Reactive Power Optimization of Power System Based on Intelligent Algorithm

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Asbstract

The devwelopment of national economy has driven the development and expansion of the power system, and each part of the power grid has become more and more complex, which has higher requirements on the power quality of daily life, we need electric energy is safe, reliable and qualified. Reactive power optimization of power system is one of the important methods to ensure the normal work of power system, ensure the economical and effective operation of power grid and maintain the voltage stability of nodes. In this paper, particle swarm optimization (PSO) algorithm is proposed to optimize reactive power of power system and to build corresponding mathematical model. Finally, the system with IEEE-30 node is taken as an example to carry out the calculation example analysis, and the optimization is realized through C language programming. It is verified that the optimization effect is better when the particle swarm optimization algorithm is used for optimization.

Keywords: power system, reactive power optimization, intelligent algorithm, particle swarm optimization, power flow calculation

I. Introduction

Nowadays, electric energy plays an indispensable and important role in People's Daily life.In the 1960s, J.Carpenter first proposed the concept of optimal power flow in power system, and subsequently, studies on reactive power optimization were gradually carried out [1, 2].Reactive power optimization problem refers to the optimization problem in which the power system achieves the expected goal and satisfies various constraints under certain operating modes [3].In the problem of reactive power optimization, there are both continuous variables and discrete variables, equality constraints and inequality constraints, and traditional solving methods are not capable of solving them [4].In recent years, the intelligent algorithm of biological community simulation has been widely concerned by researchers, and its application has successfully solved many problems.Many intelligent algorithms are listed in literature[5], including genetic algorithm (GE), particle swarm optimization (PSO), ant colony optimization (ACO) and so on.PSO algorithm can easily solve multi-dimensional, multi-objective, discrete optimal value.In literature [6], trajectory optimization of carrier rocket was carried out, and the author used the improved particle swarm optimization algorithm, which showed good optimization effect andimproved carrier capacity more effectively.Literature [7] adopts PSO algorithm to optimize the design of the target. Compared with the previous design, the optimized object has a smaller volume.In literature [8], a bridge cable force optimization method using hybrid PSO algorithm to influence matrix concept was proposed, which effectively avoided obstacles in autonomous path planning of uav and obtained local optimal solution, reflecting that PSO algorithm performs best in solving optimization problems.In reference [9], PSO algorithm is used to transform the problem of parameter identification, and the simulation results show that the identification accuracy of this method is more than 98%, with good identification effect.In this paper, PSO is used for reactive power optimization of power system. Compared with voltage and power loss of power system nodes after power flow calculation,PSO is verified to have a better optimization effect on reactive power optimization of power system, providing reference for future reactive power optimization of power system.

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II. Particle Swarm Optimization and Power Flow Calculation

2.1 Principle of particle swarm optimization

Particle swarm optimizationwas firstly proposed by American psychologist Kenndy and electrical engineer Eberhart in 1995 [10].In order to better understand the principle of the algorithm, we use our imagination, in an empty area, there is a flock of birds looking for food freely. However, there is only one piece of food here, and no bird knows where the food is, but they know the distance between the food and themselves. As a result, birds can easily and efficiently locate food by determining the location of the bird closest to the food. Similarly, PSO can be used to find the best position of particles by searching in space and combining with the cooperation and competition between particles [11].

PSO first needs to initialize particles, which are uniformly distributed in a given space, and all particles have an adaptive value, which is determined by the optimization function[12].PSO can be described mathematically as follows: assume a particle community, set the total number of particles as popsize, the dimension of particles as m, and the termination condition of the algorithm as maxiter.The flight speed of the its particle at time t and its position in the search space Xi=(Xi1, xi2.xid), put Xi into the fitness function to get the fitnessvalue. Particle velocity:Vi=(Vi1,Vi2.Vid). The best position experienced by the its particle individual:pbesti=(Pi1, pi2.pid) and the best positionexperienced by the population : gbest=(g1, g2.gd).All particles can update the velocity and position of particles according to equations (1) and (2), as shown in equations (1) and (2).

$$v[]=\omega * v[]+c1*rand()*(pbest[]- present[])+c2*rand()*(gbest[] - present[]) \quad (1)$$

$$\text{present}[\ ]= present[\ ]+v[\ ] \quad (2)$$

In the above equation: $c1$, $c2$ is the learning factor and is usually valued at 2; w is the inertia weight coefficient; $\text{rand}(\ )$ is a random number between (0,1).

2.2PSOalgorithm implementation process

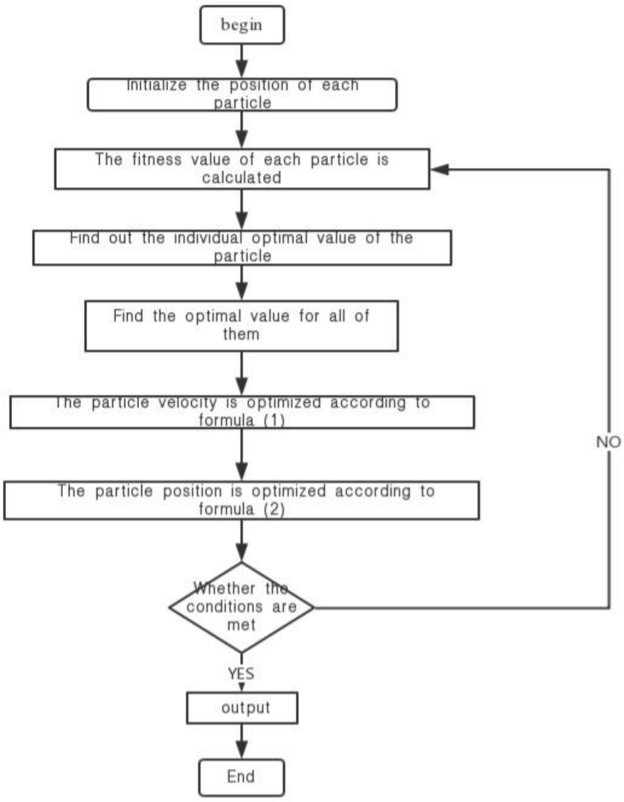

Figure 1 PSO algorithm implementation process

2.3 Flow calculation

For the power system, the power flow calculationandanalysis of the operation of the power grid are very critical parts of the research. The so-called power flow calculation refers to the steady-state calculation of an extremely complex power system under the condition of normal operation or fault operation. The purpose of power flow calculation of power system is to check whether the voltage of the node meets the requirements, whether the distribution and distribution of power are reasonable, and whether thse components incorporated into the power grid are overloaded.

The mathematical model for power flow calculation of power grid can be expressed in equations (3) and (4).

$$\sum_{i} P_{gi} = \sum_{i} P_{li} + \Delta P \quad (3)$$

$$\sum_{i} Q_{gi} = \sum_{i} Q_{li} + \Delta Q \quad (4)$$

In the above equation: P_{li} is the active power consumed by the node; ΔP is the active power consumed by the load; P_{gi} isprovide active power to the node; Q_{li} is the reactive power consumed by the node; ΔQ isthe reactive power consumed by the load; Q_{gi} is provide reactive power to nodes.

The inequality constraint conditions are as follows:

$$P_{imin} \le P_i \le P_{imax} \quad (5)$$

$$Q_{imin} \le Q_i \le Q_{imax} \quad (6)$$

$$U_{imin} \le U_i \le U_{imax} \quad (7)$$

Variables are expressed as follows: U_i is the voltage amplitude of node i ; P_{imin} and P_{imax} are active power constraints of node i ; Q_{imin} and Q_{imax} are reactive power constraints of node i ; U_{imin} and U_{imax} are voltage constraints ofnode i .

2.3.1 Newton-laffson method for power flow calculation

Newton-laffson method has become one of the most widely used methods in solving the problem of power flow calculation by virtue of its own characteristics and advantages in solving such problems, and has been adopted by many researchers in the research process of power flow calculation.

The equations for calculating power flow by using bovine rafah are as follows：

$$S_{ij} = U_i \sum_{j=1}^{n} Y_{ij} U_{ij} = P_i + jQ_i \quad (8)$$

Put equation (8) into the mathematical model of power flow calculation and get the following equation:

$$P_i = U_i \sum_{j=1}^{N} U_j (G_{ij} \cos\beta_{ij} + B_{ij} \sin\beta_{ij}) \quad (9)$$

$$Q_i = U_i \sum_{j=1}^{N} U_j (G_{ij} \sin\beta_{ij} + B_{ij} \cos\beta_{ij}) \quad (10)$$

In equations (9) and (10): U_i is node voltage; P_i is the injected active power; Q_i is the injected reactive power; i is 1, 2...Integers in n.

2.3.2 Steps of newton-laffson method for power flow calculation

The steps of Newton-laffson method's power flow calculation:

(1) Form node admittance matrix Y_B;
(2) Set the initial voltage of each node;
(3)Substitute the result in step 2 into the modified equation;
(4) Solve each element of jacobian matrix;
(5)The above modified equation is solved to obtain the unbalance of voltage at each node;
(6)Calculate the new voltage value of each node;
(7)Get the result of step 6 and proceed to the next iteration from step 3;
(8) Calculate the results of relevant parameters.

III. Reactive Power Optimization of Power System Based on PSO

3.1 Reactive power optimization mathematical model of power system

The reactive power optimization process of the power system is mainly solved from two aspects. One is to determine the "point", which is the point to be compensated. We need to know which point in the whole network meets our requirements. The second is to determine the "quantity", which is the quantity to be compensated. We need to know how much to be compensated and put the amount to be compensated into the power system. Through the above two measures, reactive power optimization can be carried out to meet our relevant demand for electric energy, so that people's life, related career development and social development can be more beautiful. Moreover, through optimization, the operation of the power system is more stable and can bring significant economic benefits [13].

The mathematical model of reactive power optimization of power system [14] contains objective function, power constraints and variable constraints. The commonly used mathematical model for optimization is:

$$\begin{cases} \min f(u,x); \\ s.t. g(u,x) = 0; \\ h(u,x) \le 0; \end{cases} \quad (11)$$

In this mathematical model: u is the voltage value; x is a variable of the voltage value; $f(u,x)$ is the objective function of reactive power optimization, according to which the planning and design of the objective can be selected; $g(u,x)$ is the formula of node power flow calculation, which is the constraint part of reactive power optimization equation; $h(u,x)$ is a constraint on the maximum or minimum value of the control variable, which is the inequality constraint part of reactive power optimization.

3.2 Objective function and constraint conditions in reactive power optimization

3.2.1 Objective function

In order to ensure the voltage quality of the power network, the network loss in the power system can be reduced by changing the terminal voltage of the generator, changing the switching quantity of the reactive power compensation configuration and adjusting the transformer tap. Therefore, from the perspective of economic operation of the power network, the objective function is usually made to minimize the loss of active power network, and the objective function is expressed as follows:

$$Min P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} G_{ij} (U_i^2 + U_j^2 - 2U_i U_j \cos\beta_{ij}) \quad (12)$$

In the above equation: β_{ij} isthe phase Angle difference between nodes i and j ; U_{i} isthe voltage of node i ; U_{j} isthe voltage of node j; G_{ij} isthe branch conductance between node i and j ; N is the number of system branches involved in calculating the loss of the active network.

3.2.2 Equation constraints for reactive power optimization

In the process of reactive power optimization of power system, the constraints of reactive power optimization are composed of two parts: equality constraints and inequality constraints.In general, the balance of active and reactive power in the power grid is adopted as the equation constraint, that is, under the power flow distribution of the power grid, the active and reactive power consumed by the system is equal to the reactive power generated by the active power and reactive power compensation configuration generated by the system output.

The equation constraint in the general constraint condition of reactive power optimization is the power flow equation of active power and active power in the power system, which can be expressed as follows:

$$P_i = U_i \sum_{j=1}^{N} U_j (G_{ij} \cos\beta_{ij} + B_{ij} \sin\beta_{ij}) \quad (13)$$

$$Q_i = U_i \sum_{j=1}^{N} U_j (G_{ij} \sin\beta_{ij} + B_{ij} \cos\beta_{ij}) \quad (14)$$

In the above equation: N isthe total number of nodes; β_{ij} is the phase Angle difference between i and j ; G_{ij} is the branch conductance between node i and j ; B_{ij} is the branch current between node i and j ; U_i is the voltage at node i ; Q_{i} is the reactive power injected at node i ; P_{i} is the active power injected at node i .

3.2.3inequality constraints for reactive power optimization

In the actual operation process of power system, researchers often need to analyze and consider from multiple aspects. Among many problems, whether the voltage meets the conditions is a very important issue. We usually judge whether the voltage has reached the rated voltage value or not, because only when the voltage of electrical equipment or important nodes meets the requirements and reaches the rated value, the whole power network will operate normally and reliably. Meanwhile, the operation of power system is also restricted by other conditions, such as power output. Make the power system run reliably by adjusting the changing conditions.

The constraint conditions are:

$$U_{Gi\min} \le U_{Gi} \le U_{Gi\max}, i \in N_G \quad (15)$$

$$Q_{Ci\min} \le Q_{Ci} \le Q_{Ci\max}, i \in N_c \quad (16)$$

$$T_{Ki\min} \le T_{Ki} \le T_{Ki\max}, i \in N_T \quad (17)$$

In the above formula: N_T is the sum of adjustable transformers; N_C is the sum of compensating capacitor nodes; N_G is the sum of generator nodes; $T_{Ki\min}$ is the lower limit of the position of tap; Q_{Cimin} is the lower limit of compensating capacity; $U_{Gi\min}$ is the lower limit of voltage; $T_{K\mathrm{imax}}$ is the upper limit of the sub's position; $Q_{C\mathrm{imax}}$ is the upper limit of compensation capacity; $U_{G\mathrm{imax}}$ is the upper limit of voltage; $T_{K\mathrm{i}}$ is the location of the tap; Q_{Ci} is the capacity to compensate; $U_{G\mathrm{i}}$ is the amplitude of the voltage.

3.3 Reactive power optimization of power system based on PSO

According to the above mathematical model and constraint conditions, combined with the steps of PSO, the steps of reactive power optimization of power system based on PSO are obtained as follows:

(1)Input data.First, input all the initial data needed in the optimization process. Then, determine the corresponding data of the particle and initialize it.

(2)Calculation of individual fitness value of particles.Firstly, power flow is calculated, network loss and power flow distribution are calculated, and then relevant parameters are calculated. For variables beyond the limitation requirements, the output of this variable is a new restriction of constraint conditions.

(3)Record individual extreme value and global extreme value.According to the above formula, the new velocity and position can be solved.

(4)Judge whether the output result can reach the global optimal, so as to judge whether the individual extreme value and the whole extreme value can continue to be updated.

(5)According to the constraint conditions in the iterative process, judge whether the data obtained in the whole process meet the convergence requirements.

(6)Output the optimal solution after optimization.Output all relevant parameters.

IV. Results and Analysis of Experiment

In order to verify the effectiveness of particle swarm optimization for power system, this paper uses C language programming to write power flow calculation and PSO for reactive power optimization program, and combines commonly used IEEE-30 node for verification and comparative analysis of results.

IEEE-30 node system consists of 6 generator nodes, 21 load nodes, 37 power lines and 4 transformer branches with adjustable transformer ratio, and is equipped with a set of shunt capacitors at 10 nodes and 24 nodes respectively.The 1 node of the generator is usually taken as the balance node, and the nodes of other generators are set as PV node.

The wiring diagram of the standard test system for IEEE-30 node system is shown in figure 2. The original data parameters are all based on 100MVA.The generator terminal voltage of this system is continuously adjustable, the transformer's variable ratio adjustment range [0.9, 1.1] (standard value), and the adjusting step length of tap is 2.5%.The upper and lower limits of voltage of each node are [1.05, 0.95].Node 10 and node 24 are equipped with reactive power compensation devices. The segmented compensation of node 10 is 0.1, and the upper limit of compensation is 0.50(standard value); the segmented compensation of node 24 is 0.02, and the upper limit of compensation is 0.10(standard value).

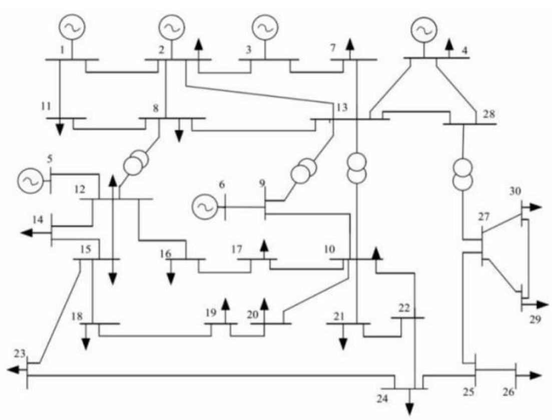

Figure 2Network structure diagram of IEEE-30 node system

The initial running state of IEEE-30 system and the active power network losses during the initial operation are calculated by using Newton-laffson method for power flow calculation. The results are shown in table 1.In the optimization calculation of particle swarm optimization, the selected parameters are as follows: the population size of basic particle swarm optimization is 60, and the evolutionary iteration number of the population is 100. The results shown in table 2 are the optimization results of IEEE-30 system based on particle swarm algorithm, and the active power network loss after particle swarm optimization is calculated.

Table 1 IEEE-30 intial operating state of the system

node	Voltage amplitude	Voltage phase Angle	Power active	Reactive power	Load active	Load reactive
1	1.05	0.00	1.00	0.40	0.00	0.00
2	1.03	-1.51	0.81	-0.19	0.22	0.13
3	1.01	-6.60	0.51	0.25	0.95	0.20
4	1.02	-5.53	0.20	0.38	0.00	0.00
5	1.01	-6.43	0.20	0.11	0.00	0.00
6	1.02	-4.54	0.19	0.06	0.00	0.00
7	1.01	-6.32	0.00	0.00	0.23	0.11
8	1.01	-4.50	0.00	0.00	0.08	0.02
9	0.99	-6.90	0.00	0.00	0.00	0.00
10	0.99	-9.14	0.00	0.00	0.06	0.03
11	1.02	-3.80	0.00	0.00	0.03	0.02
12	0.99	-8.32	0.00	0.00	0.12	0.08
13	1.02	-5.32	0.00	0.00	0.00	0.00
14	0.98	-9.20	0.00	0.00	0.07	0.02
15	0.96	-9.21	0.00	0.00	0.09	0.03
16	0.98	-8.85	0.00	0.00	0.04	0.02
17	0.97	-9.22	0.00	0.00	0.09	0.07
18	0.96	-10.16	0.00	0.00	0.04	0.01
19	0.96	-10.23	0.00	0.00	0.10	0.04
20	0.97	-10.14	0.00	0.00	0.03	0.01
21	0.97	-0.63	0.00	0.00	0.17	0.12
22	0.97	-9.61	0.00	0.00	0.00	0.00
23	0.96	-9.84	0.00	0.00	0.09	0.07
24	0.96	-10.16	0.00	0.00	0.09	0.07
25	0.96	-10.14	0.00	0.00	0.00	0.00
26	0.94	-10.70	0.00	0.00	0.04	0.02
27	0.97	-9.81	0.00	0.00	0.00	0.00
28	1.00	-5.83	0.00	0.00	0.00	0.00
29	0.94	-11.24	0.00	0.00	0.03	0.01
30	0.93	-12.22	0.00	0.00	0.11	0.02

Table 2 Results of particle swarm optimization on IEEE-30 nodes

node	Voltage amplitude	Voltage phase Angle	Power active	Reactive power	Load active	Load reactive	Reactive power compensa-tion
1	1.06	0.00	0.99	-0.25	0.00	0.00	0.00
2	1.06	-1.93	0.82	-0.15	0.22	0.13	0.00
3	1.06	-6.90	0.51	0.03	0.95	0.20	0.00
4	1.06	-6.13	0.20	-0.02	0.31	0.31	0.00

Continue to table 2

5	1.05	-4.80	0.20	-0.01	0.32	0.32	0.00
6	1.05	-6.60	0.20	-0.08	0.00	0.00	0.00
7	1.04	-6.70	0.00	0.00	0.23	0.12	0.00
8	1.04	-4.75	0.00	0.00	0.08	0.02	0.00
9	1.03	-7.03	0.00	0.00	0.00	0.00	0.00
10	1.03	-8.88	0.00	0.00	0.06	0.02	0.00
11	1.04	-3.98	0.00	0.00	0.03	0.01	0.00
12	1.06	0.87	0.00	0.00	0.12	0.08	0.00
13	1.05	-5.70	0.00	0.00	0.00	0.00	0.00
14	1.04	-9.03	0.00	0.00	0.06	0.02	0.00
15	1.03	-9.21	0.00	0.00	0.09	0.03	0.00
16	1.03	-8.68	0.00	0.00	0.04	0.02	0.00
17	1.04	-9.04	0.00	0.00	0.09	0.06	0.00
18	1.02	-9.80	0.00	0.00	0.04	0.01	0.00
19	1.02	-9.95	0.00	0.00	0.10	0.04	0.00
20	1.02	-9.75	0.00	0.00	0.02	0.01	0.00
21	1.02	-9.42	0.00	0.00	0.18	0.11	0.00
22	1.03	-9.43	0.00	0.00	0.00	0.00	0.00
23	1.03	-9.93	0.00	0.00	0.04	0.02	0.00
24	1.03	10.23	0.00	0.00	0.09	0.07	-0.11
25	1.02	-10.10	0.00	0.00	0.00	0.00	0.00
26	1.00	-10.61	0.00	0.00	0.04	0.03	0.00
27	1.02	-9.77	0.00	0.0	0.00	0.00	0.00
28	1.05	-6.20	0.00	0.00	0.00	0.00	0.00
29	1.01	-11.00	0.00	0.00	0.03	0.01	0.00
30	1.00	-11.90	0.00	0.00	0.11	0.03	0.00

In the initial state, the network loss is large, and its value is 0.057. Moreover, the voltage of each node in IEEE-30 system is low, among which the node 30 has the lowest voltage, its value is 0.93, followed by the voltage value of 0.94. The nodes with this voltage value are 15, 18, 19, 23, 24 and 25.After particle swarm optimization, the active power network loss of IEEE-30 node system is reduced. At this time, the active power network loss value is 0.054. At the same time, as can be seen from table 2, the amplitude level and stability of node voltage are generally improved.By comparing and analyzing the data obtained from table 1 and table 2, the particle swarm optimization algorithm reduces the active power loss of the system and improves the voltage level of nodes,which shows a good optimization effect in the optimization process.

V. Conclusions

In this article, using the PV generator node voltage, compensating capacity of reactive power device and adjustable change ratio of voltage as control variables, the minimum active in system network loss as objective function, the node voltage, lower limit and selection on the node, the inequality of the lower limit on the generator's as constraint conditions, a mathematical model of the power system reactive power optimization.

In this paper,particle swarm optimization, an intelligent algorithm, is used to optimize the reactive power of the power system, which avoids the problems such as difficulty in calculation, difficulty in solving and trouble in data processing, etc., and accelerates the convergence speed and improves the accuracy in the optimization process, and effectively reduces the premature convergence phenomenon.Finally, an example analysis to the IEEE - 30 node power system as an example, through programming, and analyze the output results, show that mentioned in this paper, particle swarm optimization algorithm in reactive power optimization process of the optimization results show the effect is very remarkable, show that the algorithm has a high application value and can be quickly found in get rid of the conditions of local optimal solution, and has the ability to better meet the requirements can be meet the diversity of the reactive power optimization process.

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References

[1] ZhengfengWang.Reactive power and power system operation [M]. Beijing: China electric power press, 2009.1-86.

[2] WenzhongZhao. Analysis of reactive power transmission characteristics based on simple power system model [J]. Automation and instrumentation,2010(02):128-130.

[3] YuanZou. Analysis and research on voltage stability of power system [J]. Science and technology wind,2019(05):188.

[4] HongxinLi,Yinhong Li,Zhihuan Li. Comparison and evaluation of multi-objective evolutionary algorithm for reactive power optimization [J]. Power grid technology, 2013, 37(6):1651-1658.

[5] Xiaowen Wang,YanhuiZhao.Research review on reactive power optimization algorithm for power system (part one) [J]. Journal of shenyang institute of engineering (natural science edition), Oct. 2014 (3): 22-23.

[6] JunhuiHuang, Weiyuan Wang, Haiqian Wang, Haikun Li. Research on reactive power optimization and voltage control of ac and dc systems based on simulated annealing genetic algorithm [J]. Power system protection and control,2016,44(10):37-43.

[7] LiuZhang, Xuemei Zhang, Qiong Tang. Optimal design of carrier rocket trajectory based on combined-particle swarm optimization [J]. Missile and space launch technology,2016(06):1-5.

[8] XuzhenLi. Optimization design of planetary gear transmission based on particle swarm optimization [J]. Mechanical engineering and automation,2018(06):98-100.

[9] YanjiangChen. Cable force optimization of pedestrian tie steel arch bridge based on hybrid particle swarm optimization [A]. Industrial architecture 2017 supplement III[C].

[10] WuWei, YanGuo. Multi-objective optimization algorithm for dynamic particle swarm optimization based on crowded distance[J].Computerengineering and design,2011,32(04):1422-1425+1452.

[11] Dongrui Zhou. Research on reactive power optimization of distribution LAN based on particle swarm optimization [D]. Shandong University,2015.

[12] YongjunZhang, Zhen Ren, Bangfeng Li. Review of research on optimal reactive power dispatching of power system [J]. Power grid technology,2005(02):50-56.

[13] LiangSun,LinghongLv,Xiuqi Zhang. Review on application of intelligent optimization algorithm to reactive power optimization of distributed power distribution network [J]. Journal of Northeast DianliUniversity,2017,37(04):27-31.

[14] JunZhang, Zhipeng Bi. Reactive power optimization based on improved genetic algorithm[J]. Prospect of science and technology,2016,26(27):286.