Location Optimization of Distributed Generation Based on Improved Particle Swarm Optimization Considering Permeability

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Abstract. Currently, existing location methods are difficult to adapt to increasingly distributed generation (DG), owing to the rapid growth of distributed accessing scale and the uncertainty of time and space in new energy generation. In this paper, a novel combined Greedy algorithm (GA)/particle swarm optimization (PSO) is proposed for optimal location of DG on distribution systems. The impact of different access locations of distributed power sources on network loss and voltage distribution of distribution network is analyzed. Considering the minimum network loss and voltage stability, the permeability range of different access modes to distributed power generation is proposed. Finally, the feasibility of this method is verified by IEEE-33 node distribution network.

1. Introduction

In recent years, with the large-scale access of poverty-alleviating photovoltaic (PV) and wind energy in China, the complexity of optimal dispatch of active distribution network is increased accordingly. In particularly, with the large-area access of poverty alleviation photovoltaics, it has a certain impact on the safe and stable operation of the distribution network. In some areas, the permeability of distributed generation is close to 100%. It will have a large randomness for the access and exit of the distributed generation (DG). Thus, improper access of DG will have many negative effects on the power grid, such as poor stability of the distribution network, deterioration of voltage quality, and occurrence of harmonics and so on [1-2].

In this way, it is very necessary to consider the location of the DG in the planning stage. But the qualifications of traditional planning methods are relatively simple [3]. It is difficult to adapt to the current multi-objective optimization process in recent years [4]. The Heuristic Search Algorithm (HSA) was used to reconfigure the distribution network structure and determine the optimal location for installing distributed power (DG) in the distribution network [5]. However, in the calculation process, this algorithm needs as much heuristic information as possible to ensure the prediction accuracy of the optimal solution, which leads to low efficiency in actual use. The hypercube ant colony optimization algorithm (HC-ACO) has been applied to solve the problem of distribution network fault...
reconstruction. The algorithm shows better robustness, but it leads to a large amount of computation [6]. The genetic algorithm (GA) has the advantages of small computation and fast convergence in DG location, but it also shows that the calculation results are overly dependent on the initial value and it is difficult to search for the global optimal solution [7]. In addition, the particle swarm optimization (PSO) method is often used to determine the optimal configuration of the access point, but it is easy to fall into the local optimal problem when dealing with discrete problems [8].

Therefore, an improved PSO algorithm is proposed for the multi-target feeder reconstruction problem of distributed power generation. The algorithm searches the optimal solution in the selective space, which effectively improves the computational efficiency and guarantees the global optimization of the reconstruction results. Aiming at the problem of location of DG in the distribution network, a mathematical model including power loss, voltage quality and DG permeability is established as the objective function. Finally, the simulation was performed on the IEEE-33 standard node test system.

2. Establishment of multi-objective model

Considering the minimum line loss and voltage stability, the multi-objective non-linear combinatorial optimization problem of actual distribution network is solved. The objective function is as follows:

2.1. The Objective function of power loss minimization

\[
\min f_1 = \frac{\sum_{m=1}^{M} K_i r_i (P_i^2 + Q_i^2)}{U_i^2}
\]

Wherein \(M\) is the number of branches, \(k_i\) is the \(i\)-th road state, and \(r_i\) is the resistance value.

2.2. The Objective function of Voltage stability

\[
\min C_2 = \sum_{i=1}^{N} (U_i - U_{\text{exp}})^2
\]

Wherein \(N\) is the total number of distribution network nodes, \(U_i\) is the voltage of \(i\)-th node, and \(U_{\text{exp}}\) is the desired steady-state voltage amplitude (1.0p.u). Therefore, the multi-objective function is established as \(F = \min (f_1, f_2)\), and the the power flow equivalent constraints are as follows:

\[
P_i + P_{FGi} = U_i \sum_{j=1}^{N} U_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) + P_{Li}
\]

\[
Q_i + Q_{FGi} = U_i \sum_{j=1}^{N} U_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) + Q_{Li}
\]

\(P_{FGi}\) is injects active power of distributed power at node \(i\); and \(Q_{FGi}\) is injects active power of distributed power at node \(i\). Distributed power output power constraint can be expressed as:

\[
P_{FGi,\text{min}} \leq P_{FGi} \leq P_{FGi,\text{max}}
\]

Wherein \(P_{FGi,\text{min}}\) is minimum and maximum of adjustable power at node \(i\) about the distributed power, respectively.

In addition, it should be noted that, in the ideal case, when the DG permeability is 100% (that is, the DG capacity and the line load ratio \(K\) is 1), the line loss rate is the smallest. When the DG permeability is 200% (i.e. the DG capacity and the line load ratio \(K\) is 2), the line loss rate is the same
as when the DG is not connected; when the DG permeability is greater than 200% (i.e. the DG capacity and the line load ratio $K$ are greater than 2), the line loss rate increases as the value of $K$ increases.

2.3. Solution algorithm

PSO algorithm and greedy algorithm are both non-aftereffect algorithms, that is, the state before a certain stage will not affect the subsequent process, only related to the current state. The combination of the two algorithms can speed up the PSO algorithm and effectively improves the computational efficiency and guarantees the global optimization of the reconstruction results. When the PSO algorithm finds the individual best $p_{best}$ it enters the greedy sequence. When there is no repetition of each item in the greedy sequence, the optimal solution is easily obtained. In order to measure the quality of the feasible solution, we need to give a value function $F=\min (f_1, f_2)$. The feasible solution that maximizes or minimizes the objective function is called the optimal solution. The greedy sequence $[T_1, T_2, \ldots, T_n]$ establishes a new feasible solution $C$ according to priority order, finds the task $T_k$ with the highest priority in candidate set $C$, removes $K$ column, establishes solution set $S$, $j=i+1$, and obtains the optimal solution of the problem according to $F=\min (f_1, f_2)$. Flow chart shown in Figure 1.

![Figure 1. Flow chart of optimal sitting of DG with PSO-GA algorithm.](image)

For radial connection of overhead network, considering the normal level of line load rate in the range of 40%-50%, PSO algorithm and PSO-GA algorithm are used to optimize the location of distributed power supply when low permeability (10%), medium permeability (40%) and high permeability (80%) are selected respectively for the permeability of distributed power system. The following table shows the statistics of distribution line network loss under various distributed power supply access schemes.

| Algorithm          | Penetration rate | Power loss | Node          |
|--------------------|------------------|------------|---------------|
| PSO                | 10%              | 156.74     | 1, 2, 17, 25  |
| PSO-GA algorithm   |                  | 142.22     | 3, 8, 12, 16  |
| PSO                | 40%              | 144.54     | 1, 3, 18, 22  |
| PSO-GA algorithm   |                  | 102.21     | 31, 21, 24, 16|
| PSO                | 80%              | 177.22     | 23, 31, 31, 31|
| PSO-GA algorithm   |                  | 88.19      | 23, 24, 7, 29 |
According to the line loss calculation, the PSO-GA algorithm is better than the PSO algorithm in the distributed power supply location, which results in better network loss reduction. When the permeability is ≤100%, the penetration rate of DG is larger the effect of the loss reduction is more obvious.

3. Voltage quality assessment
The influence of different access locations of DG on the voltage distribution of distribution network is analyzed. In this paper, the IEEE-33 node distribution network standard model is adopted. The IEEE-33 node distribution network standard model is open-loop operation under normal operation mode. The rated voltage of the system is 12.66kV, the initial set active load is 3715kW, and the reactive load is 2300kVar.

When the permeability is low permeability (10%), medium permeability (40%) and high permeability (80%), the distribution of the two algorithms is compared.

![Figure 2](image1)

Figure 2. The voltage stability comparison when the permeability is 10%, 40% and 80%, respectively.

It can be seen from the figure 2 that the location of the PSO-GA algorithm is more advantageous than the location of the PSO algorithm. On the one hand, compared with the non-DG access, any kind of access scheme will enhance the voltage of each node. Especially for the nodes at the end of the feeder, the improvement effect is more significant.

4. Influences of Permeability on Voltage Quality
When the distributed power supply capacity is large, it is easy to cause the grid voltage to exceed the maximum allowable voltage. When the DG suddenly exits from operation, the voltage at the end of the feeder may be greatly reduced, causing problems such as voltage flicker and other power quality. The DG size has a great influence on the voltage quality. Therefore, it is necessary to change the permeability of the three access locations selected by the PSO-GA algorithm and study the influence of the access capacity on the voltage of each node.

![Table 2](image2)

Table 2. Three access modes selected by the PSO-GA algorithm.

| Scheme | Scheme 1 | Scheme 2 | Scheme 3 |
|--------|----------|----------|----------|
| Node number | 3, 8, 12, 16 | 31, 21, 24, 16 | 23, 24, 7, 29 |

![Figure 3](image3)

Figure 3. Two types of access schemes with different penetration rates.
The simulation results of the scheme 1 changing the distributed power penetration rate are shown in the figure. It can be seen from the figure that the distributed power supply has increased the voltage of each node along the line; when the access capacity is 90% and 100%, the voltage at the end of the feeder rises sharply, which causes the flow backwards. In addition, even if the access capacity is 40%, the maximum rate of change of the node voltage is still large. Therefore, in order to suppress voltage flicker, the access capacity is preferably less than 25%.

The simulation results of changing the permeability in Scheme 2 are shown in the figure. When the total capacity reaches 60% or more, the voltage of the nodes 19, 20, 21 exceeds the rated voltage. When the capacity is 40% or less, it can ensure that the maximum rate of change of the node voltage is small, the power quality problem of voltage flicker can be avoided, and the problem of power grid relay protection and reverse power is not affected. The best access capacity is less than 40% of the system capacity. At the same time, in order to prevent the local voltage from being severely exceeded, it is better to select a distributed power supply with a smaller capacity at the end of the feeder near the power supply terminal.

Scheme 3 has less effect on increasing the voltage of the access point, and most of the power is directly absorbed by the heavy load of the line, and there is no outstanding improvement for other branch feeders and the main feeder.

In summary, if the automation level of the distribution network is high and the feeder voltage regulation capability is strong, it is recommended to adopt a mode of distributed access along the main feeder. For the general distribution network, the way of feeder end access is an ideal access mode.

5. Conclusion
In this paper, the improved PSO algorithm is used to find the optimal access point of distributed power generation. The impact of different access locations of distributed power sources on network loss and voltage distribution of distribution network is analyzed. It is found that in order to reduce the line loss, the DG should be evenly connected or connected to the end of the feeder. Considering the optimization of the node voltage, the DG should be uniformly connected or connected to the end of the feeder line. Moreover, when the magnetic permeability is higher, the effect of the DG access feeder on the node voltage optimization is more obvious.

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