Research on Protection Optimization of Distribution Network Containing Distributed Power Generation Based on Sparrow Algorithm

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Abstract: In recent years, the increasing energy crisis and environmental pollution have brought attention to distributed renewable power generation such as photovoltaics and wind power. However, the integration of distributed power sources puts forward higher requirements for the safety, stability and economic operation of the power system. Traditional protection setting methods face greater difficulties in solving the contradiction between action time and protection selectivity under complex conditions including distributed power generation. In many cases, the setting value is not optimal. With the increase in the penetration rate of distributed power sources and the increasingly complex operation of distribution networks, how to achieve the optimal setting of overall protection performance has become a current research hotspot. For this reason, this paper proposes a new scheme based on the Sparrow algorithm to optimize the online protection of distributed power distribution network protection, which is verified by a calculation example.

1. Introduction

The online setting of the protection setting of the distribution network is a closed-loop management method of setting value online calculation and online modification of the setting value according to the online operation mode of the power grid. It can track the running status of the power grid in real time and perform setting calculation online to ensure the performance of the setting value. In recent years, the gradual establishment of wide-area communication networks has provided a solid material basis for realizing online setting calculations. At the same time, the existing setting calculation models are becoming increasingly unsuitable for the rapidly developing large-scale interconnected power grid. In this era, people began to carry out the online setting calculation research of relay protection under the wide area communication environment [1]. Some documents have studied the architecture and function positioning of the online tuning calculation system. Literature [2] conceived the fixed value management method based on the energy management system and the protection information system, and proposed the method of fixed value online warning and online setting according to the online operation mode of the power grid and the expected operation mode of the accident. Literature [3] puts
forward the idea of adaptive coordination protection, and introduces the adaptive coordination
protection system based on wide area communication network. Literature [4] uses simulation
technology to build an online setting calculation system based on the knowledge of the expert database.
Literature [5] and [6] researched on-line setting principles of different protection principles. However,
the existing research involves less on-line setting methods for inverse time overcurrent protection, and
still uses the step-by-step coordination setting method, which cannot meet the requirements of modern
power grids in terms of performance. Therefore, the in-depth study of the new method of online
setting calculation of inverse time overcurrent protection has become one of the important issues to be
solved urgently in the practical application of online setting calculation system.

In this paper, in the case of DG grid-connected, by building an active distribution network
operation model, using reliability evaluation theory, using the Sparrow intelligent algorithm to
calculate the more reliable power grid relay protection setting, and verifying it with calculation
examples.

2. Mathematical Model
The inverse time overcurrent protection includes two major coefficients: the time setting coefficient
$T_p$ and the starting current $I_p$. The inverse time overcurrent protection action characteristic equation
is shown in equation (1).

$$x = \frac{0.14T_{pl}}{(l_{ij}/I_{pl})^{0.02} - 1}.$$  (1)

Among them, $i$ is the number of the protection device; $j$ is the line number where the fault occurs;
$T_{pi}$ is the time setting coefficient of the protection device $i$; $t_{ij}$ is the protection action time; $I_{ij}$
is the current flowing through the protection; $I_{pl}$ is the starting current of the protection device $i$.The optimal targeting goal is:

$$\min T_{O PR} = \sum_{i=1}^{M} \sum_{k=1}^{B} \sum_{p=1}^{L} (t_{ij}^p + t_{kj}^p)$$  (2)

Among them, $M$ is the number of main protection devices; $B$ is the number of backup protection
devices; $L$ is the total number of faulty lines; $t_{ij}$ is the action time of protection $j$ as the main
protection when line $i$ has a short-circuit fault; $t_{kj}$ is when line $j$ occurs In the event of a short-circuit
fault, the total operating time of the protection $k$ as the backup protection. In order for the main
protection and backup protection to cooperate with each other, the constraint conditions shown in
equation (3) must be satisfied.

$$t_{ij}^p - t_{kj}^p \geq T_c \quad \forall i, k, j$$  (3)

Among them, $T_c$ is the minimum value of the time difference between the main protection and the
backup protection. In order to ensure the reliability of the protection, $T_c$ cannot be too small.

In this article, all inverse time overcurrent protection devices comply with the IEC255-3 standard
and meet the constraints shown in equations (4) and (5).

$$T_{pmin} \leq t_{ij}^p \leq T_{pmax} \quad \forall i$$  (4)

$$I_{pmin} \leq I_{pl} \leq I_{pmax} \quad \forall i$$  (5)

Among them, $I_{pmax}$ is the maximum load current that flows through the protection $i$ during
normal operation of the distribution network; $I_{pmin}$ is the minimum short-circuit current that flows
through the protection $i$ when the distribution network fails. Then the inverse time current protection
optimization setting problem of the distribution network is transformed into a minimum optimization
problem.

3. Improved Sparrow Algorithm
Sparrow Search Algorithm (SSA) was proposed in 2020 by Xue J and Shen B. In SSA, discoverers
with better fitness values will get food first in the search process. In addition, because the discoverer is
responsible for finding food for the entire sparrow population and providing directions for all those
who join. During each iteration, the location of the discoverer is updated as follows:
\[
X_{t+1}^I = \begin{cases} 
X_{t,I,J} \ast \left( \exp \left( -\frac{n}{ar\ast \text{iter}_{\text{max}}} \right) \right) & \text{if } R_2 < ST \\
X_{t,I,J} + Q \ast L & \text{if } R_2 \geq ST 
\end{cases}
\]  

(6)

Among them, represents the current iteration number, =1,2,3... Is a constant that represents the maximum number of iterations. Indicates the position information of the first sparrow in the first dimension. (0,1] is a random number. And represents the warning value and the safety value respectively. It is a random number that obeys the normal distribution. It represents a matrix in which each element in the matrix is all 1.

For joiners, some joiners will always monitor the discoverer during the foraging process. Once they realize that the discoverer has found better food, they will immediately leave their current position to compete for food. The location update description of the joiner is as follows:

\[
X_{t+1}^I = \begin{cases} 
Q \ast \left( \exp \left( -\frac{x_{\text{worst}}-x_{t,I,J}}{t^2} \right) \right) & \text{if } i < n/2 \\
X_{t+1}^I + X_{t,I,J}^{t+1} \ast A^+ * L & \text{otherwise}
\end{cases}
\]  

(7)

Among them, is the best position occupied by the current discoverer, which means the current worst position in the world. Represents a matrix in which each element is randomly assigned a value of 1 or -1, and. At that time, this showed that the first entrant with a lower fitness value did not get food and was very hungry. At this time, he needed to fly to other places to find food to get more energy.

When aware of danger, sparrows at the edge of the group will quickly move to a safe area to get a better position, and sparrows in the middle of the group will randomly walk around to get closer to other sparrows.

\[
X_{t+1}^I = \begin{cases} 
X_{\text{best}}^t + \beta \ast \left| X_{t,I,J}^t - X_{\text{best}}^t \right| & \text{if } f_i > f_g \\
X_{t+1}^I + K * \left( X_{t,I,J}^t - x_{\text{worst}}^t \right) & \text{if } f_i = f_g
\end{cases}
\]  

(8)

Among them, \(X_{\text{best}}^t\) is the current global optimal position. \(\beta\), as the step length control parameter, is a random number that obeys a normal distribution with a mean of 0 and a variance of 1.K \(\in \mathbb{R} \) is a random number, and \(f_i\) is the fitness value of the current individual sparrow, \(f_g\) and \(f_w\) are the current global best fitness values respectively. A constant of \(\varepsilon\) to avoid zeros in the denominator.

The algorithm flow is shown in Figure 1:
4. Case Analysis

In order to verify the correctness and feasibility of the method provided in this paper, this paper performs protection optimization settings on the IEEE14-node distribution network with DG shown in Figure 2. Among them, DG is connected to the grid at BUS 8, the maximum power is set to 247.5MVA, CB1-CB20 indicate the configured inverse time overcurrent protection device.

Set DG at the maximum output, initialize the sparrow population information according to the constraint conditions and the three-phase short-circuit current flowing through each protection, and use SSA to optimize and set each inverse time current protection parameter, as shown in Table 1.
Table 1. Three-phase short circuit optimized protection settings

| protection |  \( T_p/t \) |  \( I_p/A \) | protection |  \( T_p/t \) |  \( I_p/A \) |
|------------|-------------|-------------|------------|-------------|-------------|
| \( CB_1 \) | 0.1         | 100.00      | \( CB_{11} \) | 0.1         | 76.08       |
| \( CB_2 \) | 0.1         | 50.67       | \( CB_{12} \) | 0.1         | 50.67       |
| \( CB_3 \) | 0.1         | 100.00      | \( CB_{13} \) | 0.1         | 100.00      |
| \( CB_4 \) | 0.1         | 64.56       | \( CB_{14} \) | 0.1         | 58.68       |
| \( CB_5 \) | 0.1         | 100.00      | \( CB_{15} \) | 0.1         | 50.67       |
| \( CB_6 \) | 0.1         | 64.91       | \( CB_{16} \) | 0.1         | 85.47       |
| \( CB_7 \) | 0.1         | 92.71       | \( CB_{17} \) | 0.1         | 100.00      |
| \( CB_8 \) | 0.1         | 50.67       | \( CB_{18} \) | 0.1         | 78.68       |
| \( CB_9 \) | 0.1         | 62.79       | \( CB_{19} \) | 0.1         | 100.00      |
| \( CB_{10} \) | 0.1         | 79.15       | \( CB_{20} \) | 0.1         | 82.36       |

Calculate the action time of each protection according to the optimized setting parameters, as shown in Table 2. It can be seen from the simulation that when the number of lines is large, the action time of each protection after optimization and setting is significantly reduced. Due to the setting of constraints, there is a time difference between the action time of the main protection and the backup protection. When a fault occurs at the end of the line, the action time of each protection can be well coordinated with each other, which shortens the duration of the fault.

Table 2. Three-phase short circuit fault protection action time

| Fault location | Active protection/s | Backup protection/s | Fault location | Active protection/s | Backup protection/s |
|----------------|---------------------|---------------------|----------------|---------------------|---------------------|
| \( B_1 - B_2 \) | 0.40                | 0.88                | \( B_6 - B_{11} \) | 0.41                | 0.63                |
| \( B_2 - B_3 \) | 0.63                | 0.69                | \( B_6 - B_{12} \) | 0.50                | 1.21                |
| \( B_3 - B_4 \) | 0.68                | 1.88                | \( B_6 - B_{13} \) | 0.24                | 0.52                |
| \( B_4 - B_5 \) | 0.59                | 1.31                | \( B_6 - B_{14} \) | 0.78                | 1.76                |
| \( B_5 - B_6 \) | 0.74                | 1.42                | \( B_{10} - B_{11} \) | 0.24                | 0.34                |
| \( B_6 - B_1 \) | 0.26                | 0.46                | \( B_{12} - B_{13} \) | 0.29                | 0.38                |
| \( B_6 - B_2 \) | 0.33                | 0.64                | \( B_{13} - B_{14} \) | 0.36                | 0.52                |
| \( B_7 - B_8 \) | 0.24                | 0.40                | \( B_8 - B_5 \) | 0.85                | 1.59                |
| \( B_8 - B_7 \) | 0.23                | 0.63                | \( B_4 - B_3 \) | 0.38                | 0.42                |
| \( B_9 - B_{10} \) | 0.24                | 0.45                | \( B_9 - B_8 \) | 0.45                | 1.93                |

It can be seen from the table that the line structure and load conditions at different locations will cause different degrees of harm. When a three-phase short-circuit fault occurs at the end of the line, the number of lines is the largest, the short-circuit current is the smallest, and the impact is the greatest. The convergence curve of the sparrow algorithm is shown in Figure 3. At the beginning of the iteration, as SSA introduces the search direction, the protection action time drops faster and the convergence speed is faster; in the middle of the iteration, because the SSA population starts to update, the convergence curve is slow to prevent the occurrence of local optimal; at the end of the iteration, the curve is flat and the overall situation is obtained Optimal solution.
5. Conclusion
In this paper, the objective function is to minimize the total operating time of the main protection and the backup protection of the inverse time overcurrent protection of the distribution network, and the restriction of the distribution network is used as the constraint condition to establish the inverse time overcurrent protection of the distribution network with distributed power generation. The mathematical model of parameter optimization and setting is solved by the sparrow algorithm. The simulation results show that when the optimization problem of inverse time overcurrent protection setting is solved, the method in this paper can effectively improve the quick action of the protection while ensuring the selectivity by optimizing the setting of the inverse time overcurrent protection parameters.

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