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A review of reactive power optimization algorithm in power system

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Abstract. The paper analyses the significance of reactive power optimization, generalizes the current situation of power system development. Various optimization algorithms were introduced in this paper such as traditional optimization algorithm, intelligence optimization algorithm, including the methods of linear programming, Newton's method, heuristic optimization algorithm, etc. This research analyzes the advantages and disadvantages of each algorithm and its application direction by comparing their outstanding performance in solving discrete variables and continuous variables. The purpose of the research is to find the optimal solution of reactive power optimization algorithm, minimize the transport network loss of power system, and improve the quality of users.

Keywords: power system, reactive power optimization, traditional algorithms, intelligence optimization algorithm

1. Introduction

As the economy grows, so does the need for electricity, prompting the government to focus more on improving the country's electrical infrastructure. If reactive power is allocated and dispatched efficiently, not only can the voltage level be maintained and the stability of power system operation be enhanced, but active power loss and reactive power loss may also be minimized. It is also a crucial resource for helping dispatchers set up the appropriate operating mode and prepare for optimal reactive power usage. Power savings, higher voltage quality, and more stable power grid operation are just a few of the many tangible benefits of reactive power management. As far as the current situation is concerned, there are generally insufficient reactive power or unreasonable reactive power distribution in the power distribution system. What we need to do is to find the best algorithm for rational distribution of reactive power. The research about reactive power optimization could decrease the incidence of system breakdown and other accidents, proving that power system could operate more efficiently and economically [1]. The research of the algorithm is to better solve the discrete variables and continuous variables. The paper will analyze a variety of algorithms to solve the problem of reactive power optimization. Different algorithms can be selected to solve different problems.

2. The definition and significance of reactive power optimization

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When the system's structural parameters and load conditions are known, reactive power optimization is the process of adjusting the system's reactive power by optimizing a subset of its control variables, with the goal of achieving the system's optimal performance on one or more performance indicators. Whether or not the reactive power distribution of the system reasonably and directly affects the safety and stability of the power system, reactive power optimization is of major significance. Analyzing from the user's perspective, the most basic purpose of power system is to provide electricity to the user, the transmission error will have a great impact on the people's lives if it happens, it is necessary to ensure the normal operation of the power grid. Reactive power optimization can keep the voltage stable through the reactive power flow distribution. From the perspective of power transmission companies, reactive power optimization can effectively reduce network loss, improve transmission efficiency, reduce transportation costs, and help power transmission companies obtain more benefits. Therefore, the research on reactive power optimization has the great practical significance.

3. Introduction to reactive power optimization

The reactive power optimization of power system is a complex mixed nonlinear programming problem mathematically, which contains multiple variables and constraints, and the control variables include two kinds, namely, discrete variables and continuous variables, and it is also a multi-peak function models. In reactive power optimization, the model used will be different depending on the solution target. The article will introduce several typical power system reactive power optimization models.

3.1. Reactive power optimization model considering network loss

Objective function:

$$min\, F = min \sum_{k=1}^{nl} G_{jy}\, [u_i^2 + u_j^2 - 2u_i u_j\, cos(\delta_j - \delta_i)]\#(1)$$

Subject to:

$$\begin{cases} P_i - U_i \sum_{j=1}^{n} U_j\, (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) = 0 \\ Q_i - U_i \sum_{j=1}^{n} U_j\, (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) = 0 \\ u_{i\,min} \le u_i \le u_{i\,max} \\ Q_{Gi\,min} \le Q_{Gi} \le Q_{Gi\,max} \\ Q_{Ci\,min} \le Q_{Ci} \le Q_{Ci\,max} \\ T_{i\,min} \le T_i \le T_{i\,max} \end{cases} \quad (2)$$

In (2): nl means total number of legs, u is voltage, G_{jy} is conductance, Q_{Gi} is reactive power output of generator, Q_{Ci} is reactive power compensation capacity of reactive power compensation device, $T_i$is the i-th on-load voltage regulating transformer ratio.

3.2. Reactive power optimization model with minimum difference between node voltage and specified value

Objective function:

$$\min F = \min \sum_{k=1}^{n} \frac{\left|U_j - U_{jspec}\right|}{\Delta U_{jspec}} \quad (3)$$

In (3): N is the total number of nodes(except for balance nodes), U_{jspec} and ΔU_{jspec} represent the given value of node voltage and its maximum offset.

3.3. Summary of reactive power optimization

In the literature [2],we know that the reactive power optimization of power system is a complex mixed nonlinear programming problem mathematically, which contains multiple variables and constraints, and the control variables include two kinds, namely discrete variables and continuous variables, and it is also a multi-peak function. There are different methods for solving reactive power optimization problems, and the scope of application of each method is different, so it is necessary to use appropriate methods to get the optimal solution. In general, there are two optimization algorithms, which are traditional algorithm, and intelligent optimization algorithm.

4. Traditional algorithm

Typically, the focus of traditional optimization techniques is on structured problems with well-defined issue and condition descriptions, as well as restrictions.

4.1. Linear programming method

The reactive power optimization problem can be linearly approximated by applying the principle of linear programming, which entails using the Taylor formula to expand the objective function and constraint conditions, respectively, while ignoring the higher order term and keeping only the constant term and the first order term. The issue of reactive power optimization has been addressed with this strategy in the past [3]. The simplified gradient approach is advantageous for solving the large-scale optimal power flow problem because the algorithm is straightforward, the beginning value is unnecessary, it is straightforward to implement, and it is convenient to solve. The disadvantage of this method is that it is easy to appear sawtooth phenomenon, the convergence performance is poor, and the closer to the optimal point, the slower the convergence, and the huge amount of calculation. In reference [4], an algorithm is used to modify the step size, and the convergence characteristics are checked every time the optimization is carried out. Another method is called interior point method.The idea behind this technique is to begin in the feasible zone and advance in the direction that will lead to the fastest possible decrease in the objective function, all the while searching for the best possible answer. The optimization process of this algorithm is always carried out in the feasible region. Affine scaling method is a kind of interior point method that is widely used and developed. The original affine scaling method and the dual affine scaling method are the most frequent, and the original dual affine scaling interior point method (also known as the path following method) is the most promising. Good robustness and convergence are hallmarks of the path following approach, and the calculation time is relatively insensitive to changes in system size[5]. The path following method was successful in solving the document [6]. Optimization of reactive power as a linear programming problem. The experimental results show that the algorithm has polynomial time complexity, stable iteration convergence times, and is not significantly affected by the system size. Therefore, when the system size is relatively large, the algorithm has advantages over the exponential time complexity simplex method. The optimization path, however, must adhere to the primal dual path, and the starting iteration point must be within the feasible region. The optimization procedure will also be influenced by the step size of the control variable. By enhancing the algorithm in document [6], the initial point is no longer constrained to the feasible region, and the optimization process is not restricted to the primal dual path; yet, the algorithm is still able to converge to the optimal solution, and its convergence performance is stable. Since linear programming has been developed to a pretty high standard, its physical notion is well understood, its mathematical model is straightforward, its calculation time is short, and its calculation scale is effectively infinite. But the true mixed non-linearity is approximatively linearized by this procedure [7].

4.2. Newton's method

Convergence is faster and the search direction is more natural in the Newton method because it uses the Jacobian matrix generated by the first derivative of the system power flow equation and the Hessian matrix formed by the second derivative of the objective function. The disadvantage of Newton method is that if the deviation of initial value selection is too large, the iterative direction will be wrong and the optimal solution cannot be obtained. Newton's method does not guarantee that the function value will decline at each iteration, nor does it guarantee certain convergence. Therefore, some remedial measures are proposed, one of which is the line search technology, that is, searching the optimal step size. The specific method is to select some typical discrete values, such as 0.0001, 0.001, 0.01, etc., and compare which value will decrease the function value the fastest as the optimal step size. Compared with gradient descent method, Newton method has faster convergence speed, but the cost of each iteration is also higher. In each iteration, in addition to the gradient vector, the Hessian matrix is also calculated, and the inverse matrix of the Hessian matrix is solved. At the same time, it takes a lot of time to solve the Hessian matrix, and the conjugate gradient method can solve this problem, but it only shows convergence in the region where the quadratic nature of the objective function is obvious, so the use of this method has limitations [8].

4.3. Dynamic programming

The principle of the dynamic programming method is to divide the problem into stages where Hong Kong people are connected according to the time or space order. First, analyze each stage separately, and then obtain the overall optimal solution through balance and coordination. Compared with linear programming and nonlinear programming, the objective function and constraints of dynamic programming can often obtain the global optimal solution with good convergence even if they do not strictly observe the linearity and convexity. The idea of this method is clear, but if there are too many variables, the modeling will become complicated, the calculation speed will be slow, and there will be "dimension disaster", which restricts its application in practical projects. In addition, as long as the "time period" factor is artificially introduced, the dynamic programming method can also deal with some static optimization problems that are not related to time [9].

From the analysis of the above algorithms, we can see that each traditional optimization algorithm has the same defect in varying degrees: it requires high accuracy of the mathematical model, but the more accurate the model is, the more complex the corresponding is, which is not conducive to practical application, cannot solve the discrete variable problem well, and requires high initial values, "curse of dimensionality". To solve these problems, various intelligent algorithms have emerged as the times require.

5. Intelligence optimization algorithm

A heuristic algorithm is a type of intelligent optimization method. To identify the optimal solution to an optimization problem, this is a crucial piece of knowledge to have as soon as possible [10]. This method is a strategy that ignores some limitations to achieve the goal, and makes a fast response with the highest precision. Compared with the complex method, it can save the most time [11]. Heuristic algorithm is an algorithm developed by people inspired by nature.

5.1. Genetic algorithm

Genetic algorithm is an intelligent algorithm that simulates the evolution and mutation of organisms. The specific method is as follows: first, a series of initial solutions are randomly generated, then each group is decomposed into a "chromosome", and several chromosomes form a group, and after comparing with the preset target value, the maximum value is selected to replicate, and the next generation of chromosomes is generated by cross-mutation. The next generation of chromosomes will inherit the excellent genes of the previous generation and continue to develop in the optimal direction. The advantage of this method is that it is robust, it can find the global optimal solution with the maximum probability, and there is no problem of dimension disaster. Its shortcomings are also obvious. Too many iterations will lead to slow optimization, which makes it difficult to optimize large-scale power systems. In literature[12], an improved immune genetic algorithm is proposed, which can enhance the local optimization ability and improve the convergence speed and accuracy of the algorithm.

5.2. Annealing algorithm
Using the same concept as metal annealing, the annealing algorithm is a heuristic algorithm that may be used to quickly and efficiently identify the global optimal solution. The algorithm's guiding idea is, first, precise temperature regulation of the object, second, a rough search of the range, and third, a precise search of the immediate vicinity. The theory behind this approach is straightforward, which makes it easy to put into practice. However, because it has no memory function, there will be local repeated search, and the larger the scale of the system, the more complex the algorithm, which will lead to slower computing speed[13]. Combined with the actual operation characteristics of the power system and the properties of the simulated annealing algorithm, the method in Ref. [14] improves the original simulated annealing algorithm and improves the search efficiency and optimization speed. A method is introduced in Ref.[15], which combines the memory-guided search method with the pattern method for local optimization. The pattern method first optimizes each link, and finally selects the optimal value of all the search results as the output result. This algorithm not only avoids repeated optimization to some extent, but also makes up for the weakness of random search method with poor local optimization ability.

5.3. Particle swarm optimization algorithm
The optimization technique known as particle swarms was first conceived as a way to simulate the way birds hunt for food. By modeling the social system and creating a particle swarm in a high-dimensional space, we can ensure that each individual particle is always moving in the right direction at the right speed and following the best course of action for the swarm as a whole[16]. The basic iterative equation is [17]:

$$V_i(k+1) = \omega V_i(k) + c_1 \mathrm{rand}(\quad)\left(X_{pid} - X_{id}\right) + c_2 \mathrm{rand}(\quad)\left(X_{gd} - X_{id}\right) \tag{4}$$

$$X_i(k+1) = X_i(k) + V_i(k+1) \tag{5}$$

In(4): V_i=$(v_{i1} + v_{i2}, \dots, v_{iN})$ is the random velocity of particles, $X_p = (x_{p1} + x_{p2} + x_{p3}, \dots, x_{pN})$ is the optimal position of a particle, $X_g = (x_{g1} + x_{g2} + x_{g3}, \dots, x_{gN})$ is the optimal position of particle swarm, c_1 and c_2 are acceleration factors, ω is the inertia factor, rand() represents a random number between 0 and 1, where the speed of the example is less than the latter equal to the maximum speed of the particle.

This algorithm lacks mutation and crossover, yet each particle follows the best particle to seek. This approach has good convergence, rapid computation speed, and no dimension disaster, thus it can find the global optimal solution. This algorithm easily finds the local optimal solution. The particle swarm optimization approach enhances calculation accuracy, convergence stability, and calculation time [18].

6. Conclusion
First of all, this paper introduces the general reactive power optimization model. Secondly, the principles, advantages and disadvantages of various basic optimization algorithms are summarized and analyzed, and some methods to improve the algorithm are listed. However, the convergence rate, the accuracy of the results and the final optimization effect still can not be fully taken into account. With the continuous exploration of the algorithm, the system model can be made more accurate, the active power loss can be minimized, and the transmission efficiency and power quality can be improved. In the future, reactive power optimization research, a series of considerations should be carried out in combination with the emerging problems, so that the reactive power optimization algorithm can keep pace with the times and more and more adapt to the development of power system.

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