Setting value optimization method in integration for relay protection based on improved quantum particle swarm optimization algorithm

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Setting value optimization method in integration for relay protection based on improved quantum particle swarm optimization algorithm

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Abstract. With the establishment of the integrated model of relay protection and the scale of the power system expanding, the global setting and optimization of relay protection is an extremely difficult task. This paper presents a kind of application in relay protection of global optimization improved particle swarm optimization algorithm and the inverse time current protection as an example, selecting reliability of the relay protection, selectivity, quick action and flexibility as the four requires to establish the optimization targets, and optimizing protection setting values of the whole system. Finally, in the case of actual power system, the optimized setting value results of the proposed method in this paper are compared with the particle swarm algorithm. The results show that the improved quantum particle swarm optimization algorithm has strong search ability, good robustness, and it is suitable for optimizing setting value in the relay protection of the whole power system.

1. Introduction
With the construction of UHV power grid and the promotion of smart grid, grid scale continues to expand; the relationship between protections has become more complex. Traditional relay setting calculation using the method of step by step with that of the conservation and protection of adjacent elements one by one with the whole fix a value more than the results, select from the minimum and maximum value as the protection zone. This method is simple to come true, but not considering the interaction between the protection values, it is difficult to get the full model grid protective properties of the optimal value [1-2].

With the continuous development of artificial intelligence technology and has adaptive intelligent protection relay theory into a new direction of development. According to the importance of protection of Definite time to the protection cooperation relations, paper [3] Proposed optimization based on genetic algorithms relay setting algorithm, which using constraint interval with the point of the whole network segment coding for II phase Distance Protection Setting Calculation Optimization of a preliminary study. Paper [4] improved traditional particle swarm algorithm, come up with a suitable relay setting calculation of global optimization improved PSO algorithm and genetic algorithm optimization based relay setting calculation were compared, results improved particle swarm optimization algorithm can be applied to relay setting.

Genetic Algorithm and Particle Swarm is a new class of swarm intelligence evolutionary algorithms, their application in the power system optimization in the ascendant. If these two types of algorithm into actual projects and improve the algorithm theory, it is very meaningful work. But genetic
algorithms suitable for solving a plurality of constraints under the protection setting calculation problem, and there is slow calculation, instability in solving complex multidimensional problem; Particle Swarm although modelling is simple and convenient parameter control, but easy to fall into local optimum [5]. By combining the advantages and disadvantages of existing research premise, this paper proposes an improved particle swarm algorithm based on quantum theory. Based on the relay protection of "four" to establish optimization objectives, to solve most accurate advantages, to reduce the number of iterations, to shorten optimization time, the method is suitable for large and complex power grid setting global optimization.

2. Establish objective function

The optimization problem of the set value of relay protection is that more than one goal, multi-variable and multi-constraint the global optimization problem. Based relay protection "four" principle to establish anti-time protection of optimizing the objective function, including speed and mobility, reliability, selectivity and sensitivity of the relay protection. And give appropriate weight for each objective function, the objective function of specific components as follows:

(1) Speed

When the power system failure, short-circuit current lasts longer, the greater the harm to the system the greater. In order to make the rapid removal of the fault protection device, and therefore the duration of the fault as the optimization target. \( t_i \) is the fault duration, \( P_i \) is the degree of fault on the normal operation of the system. \( Q_i \) is the failure time, which is the product of \( t_i \) and \( P_i \) under various fault conditions. Therefore, the shortest failure time is the optimization goal of the protection coordination, namely:

\[ Q_i = \sum \Delta t_i P_i \]  

(1)

(2) Selectivity

When the power system fails, the protection device must have a selective action, in order to reduce the scope of the fault. So in the process of protection coordination ,closing to the supply side the protection time should be longer than the protection time moving away from the power supply side as the objective function, Denoted as \( \Delta t_{i,j} \). After the failure, contrary to this principle with the protection the total number is smaller, the fit between the behalf of the better protection. After considering the safety differential relays dropout delay, the circuit breaker trip time and the arcing time and other factors, \( \Delta t_{i,j} \) is usually set between 0.3S to 0.5S, the paper select 0.4S, there are:

\[ \Delta t_{i,j} = t_{i,j} - t_{j,i} \]  

(2)

(3) Sensitivity

When relay protection with the protection the sensitivity closer to the point of failure should be higher. In calculating the sensitivity, direct use of under the minimum operating mode, the numerical of two-phase of short-circuit current flow through each protection device. \( K_{\text{min}} \) is the minimum sensitivity, \( K_{i,j} \) indicates malfunction of the power supply side in recent backup protection element sensitivity; \( K_{i,j} \) indicates the fault to near side of the main power supply protective element sensitivity. \( N_{K_{i,j}} \) is the minimum value as the optimization target, there are:

\[ N_{K_{i,j}} = \begin{cases} 0, & K_{i,j} \geq K_{i,j}^* \\ 1, & K_{i,j} < K_{i,j}^* \\ 0, & K_{i,j}(K_{i,j}) > K_{\text{min}} \\ 1, & K_{i,j}(K_{i,j}) < K_{\text{min}} \end{cases} \]  

(3)

According to the actual situation of the system and related parameters characteristic of protect itself differences, giving these four optimization metrics respective weight coefficients, and then summing these indicators contain coefficient as the objective function, obtained an unconditional single objective optimization model optimization model express by G:
\[ G = \alpha \sum_i p_i + \gamma \sum_j (s_j - \bar{s}_j) + \lambda \sum_j N_{s_j} \]  
\[ (4) \]

In the equation, \( \alpha, \gamma, \lambda \) between 0 and 1, denote the degree of deviation protection setting calculation in four different indicators, and meets \( \alpha + \gamma + \lambda = 1 \), according to a flexible system component parameter settings and changes, so that the whole network relay setting calculation optimal value.

3. Improved quantum particle swarm optimization

Since the particle swarm algorithm has the advantage of simple, so its model attracted widespread attention, but most of the improved algorithm still cannot make the algorithm has better convergence. To better address this issue, we proposed new algorithms based on the standard particle swarm algorithm - Quantum Particle Swarm Optimization. In the process of convergence, \( i \) particle constantly close to the point \( P_i \), until the particle fall within \( P_i \). From the perspective of Quantum Theory, during convergence the point of \( P_i \) has attractive potential, which attracting particles converge to \( P_i \) so that the whole group has clustering. Thus particles can search the entire solution space, which has a better convergence.

In the quantum particle swarm, introducing \( \delta \) potential drop, position of the particles can be described as the Schrödinger equation:

\[ X_{i,t}(t + 1) = P_{i,t}(t) \pm \alpha \cdot m_{best,j}(t) - X_{i,t}(t) \times \ln \left( \frac{1}{u_{i,t}} \right) \]  
\[ (5) \]

\[ \alpha = 1 - 0.5 \times t / \text{MAXTER} \]  
\[ (6) \]

In the equation, \( U_{i,t}(t) \) is a random number between 0 and 1; \( \alpha \) is the Shrinkage expansion coefficient, \( t \) is the current number of iterations, \( \text{MAXTER} \) is the total number of iterations; \( m_{best} \) stands for "average at best location". The equation (6) is called quantum particle swarm optimization. Update equation for the particle swarm algorithm:

\[ m_{best} = \frac{1}{M} \sum_{i=1}^{M} P_{i,t} \]  
\[ (7) \]

\[ P_{i,j}(t) = \frac{\phi_1 P_{i,j} + \phi_2 P_{g,j}}{\phi_1 + \phi_2} \]  
\[ (8) \]

\[ X_{i,t}(t + 1) = P_{i,t}(t) \pm \alpha \cdot m_{best,j}(t) - X_{i,t}(t) \times \ln \left( \frac{1}{u_{i,t}} \right) \]  
\[ (9) \]

In the equation, \( M \) is the racial scale, \( m_{best} \) stands for "average at best location", \( \phi_1, \phi_2 \) is random number between 0 and 1, and meets \( \phi_1 + \phi_2 = 1 \). \( P_{i,j}, P_{g,j} \) represent current local optima and the current global optimal solution.

Quantum particle swarm algorithm has achieved great success in dealing with continuous function optimization problems. But when the situation appears that best location of individual particles and the best place of groups very close, movement of particles will only be a very small space, thus losing the global search capability, there is still the possibility of falling into local optimum, in practice. In order to improve the convergence properties of a quantum particle swarm optimization, this paper presents an improved algorithm. The particle swarm split into two groups, the two groups simultaneously search in two stages.

Paper [6] has been proved theoretically that a single particle boundedness important condition. The important conditions are: if \( \alpha < 1.781 \) particle swarm convergence; if \( \alpha > 1.781 \) particle Swarm diverging. Therefore, this paper shall divide into two groups average particle swarm, each group is divided into two stages. The first stage in accordance with the equation (6) setting expansion factor shrinkage, \( a_{1,1} \), the first stage Setting parameters \( a_{1,2} \geq 1.781 \); The first stage of another group setting parameters \( a_{2,1} > 1.781 \), the second stage in accordance with the equation (6) setting expansion factor shrinkage \( a_{2,2} \).
To set the objective function; To allocated pbest; To update pbest position; To update gbest position;
If: \( t = \text{MAXITER} \) & \( \text{run} = \text{runmax} \)
Start
If: \( t < \text{MAXITER} \),
Then \( t = t + 1 \)
If: \( t = \text{MAXITER} \), \( \text{run} < \text{runmax} \)
Then \( t = 0 \);
\( \text{run} = \text{run} + 1 \)
End
Yes
No

4. Example of simulation and analysis
In this paper, the grid shown in Figure 2 as an example of the effectiveness of the improved quantum particle swarm algorithm for authentication. Reference capacity is 100MVA, each component parameters in Table 1. The most serious failure of the system as an example, that the bus occurs Three-phase short-circuit fault, bus III、IV、V、VI Three-phase short-circuit fault of F1, F2, F3, F4, protection after the failure of the current flowing value as shown in Table 2; The level of bus voltage is higher, the more connections, danger of failure the greater. Therefore, based on the voltage level and the number of connections for each bus to determine the failure rate of four fault hazards were 1、1、(1/3)、(1/3). The weighted average of equation (1)、(2) and (3) as the objective function, the resulting optimization models such as the equation (4).

Given weight coefficient, the timing requirements, guarantee the accuracy of the protection possible match this article selected \( \alpha = 0.3 \), \( \gamma = 0.5 \), \( \lambda = 0.2 \); Also can according to each bus fault protection the special requirements of performance indicators, set weight respectively. Runmax is 10 times, the maximum number of iterations MAXTER for 5000 times, particle dimension to 18, the population size of 30, after the program automatically choose the best results.

| Name | Equivalent | T. 1# | T. 2# | T. 3# | T. 4# | T. 5# | T. 6# | L1 | L2 | L3 | L4 | L5 |
|------|------------|------|------|------|------|------|------|----|----|----|----|----|
| Z1   | 1          | 0.12 | 0.12 | 0.15 | 0.15 | 0.108| 0.108| 0.0748| 0.0748| 0.1285| 0.1588| 0.1588|

Figure 1. Flow chart of optimized setting value.
Figure 2. Schematic diagram of power grid.
To avoid the influence of a single test on the final result of chance, all programs are required to run continuously runmax times. The maximum number of iterations is MAXTER, automatically selects the best result after the run. Figure 1 is a flowchart of optimizer value.
Table 2. The parameters of power system

| NO. | BRK 1 | BRK 2 | BRK 3 | BRK 4 | BRK 5 | BRK 6 | BRK 7 | BRK 8 | BRK 9 |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| F1(Bus III) | 0 | 0 | 37.15 | 37.15 | 192.84 | 192.84 | 74.30 |
| F2(Bus IV) | 0 | 0 | 112.93 | 112.93 | 112.93 | 112.93 | 222.18 |
| F3(Bus V) | 0 | 0 | 34.76 | 34.76 | 180.45 | 180.45 | 69.53 | 215.09 | 215.09 |
| F4(Bus VI) | 213.40 | 213.40 | 107.75 | 107.75 | 107.75 | 107.75 | 211.98 |

Table 3. The setting results based on the particle swarm algorithm

| NO. | result | BRK 1 | BRK 2 | BRK 3 | BRK 4 | BRK 5 | BRK 6 | BRK 7 | BRK 8 | BRK 9 |
|-----|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fault1 | T/s  | 0.39 | 0.32 | 0.57 | 1.67 | 0.41 |
| (bus III) | K    | 3.24 | 4.87 | 5.83 | 28.86 | 2.99 |
| Fault2 | T/s  | 0.20 | 0.18 | 0.80 | 2.03 | 0.28 |
| (bus V) | K    | 18.04 | 27.06 | 3.64 | 18.04 | 7.49 |
| Fault3 | T/s  | 1.72 | 0.85 | 1.31 | 2.54 | 2.14 | 0.78 | 0.23 |
| (bus VI) | K    | 1.08 | 1.62 | 2.18 | 10.82 | 0.92 | 17.86 | 17.86 |
| Fault4 | T/s  | 0.16 | 0.16 | 0.21 | 0.19 | 0.91 | 2.15 | 0.30 |
| (bus VI) | K    | 45.46 | 45.46 | 15.69 | 23.54 | 3.17 | 15.69 | 6.49 |

5. Conclusion
This paper presents an intelligent protection algorithms based on improved quantum particle swarm algorithm for power system protection operation time and sensitivity optimization, with the test results show that the improved results of quantum particle swarm algorithm can meet the network to maximize all protection time minimum and selectivity requirements. Improved quantum particle swarm compared to particle swarm algorithm, search a better convergence point. Quantum particle swarm algorithm will also lead to premature convergence of particle swarm optimization, in order to improve the performance of the quantum particle swarm optimization algorithm for improved weight selection, Simulation experiment and contrast analysis of quantum particle swarm optimization algorithm that can improve the protection is very effective in optimal coordination of setting calculation and improve the overall performance of the relay protection in the distribution network.

6. References
[1] Zhou Te-jun, Qiu Jian, Wang Chun-yi et al. “Application of visualization technology based on SVG in on-line relay settings verification system,” Power System Protection and Control, vol 16, pp.112-117, 2015.
[2] Gao Xu, Du Li-yan, Li Xue-dong, et al. “Substation locating method in integrated relay graph splicing based on improved genetic algorithm,” Power System Protection and Control, vol 43, pp.74-78, 2015.
[3] Li Ben-yu, Shi Heng-chu, Zhai Hai-yam, et al. “Development and application of relay protection setting and coordination calculation processing management system based on the SOA,” Power System Protection and Control, vol 24, pp.102-109, 2014.
[4] Zhao Jian-li, Fan Chun-ju, Le Quan-ming et al. “Application of an enhanced genetic algorithm for protection relay setting coordination,” Power System Protection and Control, vol 22, pp.6-9, 2007.
[5] Ye Qing, Zhu Yong-qiang, Li Hong-xian, et al. “Model parameter conversion between power system software based on IGA,” Power System Protection and Control, vol 9, pp. 95-100, 2015.
[6] Fu Guang-jie, Lin Dong-xue. “A research on optimal filter configuration for the distribution network based on hybrid particle swarm algorithm,” Power System & Automation, vol 1, pp.74-77, 2015.