the results are basically consistent, and the accuracy and reliability of the algorithm are verified. Finally, considering the economic factors of the system, adjusting the connected capacity of the distributed energy-wind power and photovoltaic, and obtaining the best access ratio (proportion), the economical efficiency of the system is improved, and it has referential value.

1. Introduction
Distributed energy is the main source of power generation to meet the demands of users. It is also widely used in the research field, including the establishment of its own model, the application of system fault handling and protection circuits and the impact of grid connection, such as power flow distribution, voltage quality, active power loss in power system, etc. [1,2].

Many scholars have also made corresponding contributions in this regard. Current academic research focuses on the direction of distributed energy access to the distribution network. For example, the literature [3,4] proposed the use of genetic algorithm to optimize the reactive power of the distribution network connected to distributed energy, and its optimization effect is better, but the
convergence speed (rate) of the algorithm is poor. The literature [5] selects the basic particle swarm optimization algorithm, which has the opposite result to the former, and the algorithm converges quickly, but ignores the economical efficiency of the system. The literature [6,7] improved the particle swarm optimization algorithm, and the optimization effect is more ideal, but conducted only one case when a single distributed energy accesses to distribution network. Some scholars also research on the condition when distributed energy accesses to the entire power network or even the actual power grid. For example, the literature [8] selects the regional power grid for wind farm grid-connected research, the main direction is the processing of disturbance and the study of short-circuit protection. Literature [9,10] uses the differential evolution algorithm to optimize reactive power, and to evaluate the fault risk on reconstruction networks. The literature [11] uses the quantum evolution algorithm to optimize the reactive power of the specific network, and shows certain advantages in the optimization effect. The convergence speed and accuracy are improved. Literature [12] studies the direction of relay protection in the actual power network with photovoltaic connection. There are no literature to consider the economic factors with grid supply point and connected capacity to obtain the best ratio of power system at the same time. The reactive power optimization and economic operation of the entire power network with wind power and photovoltaics are analyzed in this paper, hope to give the best ratio for power system pre dispatch with two distributed energy.

2. Principle and improvement of particle swarm optimization algorithm

2.1. Principles of Particle Swarm Optimization Algorithm

The particle swarm optimization algorithm is an intelligent algorithm for finding the optimal solution, which simulates the foraging behavior of birds. The target search space is analogized to the flight area of the birds, the particles in the group are compared to birds, and the optimal solution sought is compared to the food sought by the birds. Specifically, the particles fly at their initial speed to find the local optimum value, and constantly update their own position and speed according to the change of the fitness value determined by the objective function, and then find the global optimal value.

First, search the velocity and position of the random and initial particle in the target space. The main parameters are as follows:

A group consists of $n$ particles

$$X = (X_1, X_2, \cdots, X_n)$$

(1)

The $i$-th particle is a $D$-dimensional vector

$$X_i = (x_{i1}, x_{i2}, x_{i3}, \cdots, x_{id})^T$$

(2)

The speed of the $i$-th particle is

$$V_i = (V_{i1}, V_{i2}, \cdots, V_{id})^T$$

(3)

The individual extremum is

$$P_i = (P_{i1}, P_{i2}, P_{i3}, \cdots, P_{id})^T$$

(4)

The global extreme value is

$$P = (P_{11}, P_{12}, P_{13}, \cdots, P_{1d})^T$$

(5)

Speed is updated to

$$V_{id}^{k+1} = V_{id}^k + c_1 r_1 (P_{id}^k - X_{id}^k) + c_2 r_2 (P_{gd}^k - X_{id}^k)$$

(6)

c_1 and $c_2$ are the acceleration factors, $r_1$ and $r_2$ are the random values evenly distributed from 0 to 1.

The location is updated to

$$X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1}$$

(7)
At the time of iteration, the objective function of the particle is calculated, so that the optimal position of the particle \( p_{\text{best}} \) at time \( t \) and the optimal position of the group \( g_{\text{best}} \) are obtained, the speed and position of the particle are updated by tracking both. The formulas are as follows:

\[
v_i(t+1) = v_i(t) + c_1 r_1 [p_i - x_i(t)] + c_2 r_2 [p_g - x_i(t)]
\]

\[
x_i(t+1) = x_i(t) + v_i(t+1), \quad j = 1, \ldots, d
\]  

(8)

(9)

2.2. Improvement of Particle Swarm Optimization algorithm

Particle swarm optimization algorithm also has its own drawbacks. It is easy to get into (be lost in) the best local position and complete the convergence too early. In order to improve the search effect of optimal solution, the inertia weight coefficient \( \omega \) is introduced to correct the formula (8):

\[
v_i(t+1) = \omega v_i(t) + c_1 r_1 [p_i - x_i(t)] + c_2 r_2 [p_g - x_i(t)]
\]

\[
x_i(t+1) = x_i(t) + v_i(t+1), \quad j = 1, \ldots, d
\]  

(10)

(11)

The inertia weight \( \omega \) could affect the search ability of the particle. Larger \( \omega \) can enhance the overall search ability of the algorithm, and smaller \( \omega \) can improve the local search ability of the algorithm. \( \omega v_i(t) \) is the original speed of the particles, \( c_1 r_1 [p_i - x_i(t)] \) is the local search ability of particles. \( c_2 r_2 [p_g - x_i(t)] \) is the overall search ability between. Equation (11) is to adjust the moving position of the particles influenced by each other in the space. Throughout the whole solution, the inertia weight \( \omega \), the acceleration factors \( c_1 \) and \( c_2 \), and the maximum velocity \( v_{\text{max}} \) maintain the particles' balance of search capabilities between the overall and the local.

In the particle swarm optimization algorithm with adaptive weight applied in this paper, the expression of the weighting coefficient is:

\[
\omega = \begin{cases} 
\omega_{\text{min}} & f \leq f_{\text{avg}} \\
\omega_{\text{min}} + \frac{(\omega_{\text{max}} - \omega_{\text{min}}) \cdot (f - f_{\text{min}})}{f_{\text{avg}} - f_{\text{min}}} & f > f_{\text{avg}} 
\end{cases}
\]  

(12)

Among them, \( \omega_{\text{min}}, \omega_{\text{max}} \) are the minimum and maximum values of \( \omega \) respectively, \( f \) is the current objective function value of the particles, \( f_{\text{min}} \) and \( f_{\text{avg}} \) are the current minimum target value and the average target value of all particles respectively.

The weight coefficient \( \omega \) adjusts its own size according to the change of the objective function value of the particle, thereby improving the optimization effect of the algorithm.

3. Network reconstruction and model simulation analysis

In general, the mathematical model selected by the reconstruction network is the minimum value of the active network loss. However, considering the factors of system stability, in the process of pursuing the minimum active power loss, it is necessary to ensure that the reactive power is in a reasonable range. In this paper, the minimum weighting value of total reactive power optimization and total active network loss is selected as the objective function. Its mathematical expression is:

\[
F = \min \sum_{j=1}^{n} \left[ \lambda R_j \cdot \frac{P_j^2 + Q_j^2}{U_i^2} + (1 \cdot \lambda) \cdot Q_j \right]
\]  

(13)

Among it, \( F \) is the objective function value, \( \lambda \) is the weighting coefficient, \( R_j, P_j, Q_j \), and \( U_i \) are the resistance, active power, reactive power, and node voltage of the i-th branch, respectively.

Different node types of wind power and photovoltaic access to systems would have different effects on the performance of the power network. Distributed energy is more suitable as a PV node to access to the power network. When they are connected to the power network as the PQ nodes and the
PV nodes, the system has a good effect on the reduction of the active power loss and the improvement of the system’s economical efficiency, but the voltage of the system may exceed the limit and the voltage quality would decrease.

When they are connected to the power network as the PV nodes, the reduction of the system’s active power loss and the improvement of the system’s economical efficiency are not as good as the former, but the voltage of the system doesn’t exceed the limit, and the voltage quality is maintained in a good state. This paper selects PV nodes as the node types for wind power and photovoltaic to access to the system. The compensation nodes and compensation capacity of the wind turbines and photovoltaics are as shown in Table 1.

Table 1. Compensation nodes and compensation capacity of wind turbines and photovoltaics.

| Model | compensation node number | compensation capacity /pu |
|-------|---------------------------|---------------------------|
| IEEE-14 wind turbine | 6 | 0.2 |
| photovoltaic | 3 | 0.5 |
| IEEE-30 wind turbine | 8 | 0.15 |
| photovoltaic | 13 | 0.2 |

The power flow data before and after the wind turbines and photovoltaics access to power network is organized as shown from Table 2 to Table 3.

Table 2. Power flow data before and after the wind turbines and photovoltaics access to the power network.

| Model | original network | unoptimized network | optimized reconstruction network |
|-------|------------------|---------------------|--------------------------------|
| IEEE-14 | Network power loss /pu | 0.1314 | 0.06678 | 0.06542 |
| | Reactive power /pu | 1.178 | 0.922 | 0.9315 |
| IEEE-30 | Network power loss /pu | 0.0606 | 0.0463 | 0.0418 |
| | Reactive power /pu | 1.372 | 1.317 | 1.354 |

Table 3. Comparison of power flow data between power networks with the wind turbines and photovoltaics connected and the original corresponding networks.

| Model | un-optimized reconstruction network | optimized reconstruction network |
|-------|-------------------------------------|--------------------------------|
| IEEE-14 | network power loss improvement /% | 49.2% | 50.2% |
| | Reactive power improvement /% | 21.7% | --- |
| IEEE-30 | network power loss improvement /% | 23.6% | 31.0% |
| | Reactive power improvement /% | 4% | --- |
The node voltages before and after the wind turbines and photovoltaic access to the power network are as shown from Figure 1 to Figure 2.

![Figure 1. IEEE-14 node voltage comparison.](image1)

![Figure 2. IEEE-30 node voltage comparison.](image2)

It can be seen from the analysis of Figure 1 and Figure 2 that the node voltages of the optimized reconstruction networks in IEEE-14 and IEEE-30 are generally unchanged compared with the original network. The numerical values are improved, and they don’t exceed the limit. According to the analysis of Table 2 and Table 3, compared with the original network, the reactive power output and network power loss of the unoptimized reconstruction networks in IEEE-14 and IEEE-30 have improvement to a certain extent, and have better effect on optimizing reconstruction network. Thereby, the inclusion of distributed energy in the power network is of great significance to the reliability and economic enhancement of the system.

### Table 4. Comparison of simulation results (network power loss)

| Model       | original network | reconstruction network |
|-------------|------------------|------------------------|
| IEEE-14     | Network power loss /pu | 0.142 | 0.072 |
| IEEE-30     | Network power loss /pu | 0.087 | 0.057 |

As can be seen from the comparison in Table 4, the power loss after the network is reconstruction is reduced.

The voltage, network power loss and reactive power output of each node are taken as the goal to judge the impact on the economical efficiency of the system, and adjust constantly the ratio of the two distributed energy access to the system. The optimization measures to the system are as follows:

IEEE-14, when the total capacity of the distributed power supply is 0.7 (the data is the per-unit value of the active power, the same below), the comprehensive effect is the best. When the capacity is less than 0.7, the optimized voltage exceeds the limit, and the optimization curve is distorted when the capacity is greater than 0.7. It is recommended to select the wind turbines to access to node 6 and to choose 0.2 as the injection capacity, the photovoltaic to access to node 3 and to choose 0.5 as the injection capacity as well. In the case of equal injection capacity and substantially equal reactive output, the network power loss is minimal and the voltages don’t exceed the limit. The following proportion of distributed energy access to the system is recommended: 5.8% for wind turbines and 14.58% for photovoltaics.

IEEE-30, when the total capacity of the distributed power supply is 0.35, the comprehensive effect is the best. When the capacity is less than 0.35, the optimization effect is poor. When the value is greater than 0.35, the optimization curve is distorted. It is recommended to select the wind turbines to access to node 8 and to choose 0.15 as the injection capacity, the photovoltaic to access to node 13 and to choose 0.2 as the injection capacity as well. In the case of equal injection capacity, the reactive power output and the network power loss are the smallest, and the voltages don’t exceed the limit.
following proportion of distributed energy access to the system is recommended: 4.63% for wind turbines and 6.18% for photovoltaics.

In order to ensure the stability of the system, the proportion of distributed energy accounts for less than 25% of the total capacity is the acceptable range to access to the system. Through analysis, the proportion of distributed energy access to power network in IEEE-14 and IEEE-30 is in a reasonable range and has referential value.

4. Conclusion

Due to the rapid development of the national economy and the improvement of the quality of users’ life, the requirements for power development are also growing day by day. The reconstruction of power networks has become a trend. The distributed energy, by virtue of certain economical efficiency, reliability, flexibility, environmental protection and so forth, has become the best choice to connect to the grid. In this paper, the particle swarm optimization algorithm with adaptive weight and Newton-Raphson method are used to study the problem of connecting the distributed energy to the grid.

The main research results of this paper are summarized as follows:

- The particle swarm optimization algorithm with adaptive weight avoids the situation that the algorithm gets into (be lost in) the local optimal solution and complete the convergence too early, thus improving the search ability of the whole network.
- Select the minimum weighting value of total reactive power optimization and total active power network loss as the objective function, and use MATLAB to combine the particle swarm algorithm with adaptive weight with Newton-Raphson method so that it could be better to deal with the reconstruction of power network in conclusion of distributed energy.
- The improved algorithm is applied to IEEE-14 and IEEE-30, and the reconstruction results are analyzed. The network power loss and reactive power of the reconstruction network decrease, and the voltage quality is improved.
- SIMULARTOR software is used to establish the original model and reconstruction model of IEEE-14 and IEEE-30 respectively, and also to calculate power flow. Compared with the above results, the results are basically consistent, and the accuracy and reliability of the algorithm are verified.

Considering the economic factors of the system, adjusting the capacities of two distributed energy to access to the system and obtaining the best access ratio, make the system's economical efficiency improved.

5. Appendices

Appendix A. IEEE-14 BUS SYSTEM

Appendix B. IEEE-30 BUS SYSTEM
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