Active Distribution Network Fault Recovery Based on Particle Swarm Optimization

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Abstract. As a new mode of distribution network, it is necessary to study the minimum loss of active distribution network after line failure. Therefore, this paper proposes a method of active distribution network fault recovery based on particle swarm optimization (PSO). On the premise of satisfying the constraints of distribution network, this algorithm establishes an objective function model of balancing load based on reducing network loss. Using the active distribution network system of IEEE 33 node, the experimental simulation proves that the particle group algorithm can effectively solve the problem of active distribution network fault reconstruction by contrasting the particle group and ant group algorithm, and has the advantages of good stability and high efficiency.

1. Introduction

Recently, with more and more extreme weather events around the world, climate change and irreversible factors have brought more and more hazards to the large power grid system, and previous countermeasures are difficult to cope with the current emergency situation. Therefore, the concept of active distribution network system (ADS) has been proposed. The active distribution network overcomes the traditional distribution network mode in the past, and is able to comprehensively coordinate and control the grid-connected distributed power supply (DG) to realize the active planning, control, management and service of the distribution network [1-4]. However, due to the random and intermittent output of distributed generation in active distribution network (ADN), these factors will lead to voltage drop flicker and other phenomena in distribution network, and even reduce the power quality. Therefore, it is particularly important to study the grid loss after system failure.

In this paper, the previous studies on fault analysis are summarized as follows: Literature [5] studies the transient performance of distributed power supply fault recovery. Literature [6] takes longitudinal current differential protection as the main protection control mode of 10 kV line network segment, and studies the fault treatment and protection module of intelligent control terminal. Literature [7] considers the important means of optimizing power flow and reducing network loss in the planning stage for network reconstruction. Literature [8] deeply analyzes the fault characteristics of distributed generation and its impact on traditional protection under different preconditions. N.C. Koutsoukis and others introduced a multi-stage coordinated design method to minimize the present value of the net network investment cost for the active distribution network (ADN) [9]. Secondly, the algorithm of the optimization model is also studied and compared to some degree, for example, ant colony algorithm [10-11] genetic algorithm particle swarm optimization [12-14] and other optimization algorithms.
This paper mainly studies based on particle swarm optimization algorithm considering system recovery needs the minimum power loss, and to ensure that different power system components (such as transformer and line), safety of design in the event of a failure, also can't meet the bus voltage and line current limit exceed their respective operating conditions, the active power distribution network system fault recovery after the minimum network loss. Taking IEEE33 node distribution network as an example, experimental simulation experiments were carried out for ant colony algorithm and particle swarm optimization algorithm respectively, which proved that PSO can effectively solve the fault reconstruction problem of active distribution network and has the advantages of good stability and high efficiency.

2. Active distribution network fault recovery function

The objective of active distribution network restoration is to move the fault line to the normal line as much as possible through network reconstruction under the conditions of permissible operation and fault constraints, and the objective function of active distribution network restoration:

\[ \min f(x) = \sum_{i=1}^{N} \frac{s_i}{s_{i,\text{max}}} \]  

In the formula, \( s_i \) is the actual load, \( s_{i,\text{max}} \) is the maximum allowable load, and \( N \) is the total number of equipment.

In order to ensure that users can restore power in time, reduce the loss. At the same time, it is also necessary to ensure that when the distribution network system is restored to normal, the network loss is minimized.

\[ \min p = \sum_{i=1}^{N} K_i \left( \frac{P_i + Q_i}{U_i} \right) R_i \]  

Its constraint condition is:

\[ U_{i,\text{min}} \leq U_i \leq U_{i,\text{max}} \]

\[ S_i \leq S_{i,\text{max}} \]

Where, \( P \) represents the loss value of active distribution network; \( N \) represents the number of branches solved for the active distribution network system; Represents the state of the position of the i-branch switch in the system, which is 1 when connected to the active distribution network system and 0 when disconnected; \( P_i \) and \( Q_i \) respectively represent the reactive and active power lost on the i branch; \( u_i \) is the node voltage; \( R_i \) is the branch resistance.

3. Flow of particle swarm optimization algorithm and ant colony optimization algorithm

3.1. Mathematical description of particle Swarm optimization algorithm

In particle swarm optimization, the potential solution of the problem is regarded as the embodiment of the position of each particle [14]. If the whole particle swarm is composed of \( M \) particles, the particle position is \( x_i = (x_{i1}, x_{i2}, ..., x_{iD}) \), It is substituted into the fitness function \( f(x) \) to calculate the fitness value; The position velocity is expressed as \( V_i = (V_{i1}, V_{i2}, ..., V_{iD}) \); The optimal location of individual particles \( pbest_i = (P_{i1}, P_{i2}, ..., P_{iD}) \); The optimal location of the population \( gbest = (g_1, g_2, ..., g_D) \).

In particle swarm iteration, the velocity and position of the particle are:

\[ v_{id}^{k+1} = w v_{id}^{k} + c_1 r_1 (pbest_{id} - x_{id}^{k}) + c_2 r_2 (gbest_{id} - x_{id}^{k}) \]  

(5)
\[ x^{k}_{id} = x^{k-1}_{id} + v^{k-1}_{id} \]  \hspace{1cm} (6)

Among, \(v^{k}_{id}\) is the velocity of the particle; \(x^{k}_{id}\) represents the position of the particle for each iteration; \(c_1, c_2\) coefficient of acceleration; \(r_1, r_2\) is a random number distributed within \([0,1]\); \(w\) represent the inertia factor.

The flow of particle swarm optimization algorithm is as follows:

**Figure 1.** Flow chart of particle swarm optimization algorithm

### 3.2. A mathematical description of ant colony optimization

In the process of active distribution network reconstruction, the loss of each branch will change with the change of the whole network shape, that is, the weight of each side will change constantly, and it is far from enough to rebuild a tree with the minimum weight (namely the minimum loss of line network). Minimal-weight active distribution networks usually do not meet other limitations, such as voltage drop constraints. This paper introduces an ant colony algorithm which can learn the weight of each side. It reflects the preference degree of selected edges. The basic idea of ant colony algorithm is to choose a walking path according to the pheromone concentration and the transfer probability. After many iterations, the ant colony can reach the shortest path quickly, forming the positive feedback mechanism of pheromone. Which side the ant chooses from the set at any given time depends on the conversion probability. The probability that ant \(K\) at node \(B\) chooses to move to node \(C\) is:
In the formula:

$$P_{k,t}^{\tau}(c) = \begin{cases} \frac{\tau_{bc}^{\alpha}(t) \eta_{bc}^{\beta}(t)}{\sum_{b \in F^k} \tau_{bc}^{\alpha}(t) \eta_{bc}^{\beta}(t)}, & c \in F^k, \\ 0, & c \notin F^k. \end{cases}$$

(7)

In the formula: $F_i^k = \{0,1,...,m\}$, Represents the next feasible path for ant $K$; $\tau_{bc}^{\alpha}(t)$ is the pheromone on the edge $(b,c)$ at time $T$; $\eta_{bc}$ denotes reciprocal impedance of each side; $\alpha$ and $\beta$ respectively represent the pheromone accumulated by the individual ant during the journey and the parameters that determine the relative importance of the pheromone and the distance. In this way, the shorter and more pheromone edges are easier to select.

4. Practical example analysis

Taking IEEE 33-node distribution network as an example, this paper conducts experimental simulation of active distribution network fault reconstruction through two optimization algorithms, and makes a comparative analysis. Considering the minimum network loss, the fault recovery system was written with MATLAB, and the reconstruction results were shown in Figure 2.

As shown in Figure 2, after fault recovery, only the minimum network loss is considered. The contact switch 8-21, 12-22, 18-33, 25-29 is in a closed state, and the segment switch 7-8, 10-11, 15-16, 27-28, 9-15 is in a disconnected state. The switching operation is 9, the total network loss is 138.643kW, and the minimum node voltage p.U is 0.92873. Under the same conditions, the ant colony fault recovery
system was written with MATLAB, and the reconstruction results were obtained. See Figure 3, Connect 4 contact switches, such as 8-21, 12-22, 9-15, 25-29, and disconnect 4 segment switches, 7-8, 9-10, 14-15, 28-29. The switch operation is 8, the total network loss is 123.864kW, and the minimum node voltage p.U is 0.9431.

The simulation results show that both algorithms can realize the fault reconstruction of the network system. By comparing the two optimization algorithms, it can be seen that the particle swarm optimization algorithm can achieve the optimal network loss.

5. Conclusion
This paper studies the minimum power loss required for active distribution network fault recovery and reconstruction based on particle swarm optimization algorithm, and the main research results are as follows:

(1) The objective function of active distribution network restoration is proposed, and the limiting and limiting conditions of bus voltage and line current are given. The objective function is optimized by particle swarm optimization, and the optimal function is obtained.

(2) Taking IEEE 33-node distribution network as an example, the simulation experiment of network reconstruction after fault is carried out by using MATLAB software for two optimization algorithms respectively, and the simulation diagram and the minimum network loss value after fault recovery and reconstruction of active distribution network system are obtained. By comparing the two algorithms, the particle swarm optimization algorithm is better.

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