Optimization of reactive power in distribution networks with DG based on improved particle swarm algorithm

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Abstract. The integration of Distributed Generation (DG) into the distribution network can effectively alleviate the problems of energy shortage and air pollution, but the DG output has the characteristics of uncertainty and randomness, and the integration will lead to the change of distribution network tide distribution, which will further lead to the change of distribution network operation mode with the scale development of DG integration. In this paper, we adopt the improved particle swarm algorithm (PSO) for reactive power optimization calculation of distribution network and establish the optimization model with the system network loss as the objective function and node voltage, reactive power compensation output and transformer tapping position as the main constraints. The inertia weights of PSO are improved to make it adaptive with increasing number of iterations, and the acceleration factor is improved so that the whole particle search capability is achieved. Finally, the reactive power optimization analysis is carried out for the IEEE 33-node distribution system containing distributed power sources. The results show that DG can enhance the stability of grid operation and the proposed algorithm has good optimization performance.

1 Introduction

The integration of distributed generation (DG) into the distribution network can effectively alleviate the problem of energy depletion in which thermal power generation is the main form and reduce environmental pollution, but the integration of DG will lead to the change of distribution network tide distribution and thus change the operation of the distribution network [1-6]. Since the distribution grid voltage is closely related to the reactive power in the system, it is important to study the reactive power optimization of the distribution grid containing DG to improve the power quality and ensure the stable and stable operation of the system [7].

One of the most important parts of the optimization process is the algorithm, the principle of particle swarm algorithm is simple, with easy to implement and other characteristics, in recent years, with the development of computer technology, the algorithm is applied to new research areas such as artificial intelligence [8-9]. However, because the algorithm is limited by the convergence accuracy, easy to "premature" and other problems, many scholars at home and abroad have made a lot of improvements to this problem [10-12]. The improvement ideas mainly come from three aspects: improving the structure of the algorithm, improving the topology of the algorithm itself, improving the parameters related to the algorithm and introducing other algorithms to combine with it [13,14]. In the literature [15-18], the conventional mathematical weights are improved to random weights, which can ensure the population diversity and im-prove the phenomenon of "early maturity" if the particles obey the influence of random numbers during the search process, which is more conducive to the global search. In the literature [19] proposed an idea to adjust the inertia weight coefficients by using the inverse incomplete function. The effect of linear decreasing in the first half of the particle search and exponential decreasing in the second half is achieved after using the inverse incomplete function, so that the skills ensure the whole spatial search range in the first half and ensure the accurate and fast convergence in the later period. The literature [20] proposes an improved idea based on the cosine function. The cosine function in the concave function segment combined with the convergence characteristics of the algorithm can improve the efficiency of the algorithm to find the best. As the progress of the iterative process begins, the value of the cosine function part gradually becomes smaller, so the value of w also becomes smaller, which can solve the problem of the algorithm falling into local optimum. The literature [21] quantified the particles out of the algorithm and determined the positions of the particles by Monte Carlo simulation, which can effectively improve the problem of poor convergence of the algorithm. In the literature [22], based on the PSO.

On the binning and fission, the diversity of particles is maintained to avoid premature convergence, and the search accuracy of the algorithm is strengthened, and the convergence stability is improved through ensemble and variation.

In this paper, the inertia weights and acceleration factors are improved based on PSO to ensure the search speed and accuracy of the particles in the whole process of iteration and optimize the optimization seeking direction. An optimization model with system network loss net loss
minimization as the objective function and node voltage, reactive power compensation output and transformer tapping position as the main constraints is established. Finally, the IEEE-33 node distribution system containing distributed power supplies is used as an example for reactive power optimization analysis. Table 1. Setting Word’s margins.

2 Tidal current calculation of distribution network containing DG

2.1. Basic concepts of distribution network tide calculation

For a given power network, the parameters are power supply and load power, node voltage magnitude and phase angle. The known quantities are generally the parameters of power supply, load, balance nodes, etc.; the quantities to be solved are generally the voltage magnitude and phase angle of each bus, branch power, etc.

Distributed power access leads to a more complex distribution network structure, which also affects node voltage and node power, and has an impact on system operation. The objective function established when performing reactive power optimization generally has the minimum active power loss, and the active power in the network equation is expressed as follows:

\[
I = YU
\]  
(1)

Let there be \(n\) nodes in the system, of which there are \(m\) PQ nodes, the network equation is expressed as:

\[
I = \sum_{j=1}^{m} Y_{ij} U_j, \quad i = 1, 2, \ldots, n
\]  
(2)

Where, \(I_i\) refers to the current injected at node \(i\); \(U_j\) refers to the voltage at node \(j\); \(Y_{ij}\) is the node derivative matrix; \(n\) is the total number of nodes in the system.

\[
I_i = \frac{P_i - jQ_i}{U_i}, \quad i = 1, 2, \ldots, n
\]  
(3)

Equation (3) represents the relationship between node power and current. Bringing equation (3) into equation (2) yields

\[
P_i - jQ_i = \sum_{j=1}^{n} Y_{ij} U_j, \quad i = 1, 2, \ldots, n
\]  
(4)

Equation (4) is the basic equation for tidal current calculation. Expressions in complex form can be obtained in two forms, one is the complex form established in the right-angle coordinate system and the other is the complex form established in polar coordinates.

\[
P_i = e_i \left( \sum_{j=1}^{m} (G_{ij} e_j - B_{ij} f_j) + f_i \sum_{j=1}^{m} (G_{ij} f_j + B_{ij} e_j) \right), \quad i = 1, 2, \ldots, n
\]  
(5)

\[
Q_i = f_i \left( \sum_{j=1}^{m} (G_{ij} e_j - B_{ij} f_j) - e_i \sum_{j=1}^{m} (G_{ij} f_j + B_{ij} e_j) \right), \quad i = 1, 2, \ldots, n
\]  
(6)

Equation (5) and (6) are the tidal current calculation equations in the right-angle coordinate system form, and Equation (7) and (8) are the tidal current calculation equations in the polar coordinate form.

2.2 Tidal Current Equation

The tide calculation is part of the steady-state analysis, while the tide calculation is the basis for reactive power optimization.

2.2.1 Tidal Current Equation

Using the nodal analysis method, the relationship between the voltage and current at each node in the power network is expressed as follows:

\[
I = YU
\]  
(1)

Where, \(Y\) is the nodal admittance matrix; \(U\) refers to the voltage at each node; \(Y\) and \(U\) are the system admittance matrix and node voltage vector, respectively; \(n\) is the number of nodes.

2.2.2 Common tide calculation methods

The main methods of tidal current calculation are Gauss-Seidel method, Newton-Raphson method, PQ decomposition method.

(1) Gauss-Seidel method

The Gauss-Seidel method is based on the principle of matrix decomposition. The main idea is that for a given initial value, an estimate of the variable is obtained by calculation and brought to the next iteration to solve for the new estimate, updating the estimate step by step iteratively until the iteration conditions are met. The principle is simple and computationally small when using the Gauss-Seidel method for tide calculation, but the convergence speed is slow and not widely applicable.

(2) Newton-Raphson method

The Newton-Raphson method is referred to as the Newton-La method. The Newton-Raphson method is effective in solving nonlinear algebraic problems. The idea of solving lies in transforming nonlinear algebraic equations into the corresponding linear equations. The method has square convergence property, convergence speed can solve most of the pathological circuits, and can use sparse technology to reduce memory. However, the algorithm is complicated to program, has a strong dependence on the initial value, needs to recalculate the Jacobian matrix for each iteration, and the solution process is complicated and computationally intensive.

(3) PQ decomposition method

The PQ decomposition method is a simplification of the Oxla method expressed in polar coordinates. The difference with the Oxla method is that the nodal power in the PQ decomposition method is represented by the polar coordinate form of the voltage vector. The PQ decomposition method is suitable for power grid of 110kV
and above, and has the advantages of fast convergence, fast calculation speed, small calculation volume and low memory occupation.

2.3 Tidal current calculation for distribution networks containing DG

As already analysed, distributed power supply has a certain impact on the grid voltage and power loss when it is connected to the grid. When the distributed power supply is connected to the grid in the light load area, the power from the distributed power supply will generate additional power loss through the line transmission, which will cause the transmission efficiency to drop, so the distributed power supply should be connected to the long line or heavy load area.

2.3.1 DG access to distribution network voltage

The main purpose of the tide calculation for power systems is to obtain information on the active and reactive power, phase angle and magnitude of each node in the network. However, with the access of distributed power sources, the traditional radial distribution network structure and tidal flow direction have changed, and the location of the distributed power sources into the network has a direct impact on the node voltage amplitude and branch power. Figure 1 and Figure 2 show the equivalence circuit model of the traditional distribution network and the equivalent circuit model of the distributed power supply, respectively.

![Fig. 1. Simplified model of traditional distribution network.](image1)

![Fig. 2. Simplified model of DG distribution network.](image2)

Calculation of voltage losses in conventional distribution network equivalent circuits.

\[
\Delta U_{ij} = \frac{P_{ij}R_l + Q_{ij}X_l}{U_N} \tag{9}
\]

Where, \(U_N\) is the rated voltage of the line. Then the total voltage loss of the network is

\[
\Delta U = \Delta U_{01} + \Delta U_{12} = \frac{P_{R1}R_1 + Q_{X1}X_1}{U_N} + \frac{P_{R1}R_2 + Q_{X2}X_2}{U_N} \tag{10}
\]

Thus, \(U_2\) can be expressed as

\[
U_2 = U_0 - \Delta U = U_0 - \frac{P_{R1}R_1 + Q_{X1}X_1}{U_N} - \frac{P_{R2}R_2 + Q_{X2}X_2}{U_N} \tag{11}
\]

If the distributed power supply is connected at node 1, the voltage at this point is

\[
U_1' = U_0 - \Delta U' = U_0 - \frac{P_{R1}R_1 + Q_{X1}X_1}{U_N} + \frac{(R_1 - P_{D1})R_1 + (Q_1 - Q_{D1})X_1}{U_N} \tag{12}
\]

Similarly, if the distributed power supply is connected at node 2, the voltage is

\[
U_2' = U_0 - \Delta U' = U_0 - \frac{P_{R1}R_1 + Q_{X1}X_1}{U_N} - \frac{(R_2 - P_{D2})R_2 + (Q_2 - Q_{D2})X_2}{U_N} \tag{13}
\]

Comparing equations (11), (12) and (13), it can be concluded that the voltage will change after the distributed power supply is connected to the distribution network, the voltage loss will be reduced and the node voltage will be increased, but the magnitude of the increase is related to the power output of the connected distributed power supply and the location of the connection.

2.3.2 DG access to the distribution network loss

In a conventional network, power flows from the power source to the load, and the load consumes power equal to the sum of the power output from the power source and the power loss during transmission. After connecting to the distributed power supply, the load power is provided by both the power supply and the distributed power supply. Let the load consume active power and reactive power at a fixed rate and the line voltage is kept constant. From Kirchhoff’s current law, we have

\[
I_L = I_s + I_{DG} \tag{14}
\]

Where, \(I_L\) is the load current; \(I_s\) is the power supply current; \(I_{DG}\) is the distributed power supply current. The load current and distributed power supply current are expressed as

\[
I_L = \frac{P_s - jQ_s}{3U} \tag{15}
\]

\[
I_{DG} = \frac{P_{DG} - jQ_{DG}}{3U} \tag{16}
\]

For a network connected to a distributed power supply, the network loss in the network contains two parts: one part is the network loss from the power supply side to the distributed power supply side; the other part is the network loss from the distributed power supply side to the load side. Bringing in equations (15) and (16) to calculate the two parts of network loss are expressed as

\[
P_{L-DG} = \frac{3r x^2}{U^2} (P_s^2 + Q_s^2 + P_{DG}^2 + Q_{DG}^2) \tag{17}
\]

\[
P_{L-DG} = \frac{3r (y-x) I_s^2}{U^2} \tag{18}
\]

Where, \(r\) is the line resistivity; \(x\) is the distance between the power source and the distributed power access node; \(y\) is the distance between the power point and the load. Therefore, the active power loss of the system after...
accessing the distributed power supply is the sum of the above two parts of network loss, i.e.

\[ P_L = P_{L\rightarrow DG} + P_{L\rightarrow PS} \]  

According to the above analysis, it can be concluded that the active network loss is composed of two parts after the system is connected to the distributed power supply, but the total active network loss decreases, and the decrease is related to the power output of the distributed power supply and the location of the access node.

### 3 Improved particle swarm algorithm

In particle swarm search, we often face two problems: first, what is the number of particles in a known search area to achieve a better search effect? If the number of particles is too small, the search efficiency will be slow and the search effect will be poor; if the number of particles is large, it will lead to particle waste and increase the computation time of the algorithm. Secondly, should the iteration mode of particle swarm be synchronous or asynchronous? The synchronous mode can make the particles all per-form a complete search with the same overall cognitive level, while the asynchronous mode has better convergence speed and accuracy of the particle swarm algorithm. In order to make the particle swarm algorithm with better convergence speed and convergence accuracy, the search ability before and after particle iteration remains basically the same, some scholars propose the inertial weight coefficient \( w \), which is the standard PSO algorithm, expressed as follows.

\[
\begin{align*}
    v_{i,d}^{k+1} &= w v_{i,d}^{k} + c_1 r_1 (p_{i,d}^{k} - x_{i,d}^{k}) + c_2 r_2 (p_{g,d}^{k} - x_{i,d}^{k}) \\
    x_{i,d}^{k+1} &= x_{i,d}^{k} + v_{i,d}^{k+1}
\end{align*}
\]  
(20)

where, \( w \) is the inertia weight factor. The magnitude of the inertia weight factor can directly affect the particle velocity in the next stage.

In the literature [23], it is believed that there is a connection between inertia weights and iterative particle search, and inertia weights are more favorable for global search and vice versa for local search. After increasing the inertia weight factor, the particle should be able to quickly search the search space and traverse all positions in the space in the early stage of the search, and quickly find the region where the global op-timal solution is located. Y. Shi et al. have verified through extensive experiments that the inertial weight factor decreases linearly from 0.9 to 0.4. \( w \) the linear decreasing formula is as follows.

\[
w = w_{start} - \frac{w_{start} - w_{end}}{T_{max}} \times T
\]  
(22)

where, \( w_{start} \) and \( w_{end} \) are the starting inertia weight and the ending inertia weight coefficients, respectively. \( T \) is the number of iterations currently performed, and \( T_{max} \) is the maximum number of iterations.

As mentioned in the literature [24], when \( w \) is at a large level, it is more favorable for the particle to search the whole spatial region; when \( w \) is at a small level, it will be easier for local search or exact optimization search. Some scholars use linear decreasing strategy to improve this, which does work for a certain period of time, but with the gradual complexity of the PSO optimization problem, a single linear decreasing strategy gradually fails to meet the actual optimization search process.

In summary, this paper will improve the parameters of both inertia weights and acceleration factors of the particle swarm algorithm.

#### 3.1 Improvement of inertia weighting factor

As one of the important parameters constituting the particle swarm algorithm, the role of the inertia weight factor is reflected in the ability of the current particle to inherit the velocity of the particle under the previous iteration and has a greater impact on the velocity of the particle in the next iteration. A larger inertia weight factor is more beneficial to the global search ability of the particles, while a smaller inertia weight factor is more beneficial to determine the optimal value for the local search. In general, the particle swarm algorithm requires that the particles should have a strong search ability in the early stage of the search, and the particles should have a better search ability in the later stage as the number of iterations increases. It is common to set the inertia weight factor as a constant or a time variable. When it is set to constant, such as the standard particle swarm algorithm, it can ensure a good search ability and conver-gence speed in the early stage of the search, but in the later stage of the particle update is not enough, easy to "premature". When set to time-varying variables, it facilitates the ability of the particles to jump out of the local optimum at a later stage.

In this paper, we propose a strategy that has an adaptive adjustment capability for \( w \). Let \( w \) have the adaptive ability of decreasing with the number of iterations, basically by changing \( w \) slowly and keeping a large value in the early iterations and making the value of \( w \) decrease faster in the later iterations.

\[
w(t) = w_{end} + (w_{start} - w_{end}) \frac{T}{T_{max}}
\]  
(23)

Where, \( t \) is the current iteration number; \( T_{max} \) is the maximum iteration number; \( w_{start} \) and \( w_{end} \) denote the starting and ending values of \( w \) iteration, respectively, which are set to 0.9 and 0.4 here.

#### 3.2 Improvement of acceleration factor

In standard particle swarm algorithms, two acceleration factors are simply taken to be equal, indicating that the particles are moving toward two different optimal positions with equal weights, however, in practice, the particles have different search priorities at each stage, and simply taking two acceleration factors will disrupt the iterative process of finding the optimal direction. In this paper, we improve the acceleration factor so that its size increases with the number of iterations.

\[
\begin{align*}
    c_1(t) &= c_{1\text{start}} - (c_{1\text{start}} - c_{1\text{end}}) \times \frac{T_{max} - t}{T_{max}} \\
    c_2(t) &= c_{2\text{start}} + (c_{2\text{start}} - c_{2\text{end}}) \times \frac{T_{max} - t}{T_{max}}
\end{align*}
\]  
(24)

Where, \( t \) denotes the current iteration number; \( T_{max} \) is the maximum iteration number, \( C_{1\text{start}}, C_{2\text{start}} \) denotes the starting and ending values of the acceleration factor \( C_{1}; C_{2} \).
4 Reactive power optimization model with DG

4.1 Objective function

The objective function of the research problem in this paper is the optimal total network loss, and the expression is as follows.

\[ f = \min P_{\text{loss}} = \sum_{i=1}^{n} G_{k,j}(U_i^2 + U_j^2 - 2U_iU_j \cos \theta_{ij}) \]  

(26)

where, \( P_{\text{loss}} \) denotes the total active network loss of the system; \( G_{k,j} \) denotes the conductance of branch \( k \); \( U_i, U_j \) denote the node voltage of nodes \( i \) and \( j \) respectively; \( \theta_{ij} \) denotes the phase angle difference between two nodes \( i \) and \( j \), expressed by equation (27); \( n \) denotes the total number of branches of this system.

4.2 Constraints

The constraint conditions are divided into equation constraints and inequality constraints. The equation constraint contains active power balance and reactive power balance. The inequality constraints are mainly node voltage, generator reactive power, reactive power compensation equipment output and transformer tap position con-strains. The objective function of Equation (27) is constrained by the above constraints.

4.2.1 Equation constraints

The equation constraint is based on the law of energy conservation which requires that the active and reactive power flowing into or out of each node are equal.

\[ P_G - P_D = U_i \sum_{j=1}^{n} (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \]  

(28)

\[ Q_G + Q_D = U_i \sum_{j=1}^{n} (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \]  

(29)

Where, \( \theta_{ij} \) denotes the phase angle difference between nodes \( i \) and \( j \), expressed by equation (27); \( G_{ij} \) and \( B_{ij} \) are the conductance and electroneutrality between nodes \( i \) and \( j \), respectively; \( Q_G \) is the compensation capacity of the reactive power compensation equipment added at node \( i \); \( P_G \) is the active power injected by the generator connected at node \( i \); \( P_D \) is the active power of the load at node \( i \); \( Q_G \) is the reactive power injected by the generator connected at node \( i \); \( Q_D \) is the reactive power of the load connected at node \( i \); \( n \) is the total number of nodes in the system. Where, \( i=1, 2,...n \).

4.2.2 Inequality constraints

The control variable constraints are generally.

\[ \Delta U_{ij} = \frac{P_{R_i} + Q_{X_i}}{U_N} \]  

(30)

\[ U_{G_i,\min} \leq U_{G_i} \leq U_{G_i,\max}, i = 1,2,...N_G \]  

(31)

\[ Q_{i,\min} \leq Q_i \leq Q_{i,\max}, i = 1,2,...N_c \]  

(32)

\[ P_{G_i,\min} \leq P_{G_i} \leq P_{G_i,\max}, i = 1,2,...N_G \]  

(33)

\[ T_{i,\min} \leq T_i \leq T_{i,\max}, i = 1,2,...N_T \]  

(34)

Where, \( U_{G_i} \) is the generator terminal voltage; \( P_{G_i} \) is the active power; \( Q_i \) is the reactive power compensation device compensation capacity; \( T_i \) is the transformer ratio; \( U_{G_i,\min}, U_{G_i,\max} \) are the lower and upper limits of the generator terminal voltage amplitude at node \( i \); \( P_{G_i,\min}, P_{G_i,\max} \) are the lower and upper limits of the active power output of DG; \( Q_{i,\min}, Q_{i,\max} \) are the lower and upper limits of the compensation capacity; \( T_{i,\min}, T_{i,\max} \) are the lower and upper limits of the adjustable ratio of transformer \( i \); \( N_G, N_c \) and \( N_T \) are the number of DGs, the number of reactive power compensation devices and the number of transformers, respectively.

The state variable constraints are generally.

\[ U_{D_i,\min} \leq U_{D_i} \leq U_{D_i,\max}, i = 1,2,...N_D \]  

(35)

\[ Q_{G_i,\min} \leq Q_{G_i} \leq Q_{G_i,\max}, i = 1,2,...N_G \]  

(36)

Where, \( U_{D_i} \) is the voltage amplitude of the load node; \( U_{D_i,\min}, U_{D_i,\max} \) are the lower and upper limits of the voltage amplitude of the load node; \( Q_{G_i} \) is the reactive power amplitude of the generator output; \( Q_{G_i,\min}, Q_{G_i,\max} \) are the lower and upper limits of the generator output reactive power. \( N_D, N_G \) are the number of load nodes and DGs respectively.

Considering the possibility of the constraint variables crossing the limit, this paper uses a penalty function to introduce the constraints as penalty terms into the objective function.

\[ \min F = P_{\text{loss}} + K_u \sum_{i=1}^{N} \left( \frac{U_{D_i} - U_{D_{i,\min}}}{U_{D_{i,\max}} - U_{D_{i,\min}}} \right)^2 + K_v \sum_{i=1}^{N} \left( \frac{Q_{G_i} - Q_{G_{i,\min}}}{Q_{G_{i,\max}} - Q_{G_{i,\min}}} \right)^2 \]  

(37)

Where, \( K_u \) and \( K_v \) are penalty coefficients.

5 Results and Discussion

5.1 Base data of the algorithm system

The basic model of this example is selected from the IEEE-33 node distribution network model, which
contains 32 branches and 5 contact switch branches, except for node 1 which is a balance node, the remaining nodes are load nodes. The three-phase power reference value is 10MW and the voltage reference is 12.66kV.

As shown in Figure 3. There is one on-load regulator transformer (ratio range: 0.9-1.1, regulation step of 0.0125 connected to node 1 in this node system; nodes 7, 24 and 30 are connected to a distributed power supply, with the connection type and parameters shown in Table 1. and nodes 6 and 31 are connected to a set of capacitors (maximum capacity of 1050kW, regulation step of 8-21, 9-15, 12-22, 18-33 and 25-29 are five contact lines, which serve two main purposes: one is for the study of distribution network re-configuration, and the other is to consider the situation when a line fault causes the normal power supply to be unable to adjust the contact line switch for temporary power supply. Therefore, the impact of the contact line on the network is not considered in this paper. In addition, located in DG before the grid connection of the on-load regulator transformer ratio of 1, the compensation capacity of both groups of capacitors is 0kvar.

Table 1. DG types and parameters.

<table>
<thead>
<tr>
<th>DG</th>
<th>Access Node</th>
<th>Category</th>
<th>Meritorious contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7</td>
<td>Photovoltaic power plants</td>
<td>200kW</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
<td>Double-fed fans</td>
<td>400kW</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>Double-fed fans</td>
<td>400kW</td>
</tr>
</tbody>
</table>

5.2 Analysis of results

IEEE-33 node is more complex, this paper uses matpower7.0, an m-file package in MATLAB, to carry out the relevant calculations of the nodes and obtain the voltage and phase angle data of each node before the optimization of the IEEE-33 node operating state without access to DG. The total active power loss of the system is 201.7153kW in the above basic tide calculation result, among which the highest voltage amplitude is 0.913p.u at node 18 and 0.917p.u at node 33, which is the end node of the system, and the average voltage amplitude of each node of the system is 0.949p.u. The overall voltage level of the system is high and there is a certain situation of crossing the limit. In this paper, we set $C_i$, $C_j$ and $w$ of the algorithm according to equations (23), equations (24) and equations (25). The reactive power optimization of the IEEE-33 node system is performed using this algorithm and the standard PSO respectively, setting the number of search particles to 50 and the maximum number of iterations to 150, where the standard PSO has $C_1=C_2=2$ and $w=0.5$. Before the calculation, we need to assign initial values to multiple transformers and shunt capacitor banks. The on-load regulator transformer ratio is taken as 1 and the shunt capacitor bank initial value is taken as 0.

With equations (37) as the optimization objective, the objective function value is obtained by calculation. The optimized results after applying the two algorithms are shown in Table 2.

Table 2. Optimization results of different algorithms.

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Before optimization</th>
<th>Standard PSO</th>
<th>Algorithm of this paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active network loss/kW</td>
<td>201.7153</td>
<td>140.6299</td>
<td>114.0520</td>
</tr>
<tr>
<td>Transformer Ratio</td>
<td>1</td>
<td>0.9875</td>
<td>0.95</td>
</tr>
<tr>
<td>Qc6/kvar</td>
<td>0</td>
<td>450</td>
<td>150</td>
</tr>
<tr>
<td>Qc31/kva</td>
<td>0</td>
<td>750</td>
<td>300</td>
</tr>
<tr>
<td>QG7/kvar</td>
<td>0</td>
<td>301.7847</td>
<td>581.2118</td>
</tr>
<tr>
<td>OG24/kvar</td>
<td>0</td>
<td>368.9347</td>
<td>402.1764</td>
</tr>
<tr>
<td>QG30/kvar</td>
<td>0</td>
<td>428.0225</td>
<td>793.4801</td>
</tr>
</tbody>
</table>

From Table 2, the active network loss is significantly reduced after the system is integrated into DG, and the degree of reduction is related to the optimization algorithm used. From the comparison of the data in the table, the optimization results obtained by the algorithm in this paper are better than the standard PSO algorithm, indicating that the improved PSO algorithm proposed in this paper has better optimization performance. The calculation results also show that the optimization algorithm in this paper uses less reactive power from the reactive power compensation device, which can make better use of DG.

As can be seen in Figure 4, the improved PSO algorithm proposed in this paper is stronger than the standard PSO algorithm in terms of convergence and the energy of finding the optimal solution. As shown in Figure 4, the standard PSO algorithm achieves the optimal solution in 109 iterations, while the proposed algorithm achieves the optimal solution in only 54 iterations, which is 50.45% faster. Secondly, the final optimization result of standard PSO is 140.6299 kW, reducing the active network loss of the system by 30.28%, while the algorithm of this paper

![Fig 4. Comparison of active power loss before and after optimization](https://example.com/f4.png)
is 114.0520 kW, reducing the active network loss of the system by 43.46%, which shows that the optimization capability of the proposed algorithm is better than that of standard PSO. The above analysis shows that the proposed PSO algorithm outperforms the standard PSO in both optimization efficiency and convergence speed, which proves the effectiveness of the pro-posed model.

![Figure 5. Comparison of node voltage optimization before and after](image)

Figure 5 shows the node voltage comparison between the system before optimization, the standard PSO algorithm and the PSO algorithm proposed in this paper. After optimization, the voltage of the highest node 19 in the system is reduced from 0.998 to 1.089, the end voltage is changed from 0.925 to 1.051, and the average voltage of each point in the system is changed from 0.949 to 1.036, with a voltage optimization rate of 9.16%. The optimized system node voltages are all improved, basically between 1.0 and 1.05, which meet the voltage offset requirements.

In summary, the improved particle swarm algorithm proposed in this paper is more ideal for reactive power optimization of the IEEE-33 system.

This section analyses the grid voltage and network loss for accessing PQ, PI, PV, and PQ(V) type distributed power sources. The data and access points of each type of distributed power supply are shown in Table 3.

<table>
<thead>
<tr>
<th>Access to distributed power types</th>
<th>Access parameter setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQ</td>
<td>P=160kW ; Q=160kvar</td>
</tr>
<tr>
<td>PV</td>
<td>P=160kW ; U=0.98V</td>
</tr>
<tr>
<td>PI</td>
<td>P=160kW ; I=10A</td>
</tr>
<tr>
<td>PQ(V)</td>
<td>X=0.5pu ; xp=0.2pu</td>
</tr>
</tbody>
</table>

Table 3. Data and access points for each type of distributed power supply.

In summary, it can be concluded that the voltage increase at each node in the network is related to the type of distributed power supply and the access location. Compared with no access to the distributed power supply, the voltage at each point of the branch circuit where the access point is located increases to some extent.

6 Conclusions

In this paper, the problem that PSO is prone to fall into local optimal solutions is improved by improving inertia weights and acceleration factors for the reactive power optimization problem of DG access distribution network. The optimization simulation is carried out by the IEEE 33-node distribution network system containing DG. The results show that the system incorporated with DG can effectively reduce the active network loss and improve the voltage level, but the magnitude of the node voltage increase is related to the type of DG and the access location. The calculation results also verify that the algorithm proposed in this paper has good optimization performance and practical performance.

References


