Optimal Design of Circuit Breaker Based on Flower Pollination Algorithm

Guodong LI
Tianjin Chengjian University
Min XIE
Hebei University of Technology
Yunhe TIAN (201931903016@stu.hebut.edu.cn)
Hebei University of Technology

Research Article

Keywords: flower pollination algorithm, adaptive step size, catfish effect, mutation strategy, circuit breaker optimization design

Posted Date: April 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1531538/v1

Optimal Design of Circuit Breaker Based on Flower Pollination Algorithm

Guodong LI[1, a], Min XIE[2, b],Yunhe TIAN[2,*]
[1] School of Computer and Information Technology, Tianjin Chengjian University, Tianjin 300384, China
[2]School of Electronics and Information Engineering, Hebei University of Technology, Tianjin 300401, China
[a]lgd@tcu.edu.cn, [b]201831903025@stu.hebut.edu.cn,* Correspondence: 201931903016@stu.hebut.edu.cn ;

Abstract: The flower pollination algorithm is a new meta-heuristic algorithm that simulates the pollination behavior of flowers in nature. Aiming at the problem that the basic flower pollination algorithm is easy to fall into the local optimum and the later convergence speed is slow, the "adaptive-mutation catfish" flower pollination algorithm is proposed, Introduce the adaptive step size in the global pollination stage, introduce the mutation strategy and catfish effect in the local pollination stage, and use the classic test function to analyze the performance of the improved algorithm. The improved flower pollination algorithm is applied to the high breaking and comprehensive optimization design of the circuit breaker, the mathematical model of the high breaking and comprehensive optimization of the circuit breaker is constructed, and the optimal design method of the circuit breaker based on the flower pollination algorithm is given. The results show that the circuit breaker optimization design method based on flower pollination algorithm is feasible, and the improved flower pollination algorithm is effective.

Keywords: flower pollination algorithm; adaptive step size; catfish effect; mutation strategy; circuit breaker optimization design

1.Introduction

With the rapid development of the power distribution market and the popularization of the energy Internet, a broad application prospect is provided for the development of the electrical field [1]. As an important control electrical appliance in the power distribution system, low-voltage circuit breakers can be based on the rated current. Perform normal on and off, when the circuit is seriously overloaded or short-circuited, it can protect the circuit [2]. At the same time, the user's power consumption often rises sharply, so there should be higher requirements when designing low-voltage circuit breakers. At this stage, the design of circuit breakers with small size, high breaking capacity and low energy consumption is of great significance to the development of smart grid.

In the high breaking design of the circuit breaker, the breaking capacity of the circuit breaker is required to be strong in order to achieve the purpose of rapid breaking. When performing high breaking optimization, the electrodynamic repulsion force acting on the moving contact can be analyzed, and the moving speed of the arc between the moving and static contacts can also be analyzed. The traditional breaking capacity analysis method of circuit breaker has certain drawbacks, a large amount of calculation, and errors [3]. For this reason, combining the advanced group intelligence optimization algorithm to optimize the design of the circuit breaker's high breaking, the method is more scientific and reasonable. In the optimal design of the circuit breaker, it is not only necessary to achieve high breaking, but also to achieve as low energy consumption and miniaturization as possible under the premise of high breaking. Because in the actual design of the circuit breaker, the greater the electric repulsion, the greater the thermal energy loss, which may cause the increase of the circuit breaker's volume. For this reason, it is imperative to comprehensively optimize the design of the circuit breaker.

In 2012, Yang X S proposed a new meta-heuristic algorithm—Flower Pollination Algorithm (FPA) [4] based on the mechanism of flower pollination behavior. This algorithm has simple structure, strong optimization ability, and easy implementation. Advantages [5]. It has been applied to many fields such as wireless sensor optimization [6], power distribution system [7], aluminum matrix composite material optimization [8]. At the same time, many domestic and foreign experts and scholars have also improved the algorithm in many ways. Yang Chen et al. [9] proposed an innovative cloud mutation-based flower pollination algorithm (CMFPA) in response to the low accuracy of the algorithm and the slow convergence speed in the later stage. In the global search and optimization stage of the algorithm, multi-dimensional information is added, and use the design cloud mutation method to initialize the population. Experiments show that the improved algorithm has higher optimization speed and solution accuracy. Liang XB et al. [10] introduced Infinite Folding Iterative Chaos Mapping (ICMIC) in order to increase the diversity of the population, and introduced a comprehensive opposition (CO) learning strategy in order to enhance the algorithm's mining capabilities. The test function simulation proved that the improved algorithm is compared It has better performance than other algorithms.

In summary, an improved flower pollination algorithm that combines adaptive step size, directional mutation, and catfish effect can be proposed and applied to the optimal design of circuit breakers to improve circuit breaker performance.

2. Flower Pollination Algorithm

2.1 Basic Flower Pollination Algorithm

The flower pollination algorithm [11] can be described by four rules:

(1) Biological cross-pollination refers to the global pollination process carried out by pollinators through Levy flight. It is shown in formula(1):

$$x_i^{t+1} = x_i^t + \theta L(x_i^t - g_*) \tag{1}$$

Among them, x_i^t、x_i^{t+1} represent the solutions of the t-th and t+1-th generations, g_* represents the global optimal solution in one iteration, θ is the step size influence factor, and the fixed value is 0.01,L is the step size, it is shown as formula (2):

$$L : \frac{\lambda\Gamma(\lambda)\sin(\pi\lambda/2)}{\pi}\frac{1}{s^{1+\lambda}} \text{ (s? } s_0 > 0) \tag{2}$$

Where $\Gamma(\lambda)$ is the standard gamma function.

(2) Non-biological self-pollination can be regarded as the partial pollination process in the algorithm, and the rules are shown in formula (3):

$$x_i^{t+1} = x_i^t + \varepsilon(x_j^t - x_k^t) \tag{3}$$

Where x_j^t and x_k^t are from the same plant species, but belong to pollen of different flowers, and ε is the reproduction probability and obeys the uniform distribution on [0,1].

(3) Probability of reproduction refers to the constancy of flowers and is proportional to

the similarity of the two participating flowers.
(4) The conversion probability p controls the conversion between global pollination and local pollination, and its value is [0,1].

2.2 Improved flower pollination algorithm

(1) Improved flower pollination algorithm with adaptive step size

In the global pollination stage of the FPA algorithm, pollinators use the Levi distribution mechanism during the flight. In Levy's flight, a jumpy step is generated, so that when the flower uses the formula to update the position, it can leave the local extremum as soon as possible and enter the global search. However, during the Levy flight, the value of the step influence factor is fixed, and there is no adaptiveness in the iterative process, which leads to a small random step size, which reduces the search speed of the algorithm; and when the random step size is too large, it is very It is easy to miss the opportunity to search for the global optimal value. Therefore, in the improvement of the global pollination process of the flower pollination algorithm, an adaptive step size is introduced [12], which affects the step length in Levy's flight, which can improve the convergence speed and achieve a higher solution accuracy. The step size scaling function is shown in formula (4):

$$\theta = q * N\_iter * e^{(-t/N\_iter)} \tag{4}$$

Where q is the scaling factor, *N-iter* is the maximum number of iterations, and t is the current number of iterations.
Therefore, the improved global pollination formula is shown in (5):

$$x_i^{t+1} = x_i^t + q * N\_iter * e^{(-t/N\_iter)} * L(x_i^t - g_*) \tag{5}$$

(2) Improved flower pollination algorithm with directional mutation strategy and catfish effect

Differential Evolution Algorithm [13] is proposed by Storn and Price, which mainly evolved based on group differences. The algorithm mainly obtains the optimal solution through mutation, crossover and selection mechanisms. Based on the differential evolution algorithm, the directional mutation strategy is relatively simple to operate. In the local pollination process of the flower pollination algorithm, the introduction of mutation strategy can better coordinate the relationship between randomness and determinism. Therefore, the directional mutation strategy is integrated into the local pollination mechanism. The formula is shown in (6):

$$x_i^{t+1} = x_i^t + F * (x_j^t - x_i^t) \tag{6}$$

Among them, ε is a random number [-1,1], and F is a scaling variation factor.

The introduction of directional mutation strategy can effectively improve the search efficiency and convergence rate of the algorithm in local search, but it does not solve the problem that the algorithm is easy to fall into the local optimal solution. Therefore, the introduction of catfish effect can avoid the algorithm falling into the local optimal solution.

Catfish effect [14] is a mechanism that stimulates small fish's desire to survive.

Catfish individual: The current flower fitness value is compared to the last or the individual's historical best fitness value, if the same, is defined as a catfish individual.

Sardine individual: except for the pollen labeled as "individual catfish", all the others are labeled as "individual sardine". At this time, the individual sardine is driven by the individual catfish and will stay away from the nearest individual catfish. Therefore, the distance between the individual sardine and the individual catfish is defined as formula (7) :

$$neg\_x = \frac{x_i - A_m}{1 + \frac{1}{n}\min(\left|x_i - A_j\right|^2)} \tag{7}$$

Where x_i is the location of the individual, A_m is the catfish individual closest to individual x_i, and $\min(|x_i - A_j|^2)$ is the square of the catfish individual closest to many catfish individuals, so A_j and A_m are always consistent.

By introducing directional mutation strategy and catfish effect, the local pollination process updating formula of flower pollination algorithm is shown in (8).

$$x_i^{t+1} = x_{best}^t + F * (x_j^t - x_i^t) + neg\_x \tag{8}$$

In conclusion, this paper introduced adaptive step solution algorithm is global pollination process problems of slow convergence speed, the introduction of a directional mutation strategy and local pollination catfish effect solves the algorithm in the process of slow convergence speed and easy to fall into local optimal solution of the problem, will improve pollinate flowers algorithm named adaptive variation catfish - pollinate flowers (AMC-FPA) algorithm.

2.3 Experimental design

In order to verify the performance of the improved AMC-FPA algorithm, the algorithm is compared with the basic FPA algorithm, Bat Algorithm (BA) and Adaptive Particle Swarm Optimization (APSO).

Four classic test functions [15] are used for analysis. The classic test functions are shown in Table 1 below.

Table 1 Typical test functions

Test function	expression	Optimization interval
Sphere	$f_1(x) = \sum_{i=1}^{D} x_i^2$	[-100,100]
Schwefel2.22	$f_2(x) = \sum_{i=1}^{D} \mid x_i \mid - \prod_{i=1}^{D} \mid x_i \mid$	[-100,100]
Rosenbrock	$f_4(x) = \sum_{i=1}^{D} [100 \cdot (x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	[-2.048,2.048]
Ackley	$f_6(x) = -20exp(-0.2\sqrt{\frac{1}{D}\sum_{i=1}^{D} x_i^2})$- $exp(\frac{1}{D}\sum_{i=1}^{D} cos(2\pi x_i)) + 20 + e$	[-32,32]

Four classical test functions are used to analyze the performance of the algorithm. The optimal value of the test function is 0, the flower population size *N* is set to 40, the conversion probability *P* is set to 0.8, the maximum number of iterations in the whole process is set to 300, and the dimension is set to 30. The simulation comparison diagram is shown in Figure 2 to Figure 5.

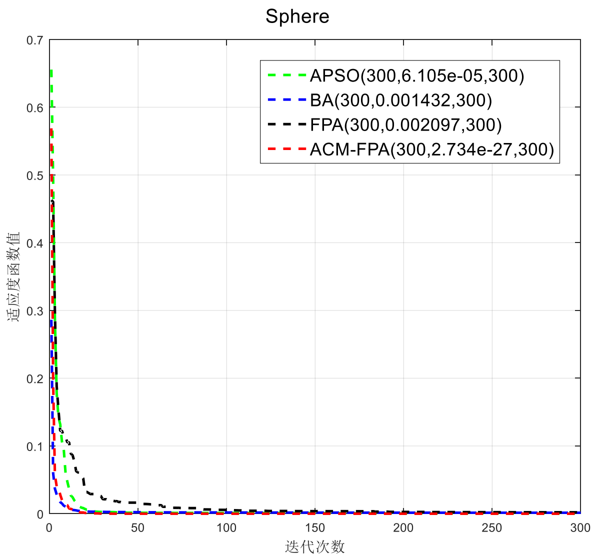

Figure 1 The Sphere function optimizes the iteration graph

As can be seen from Figure 1, compared with the other three algorithms, AMC-FPA algorithm has the highest solving accuracy, reaching 2.734e-27, while BA algorithm has the worst solving accuracy, only 0.001432.

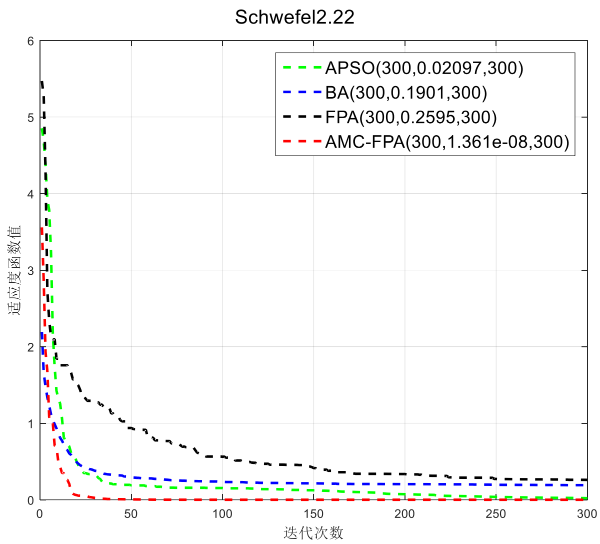

Figure 2 The Schwefel2.22 function optimizes the iteration graph

As can be seen from Figure 2, in the Schwefel2.22 function optimization iteration, AMC-FPA algorithm has the highest solving accuracy, and its effect is better than APSO algorithm, BA algorithm and FPA algorithm.

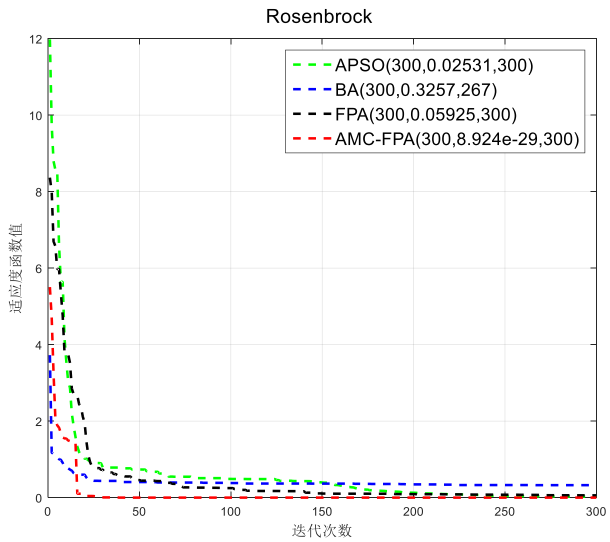

Figure 3 The Rosenbrock function optimizes the iteration graph

As can be seen from Figure 3, BA algorithm has a fast convergence speed, but poor solving accuracy. AMC-FPA algorithm has the highest solving accuracy, reaching 8.924e-29, and has the best effect.

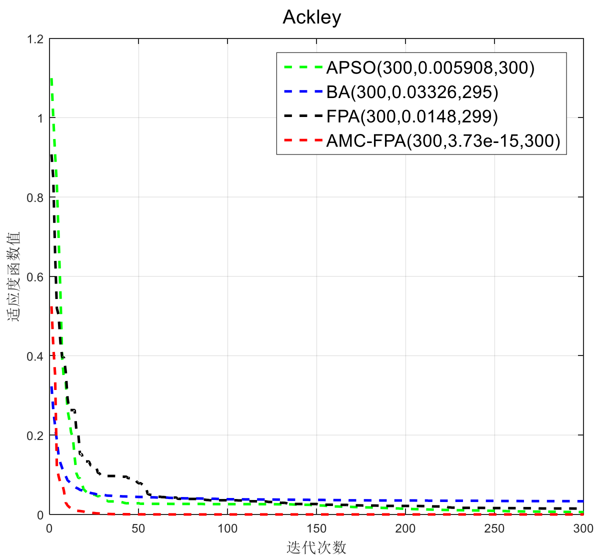

Figure 4 The Ackley function optimizes the iteration graph

As can be seen from Figure 4, AMC-FPA algorithm has the best solving accuracy, which is much higher than APSO algorithm, BA algorithm and FPA algorithm. The fitness value of the function is 3.73e-15.

3. Circuit breaker optimization design

3.1 Circuit breaker high breaking design

In order to solve the problem of poor breaking capacity of traditional circuit breakers, we can start with the electric repulsion in the arc generation stage and the arc movement speed in the arc movement stage, analyze the influencing factors, and construct the high breaking optimization model of the circuit breaker.

(1) Electric repulsion

The electric repulsion force includes Holm force and Lorentz force. The calculation

is as follows:
1) Holm force

Holm force only exists in the contact process of the moving and static contacts. When the moving and static contacts are

When pressed, the contact surface will deform, so that metallic contact is always realized between the scattered conductive spots. The contact spots have square, round, oval and other shapes. Among them, the circular conductive spots are the simplest and are recognized by the public. Therefore, the Holm force is calculated according to the circular conductive spot [16].

Suppose that there is only one conductive spot on the inner surface of the contact, or all the conductive spots are concentrated in the center to form a very large conductive spot. To simplify the analysis, suppose that the conductive spot is a superconducting sphere, not a plane, and the superconducting sphere is an allele. Under hypothetical conditions, the equipotential surface becomes a series of spherical surfaces concentric with the superconducting sphere, and the current line passes through the center of the sphere and assumes a radial shape. Suppose B is the cross-sectional radius of the contact system, r is the radius of the contact point, that is, the radius of the conductive spot, then the Holm force formula is shown in (9):

$$F_H = \frac{\mu_0}{4\pi} i^2 In(\frac{B}{r}) \tag{9}$$

Among them, μ_0 is the vacuum permeability, with a value of $4\pi\times10^{-7}$, and i is the current flowing through the contact.

Contact pressure, contact material and other factors should be considered when determining the contact radius r. The formula is shown in (10) :

$$r = \sqrt{P / \pi\xi H} \tag{10}$$

Where P is the contact pressure, ξ is the contact surface contact coefficient, ranging from 0.3 to 1, and H is the Brinell hardness of the contact material.
After finishing, the specific Holmforce formula is shown in (11) :

$$F_H = \frac{\mu_0}{4\pi} i^2 In(B\sqrt{\frac{\pi\xi H}{P}}) \tag{11}$$

2) Lorentz force

Lorentz force is also known as loop force. When the current flows through the dynamic and static contact, the current direction between the dynamic conductive rod and the static conductive rod is opposite and the interaction force is generated, so Lorentz force is generated. Parallel conductors can be used as the contact conductive rod [17].

The contact structure of the circuit breaker is very complex. When solving Lorentz force, the current density value must be obtained according to the current size, and the current is regarded as the excitation factor to analyze the three-dimensional magnetic field to obtain the magnetic field density, and finally the Lorentz force.
The calculation method of Lorentz force is shown in Figure 5.

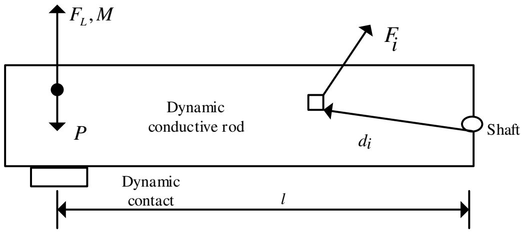

Figure 5 Calculation method of Lorentz force

In Figure 5, P is the contact pressure, FI is the force density, Di is the force arm, l is the distance from the center of the moving contact to the center of the rotating shaft, FL is the Lorentz force, and its expression is shown in formula (12):

$$F_L = M / l \tag{12}$$

The calculation formula of moment M is shown in (13):

$$M = \int_v d_i \times F_i dv \tag{13}$$

The calculation formula of force density FI is shown in (14):

$$F_i = J_i \times B_i \tag{14}$$

For the calculation of current density and magnetic flux density, the constant field equation can be used, and the current density satisfies formulas (15) and (16).

$$rot(\frac{1}{\sigma} rotT) = 0 \tag{15}$$

$$J = rotT \tag{16}$$

Where is the conductivity of the conductor and t is the vector potential.

The boundary conditions are shown in formula (17):

$$\oint T \cdot dl = I \tag{17}$$

Where I is the current flowing through the conductor.

According to the relationship between current density and magnetic flux density, magnetic flux density B can be obtained:

$$rot(\frac{1}{\mu} rotA) = J \tag{18}$$

$$B = rotA \tag{19}$$

Where μ is the conductor permeability and A is the vector magnetic potential.

In order to simplify the analysis, the Lorentz force can be calculated by the electrodynamic formula between two finite parallel conductors. Suppose the current flowing through the conductor is i, the conductor length L, the diameter d, and the distance c between the conductors. The schematic diagram of finite length parallel conductors is shown in Figure 6.

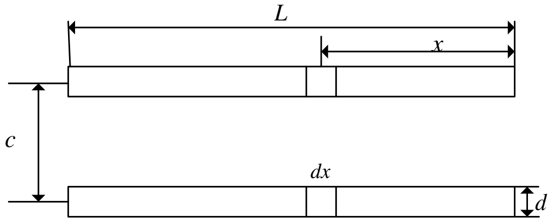

Figure 6 Schematic diagram of finite parallel conductor

Then the magnetic field strength of *dx* formula at is shown in (20):

$$B=\frac{i}{c}\left[\frac{L-x}{\sqrt{(L-x)^2+c^2}}+\frac{x}{\sqrt{x^2+c^2}}\right]\times 10^{-7} \tag{20}$$

The power on force of *dx* is shown in formula (21):

$$dF = iBdx \tag{21}$$

Then the whole length of the lower conductor is subjected to electric force, as shown in formula (22):

$$F=\frac{i^2}{c}\times 10^{-7}\int_0^L\left[\frac{L-x}{\sqrt{(L-x)^2+c^2}}+\frac{x}{\sqrt{x^2+c^2}}\right]dx = 2\times 10^{-7}\frac{L}{c}i^2 \tag{22}$$

Therefore, the expression of Lorentz force F_L is shown in formula (23):

$$F_L = 2\times 10^{-7}\frac{L}{c}i^2 \tag{23}$$

Through formula (11) and formula (23), the expression of electric repulsion force can be obtained as follows:

$$F = F_H + F_L = \frac{\mu_0}{4\pi}i^2 In(B\sqrt{\frac{\pi\xi H}{P}}) + 2\times 10^{-7}\frac{L}{c}i^2 \tag{24}$$

(2) Analysis of arc velocity

1) Arc motion process

It is assumed that the arc is formed by a cylindrical current element link, and the motion of the arc is determined by the motion and interaction of the current element. At this time, the running speed of the arc is affected by electrodynamic force, air resistance and gravity, in which gravity can be ignored [21]. There is energy balance in the process of current element movement, and the process of energy balance can determine the distribution of current element and surrounding air temperature, and finally determine the physical properties such as conductivity of current element.

2) Arc velocity

The single current element is regarded as a straight rod conductor with a mass of 0. According to the shock wave theory of G.Meunier, when the current element moves at the speed of V, a wave array surface will be generated in front of it. According to the conservation law in gas dynamics and the gas state equation, the velocity *v* formula can be obtained, as shown in (25):

$$v = C_0 \frac{(1-u)(y-1)}{\sqrt{(1-u)(y+u)}} \tag{25}$$

Where C_0 is the sound velocity in the air, and the value is 331.2m/s; y is the shock intensity.

Since the mass is 0, the current element is only affected by Lorentz force F_L and air resistance F_z. The two forces are equal in magnitude and opposite in direction. The expression of air resistance is shown in Formula (26) :

$$F_Z = 2(y-1)P_0 rL \tag{26}$$

Where P_0 is the standard atmospheric pressure 0.1013Mpa; r is the radius of current element; L is the current element length.

Combining formulas (25) and (26), the velocity of current element, that is, the expression of arc motion velocity, can be obtained, as shown in formula (27):

$$v = \frac{5\times10^{-7}\dfrac{C_0 i^2}{2cP_0 r}}{\sqrt{49+\dfrac{42\times10^{-7} i^2}{2cP_0 r}}} \tag{27}$$

According to the electric repulsion formula (24) and arc motion speed formula (27), the high breaking mathematical model of the circuit breaker is constructed and normalized, as shown in formula (28):

$$F_1 = \frac{1}{\mu_1 F + \mu_2 v} = \frac{1}{\mu_1\left(\dfrac{\mu_0}{4\pi} i^2 In(B\sqrt{\dfrac{\pi\xi H}{P}}) + 2\times10^{-7}\dfrac{L}{c} i^2\right)*10^{-1} + \mu_2\left(5\times10^{-7}\dfrac{C_0 i^2}{2cP_0 r}\Big/\sqrt{49+\dfrac{42\times10^{-7} i^2}{2cP_0 r}}\right)*10^{-3}} \tag{28}$$

Where μ_1 and μ_2 are the internal coefficient of the circuit breaker, which can be obtained by grid method.

The flower pollination algorithm is used to analyze the high breaking model of circuit breaker. The experimental parameters are set as follows: the value range of current I is 2000-3000a, the value range of contact radius B is 3 ~ 6mm, the value of contact pressure P is 2n and 4N, and the value of conductor length L is 4 ~ 8cm; The distance C between conductors is 1 ~ 3cm; The value range of contact coefficient on contact surface is 0.3 ~ 1, and the value range of current element radius R is 1 ~ 3mm.

Experiment 1: when the contact pressure is 2n, the simulation experiment is carried out through MATLAB software. The comparison algorithms include APSO algorithm, Ba algorithm, FPA algorithm and AMC-FPA algorithm. The maximum number of iterations is set to 50 times, and the experiment is repeated for 10 times to obtain the average value. The available simulation results are shown in Figure 7.

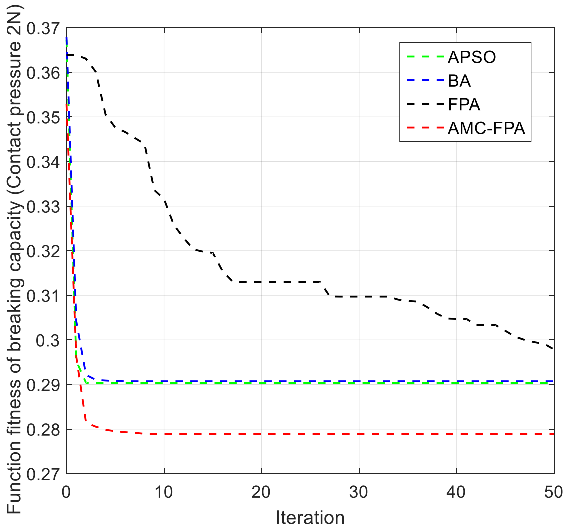

Figure 7 The iteration curve of breaking capacity fitness function (Contact pressure 2N)

According to Figure 7, when the contact pressure is 2n, the function fitness value of AMC-FPA algorithm is the best, reaching 0.2789, while the adaptation value obtained by FPA algorithm is the worst, which is 0.2978.

Experiment 2: when the contact pressure is 4N, the simulation experiment is carried out through MATLAB software. The comparison algorithms include APSO algorithm, Ba algorithm, FPA algorithm and AMC-FPA algorithm. The maximum number of iterations is set to 50 times, and the experiment is repeated for 10 times to obtain the average value. The available simulation results are shown in Figure 8.

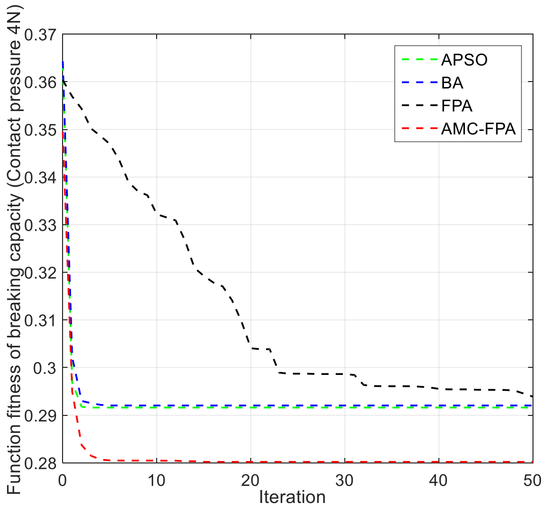

Figure 8 The iteration curve of breaking capacity fitness function (Contact pressure 4N)

It can be seen from Figure 8 that AMC-FPA algorithm has the best effect when applied to the high breaking model of circuit breaker.

The fitness values and running time of the four comparison algorithms are shown in Table 2.

Table 2 The optimization results of breaking capacity

Contact pressure	Algorithm	Fitness value	Time
2N	APSO	0.2903	0.0809
	BA	0.2907	0.0936
	FPA	0.2978	1.3166
	AMC-FPA	0.2789	0.0705
4N	APSO	0.2916	0.1024
	BA	0.292	0.1028
	FPA	0.2939	1.3681
	AMC-FPA	0.2802	0.0995

3.2 Comprehensive optimization design of circuit breaker

Comprehensive optimization of circuit breakers should be carried out on the basis of considering the high breaking capacity of circuit breakers, that is, to ensure low energy consumption and minimum mass volume [22-23]. Therefore, a comprehensive optimization model of circuit breakers is built, as shown in Formula (28).

$$\begin{aligned} F=&\beta_1\left[\frac{1}{\mu_1\left(\frac{\mu_0}{4\pi}i^2 In(B\sqrt{\frac{\pi\xi H}{P}})+2\times10^{-7}\frac{L}{c}i^2\right)*10^{-1}+\mu_2\left(5\times10^{-7}\frac{C_0 i^2}{2cP_0 r}\Big/\sqrt{49+\frac{42\times10^{-7}i^2}{2cP_0 r}}\right)*10^{-3}}\right]+\\ &\beta_2\left[\lambda_1\sum_{k=1}^{k=p}I_n^2\cos\varphi\frac{1}{\sum_{i=2}^{i=n}\frac{1}{R}}+\lambda_2 t\sum_{i=2}^{i=n}(k_1 RS^2+\frac{k_2}{R}+\frac{k_3}{R})\right]*10^{-3}+\\ &\beta_3\left[\frac{\omega_1}{4}\pi^2\rho d^2(m+2)D+\frac{\omega_2}{4}\pi D^2(540\frac{d^4}{D^2}+1.5d)\right] \end{aligned} \tag{28}$$

Variables include all influencing factors of high breaking, low energy consumption and miniaturization. High breaking factors include current i, contact radius B, contact pressure P, conductor length L, distance between conductors c, contact surface contact coefficient ξ and current element radius r. Low energy consumption factors: contact number n, conductor surface area S, phase offset Angle cosine value $\cos\varphi$, single contact resistance value R; Factors of miniaturization: spring diameter d, number of effective turns m, spring diameter D.

The flower pollination algorithm is used to analyze the comprehensive optimization model of circuit breaker.

(1) Parameter setting in Experiment 1:

1) high breaking: current i ranges from 2000 to 3000A, contact radius B ranges from 3 to 6mm, and conductor length L ranges from 4 to 6cm. The distance c between conductors ranges from 1 cm to 3cm. The contact surface contact coefficient ξ ranges from 0.3 to 1, the current element radius r ranges from 1 to 2mm, and the contact

pressure P is set to 2N.

2) Low energy consumption: the number of contacts n ranges from 10 to 15, the conductor surface area S ranges from 4 to 8mm^3, the cosine of phase offset Angle $\cos\varphi$ ranges from 0.3 to 0.6, and the resistance value of a single contact R ranges from 6 to 13. Set the rated current to 2000A.

3) Miniaturization parameters: the spring diameter d ranges from 0.6 to 3mm, the effective winding number m ranges from 5 to 13, and the spring diameter D ranges from 10 to 25mm.

(2) Parameter setting in Experiment 2:

1) high breaking: current i ranges from 2000 to 3000A, contact radius B ranges from 3 to 6mm, and conductor length L ranges from 4 to 7cm. The distance c between conductors ranges from 1 to 3cm. The contact surface contact coefficient ξ ranges from 0.3 to 1, the current element radius r ranges from 1 to 2mm, and the contact pressure P is set to 4N.

2) Low energy consumption: the number of contacts n ranges from 10 to 20, the conductor surface area S ranges from 4 to 9mm^3, the cosine of phase offset Angle $\cos\varphi$ ranges from 0.3 to 0.6, and the resistance value of a single contact R ranges from 6 to 15. Set the rated current to 2000A.

3) Miniaturization parameters: the spring diameter d ranges from 0.6 to 3mm, the effective winding number m ranges from 5 to 12, and the spring diameter D ranges from 10 to 20mm.

The set parameters were tested by Matlab software, and the AMC-FPA algorithm, APSO algorithm, BA algorithm and FPA algorithm were applied to the comprehensive optimization design. The simulation results are shown in Figure 9-10.

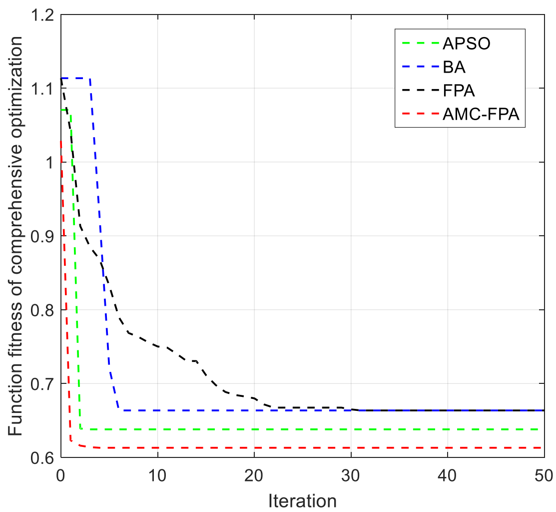

Figure 9 The iteration curve of fitness function of comprehensive optimization (experiment 1)

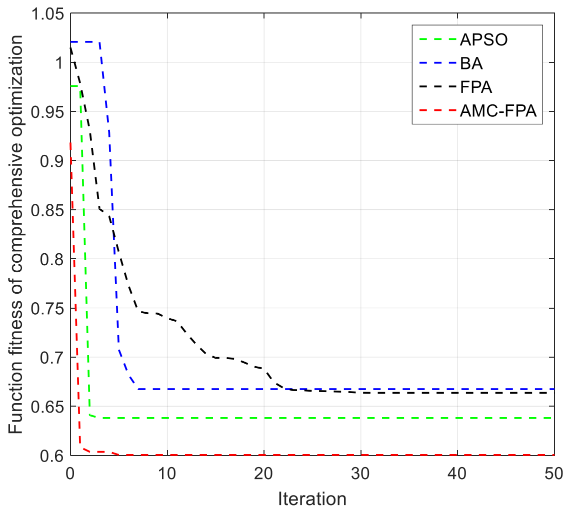

Figure 10 The iteration curve of fitness function of comprehensive optimization (experiment 2)

It can be seen from Figure 9 and 10 that AMC-FPA algorithm has the best effect in the comprehensive optimization design of circuit breaker.

In order to more clearly compare the fitness value and running time in the two experiments, it can be expressed in the form of a table. The comprehensive optimization results of the circuit breaker are shown in Table 3.

Table 3 The comprehensive optimization results of circuit breakers

algorithm	experiment one		experiment two	
	Fitness value	runtime	Fitness value	runtime
APSO	0.638	0.1178	0.638	0.1183
BA	0.6636	1.1140	0.6674	1.4352
FPA	0.6636	1.1004	0.6636	1.4279
AMC-FPA	0.613	0.1131	0.6004	0.1111

As can be seen from Table 3, when AMC-FPA algorithm is used to comprehensively optimize the circuit breaker, a better effect can be obtained, with the optimal function fitness value and the shortest running time. BA algorithm has the worst effect and cannot reach the optimal. Basic FPA algorithm has a general effect in comprehensive optimization, which is slightly worse than APSO algorithm.

4. conclusion

This paper uses an improved flower pollination algorithm to optimize the design of the circuit breaker's miniaturization, and draws the following conclusions:

(1) The improved flower pollination algorithm has better performance. The introduction of adaptive step size solves the problem of slow convergence of the algorithm's global pollination process. The introduction of directional mutation strategy and catfish effect solves the problem of slow convergence and easy to fall into the local pollination process of the algorithm. The problem of optimal solution. The proposed

AMC-FPA algorithm is better than other algorithms.

(2) Using the improved AMC-FPA algorithm to optimize the high breaking of the circuit breaker, construct a mathematical model of the high breaking of the circuit breaker, and give the optimal design method for the high breaking of the circuit breaker based on the FPA algorithm, and according to the factors that affect the high breaking of the circuit breaker For different values, two experiments were carried out and compared with APSO algorithm, BA algorithm and basic FPA algorithm. The experimental results show that the high-breaking optimization design method of the circuit breaker based on the flower pollination algorithm is feasible, and the AMC-FPA algorithm has the best effect.

(3) The improved AMC-FPA algorithm is used to optimize the comprehensive optimization model of circuit breaker. Based on the high fracture model, combined with the influence factors of low energy consumption and miniaturization model of circuit breaker, the comprehensive optimization model of circuit breaker is built, and the circuit breaker comprehensive optimization design method based on FPA algorithm is given, and verified by two experiments. And compared with APSO algorithm, BA algorithm and basic FPA algorithm. The experimental results show that the integrated optimization design method of circuit breaker based on flower pollination algorithm is feasible, and the AMC-FPA algorithm has the best effect.

In addition to AMC-FPA algorithm, other swarm intelligence optimization algorithms can also be extended to other engineering simulation optimization, so as to better optimize the design of engineering problems.

Availability of data and materials

All data included in this study are available upon request by contact with the corresponding author.

Competing Interest

The authors declare that they have no competing interests

Funding

This work was supported by the National Natural Science Foundation of China (No.42075129) and Key Research and Development Project from Hebei Province(No.19210404D, No.20351802D).

Author Contributions:

Author Contributions: Guodong LI. Conceptualization, Methodology, Software, Writing—Original Draft, Writing—Review & Editing, Supervision, Formal analysis, Visualization. Min XIE: Validation, Investigation, Project administration. Yunhe TIAN: Data Curation, Resources, Funding acquisition.

Acknowledgements

Not applicable

Reference

1. Wang Z, Si J F, Hui L S, Design of Intelligent Actuation Time Measurement for Low Voltage Electrical Apparatus. Advanced Materials Research, 709, 379-382. (2013).doi:10.4028/www.scientific.net/AMR.709.379
2. Safonov E , Frolov V.The influence of power system parameters on breaks of fault currents in the generator circuit breaker. Journal of Physics: Conference Series,1753(1): 012041(2021).doi:10.1088/1742-6596/1753/1/012041
3. Niu C P, Ding J W, F Yang, et al. Movement characteristic of a circuit breaker with repulsion force compensated contact system. Advances in Mechanical Engineering, 7(3),1-8(2015),. doi:10.1177/1687814015573820
4. Yang X S. Flower pollination algorithm for global optimization[C]//International conference on unconventional computing and natural computation. Springer, Berlin, Heidelberg,240-249(2012).doi.org/10.1007/978-3-642-32894-7_27
5. Hocine T, Salem A. Modified Flower Pollination Algorithm Constrained Optimal Power Flow[J]. Ingénierie des Systèmes d Inf.24(4): 439-444(2019). doi.org/10.18280/isi.240412
6. Sharma R, Mittal N, Sohi B S. Flower pollination algorithm-based energy-efficient stable clustering approach for WSNs[J]. International Journal of Communication Systems,33(7): e4337(2020). doi.org/10.1002/dac.4337
7. Mahendran G, Govindaraju C. Flower pollination algorithm for distribution system phase balancing considering variable de mand[J]. Microprocessors and Microsystems, 74: 103008(2020).doi.org/10.1016/j.micpro.2020.103008
8. Adithiyaa T, Chandramohan D, Sathish T. Flower Pollination Algorithm for the Optimization of Stair casting parameter for the preparation of AMC[J]. Materials Today: Proceedings, 2020, 21: 882-886.doi.org/10.1016/j.matpr.2019.07.711
9. Chen Y, Pi D. An innovative flower pollination algorithm for continuous optimization problem[J]. Applied Mathematical Modelling,83: 237-265(2020). doi.org/10.1016/j.apm.2020.02.023
10. Liang X B, Liang W, Xiong J Y. Intelligent diagnosis of natural gas pipeline defects using improved flower pollination algorithm and artificial neural network[J]. Journal of Cleaner Production,264: 121655(2020). doi.org/10.1016/j.jclepro.2020.121655
11. Rodriguez L , Castillo O , Garcia M , et al. A new meta-heuristic optimization algorithm based on a paradigm from physics: string theory[J]. Journal of Intelligent and Fuzzy Systems,41(1):1657-1675(2021). doi:10.3233/JIFS-210459
12. Wang Z D, Wu C H , Xu J , et al. Research on path planning of cleaning robot based on an improved ant colony algorithm[J]. MATEC Web of Conferences, 336:07005(2021). 10.1051/matecconf/202133607005
13. Jeyanthi K , Mangai S . Ensembled Population Rescaled Differential Evolution with Weighted Boosting for Early Breast Cancer Detection[J]. Mobile networks & applications, 24(6):1778-1792(2019). 10.1007/s11036-019-01383-8
14. Chuang L Y , Tsai S W , Yang C H . Improved binary particle swarm optimization using catfish effect for feature selection[J]. Expert Systems with Applications, 38(10):12699-12707(2011). doi.org/10.1016/j.eswa.2011.04.057
15. Derbal L , Kebbiche Z . An Efficient Parameterized Logarithmic Kernel Function for Semidefinite Optimization[J]. Acta Mathematicae Applicatae Sinica, English Series,36(3):753-770(2020). doi:10.1007/s10255-020-0955-y
16. Liu Y , Zhang G , Zhao C , et al. Influence of mechanical faults on electrical resistance in high voltage circuit breaker[J]. International Journal of Electrical Power & Energy Systems, 129:106827(2021). DOI:10.1016/j.ijepes.2021.106827

17. Fang Shuhua, Lin Heyun,Ho S.L. Contact parameter computation and analysis of air circuit breaker with permanent magnet actuator[J]. Journal of Electrical Engineering and Technology,8(3): 595-602(2013). DOI:10.5370/JEET.2013.8.3.595