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LP of Power System Network Security Application

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Abstract

In recent years, China's national economy has developed rapidly, which is accompanied by the high consumption of China's power system. Therefore, we should not only vigorously advocate the development of new energy, but also improve the utilization efficiency of energy. Therefore, power enterprises can optimize their own network security and generation scheduling, which will effectively reduce the energy consumption of power generation. Transmission network planning of power system is based on power planning, load forecasting, and the feasibility of power point and load point, which can determine the future transmission network structure, namely grid structure. At the same time, the time of grid planning is often as long as 10 years and has a variety of ways. Therefore, the original data of circuit planning is changeable, which will lead to many planning schemes. Therefore, we should choose the appropriate planning scheme, which will better achieve the purpose of low energy consumption. By introducing pattern recognition technology into linear programming (hereinafter referred to as LP) algorithm, the power system can improve the performance of LP security constrained scheduling, which will improve the security constrained scheduling in the electricity market environment. Finally, this paper uses the LP algorithm to practice the three modes of energy consumption.

Keywords: *Power System, Network Security, Lp;*

1. Introduction

China is facing a major energy problem, which is the contradiction between the increasing energy demand of human society and the decreasing of existing energy[1]. China's national economy has developed rapidly, which is accompanied by high energy consumption. Therefore, in the context of energy crisis, China not only needs to vigorously advocate the development of new energy, but also to improve the efficiency of energy utilization. Power market is the inevitable trend of the development of the power industry. The development of the power market poses new challenges for the application of power system network security[2]. Power market technical support system is an automatic system which serves the operation of power market, which is the core part of power system network security[3].

China's total power generation in 2018 was 7111.77 billion kW/h. It can be seen that the traditional thermal power generation and hydropower generation are still the most important power generation mode in China, which will show a slow growth trend in the future. Therefore, China's power system should optimize the current generation dispatching mode under the constraints of system feasibility and security[4]. By making full use of the existing resources, the power company can reasonably arrange the operation mode of each generating unit, which will minimize the total operation cost[5].

Optimal power flow (hereinafter referred to as OPF) of power system is the distribution of power flow that can satisfy all the specified constraints by optimizing the control variables when the structural parameters and load conditions of the system are given, which will make one or more performance indicators reach the optimal[6]. Therefore, we should establish an OPF model based on strict mathematics[7]. By improving the convergence performance of the algorithm, we can improve the

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calculation speed and the OPF algorithm[8]. Since its birth, OPF has been widely used in safe operation, economic dispatch, power grid planning, reliability analysis, congestion management and energy management system.

LP is a process of finding the maximum or minimum value of a linear function under the constraints of a set of linear equations or inequalities. The simplex method is a basic method to solve LP problems[9]. The improved simplex method is described in a compact matrix form, which is more suitable for computer programming[10]. LP is suitable for solving a large number of power system optimization problems, such as transmission system operation and planning, OPF, security control, hydropower planning, state estimation, etc. Therefore, LP is very suitable for the study of power system network security applications, such as the scheduling of network security constraints. The main advantages of LP are computing speed and reliability, which can meet the requirements of real-time applications[11].

2. The history of LP

The earliest security constrained scheduling is derived from OPF. LP method is an important branch of OPF. The classical Lagrangian technique and successive approximation are two pioneer techniques for OPF in LP. In the early 1960s, we used the traditional Lagrangian technique to describe the OPF problem, which needs to consider the equality constraints of the power flow equation. In 1962, Carpentier proposed Kuhn Tucke optimality conditions, which are constrained by power flow balance and control variable method. In the 1980s, the OPF of LP method has made great progress. Piecewise linearization and sparseness techniques have become mature techniques in active power allocation programs. With the development of OPF and security constrained dispatch, new algorithms are introduced into the field of power system network security. In 1974, podmore introduced the concept of linearization of nonlinear network security constraints. In the same year, wollenberg and stadlin used linearized network security constraints, which indicates that LP technology is really applied to security constrained scheduling problems. In 1987, sandersh proposed an algorithm called "constrained economic allocation computation (CEDC)", which was successfully applied to real-time security constrained scheduling. The introduction of LP technology plays an important role in the development of security constrained scheduling. For half a century, the application of LP in power system has been keeping vigorous vitality. The development history of LP OPF is shown in Figure 1.

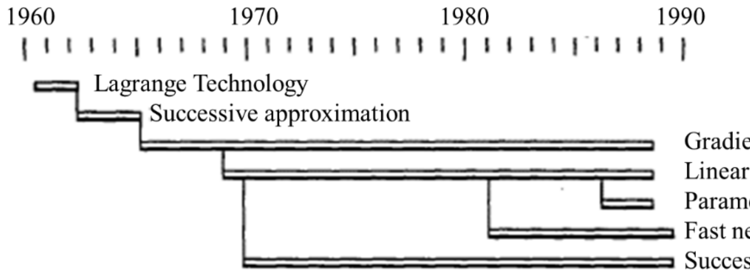

Figure 1. The development history of LP OPF.

3. Reactive power optimization model algorithm of power system

3.1. Classical mathematical algorithm

3.1.1. Simplified gradient method

The simplified gradient method is the first successful algorithm for solving large-scale OPF problems. In polar coordinates, multiplier method is used to deal with equality constraints and penalty function is used to deal with inequality constraints[12]. By controlling the negative gradient direction of variables, we can optimize. The simplified gradient method has the first-order convergence, simple principle, small storage requirement and simple program design. However, in practical application, the simplified gradient method has many shortcomings, such as sawtooth phenomenon, poor convergence, slow convergence rate, large amount of calculation, more time-consuming and so on. At the same time, when the penalty function is used to deal with inequality

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constraints, the selection of penalty factor has a great impact on the convergence of the algorithm[13]. At present, the simplified gradient method has been rarely used.

3.1.2. Second planning method

Quadratic programming is a special case of nonLP, which means that the objective function to be solved is quadratic and the constraint condition is linear expression. In the quadratic programming method, the optimization objective function is expanded at the equilibrium point by Taylor expansion, and the quadratic term is retained, and the constraint condition is expanded by Taylor expansion to retain the first term[14]. By repeated calculation at the new equilibrium point, when the change of the objective function is less than a certain threshold value, it will be considered as computational convergence[15]. Therefore, the quadratic programming method transforms the nonLP problem into a series of quadratic programming, which is called sequential quadratic programming algorithm[16].

3.1.3. LP method

LP algorithm is similar to quadratic programming algorithm, which is Taylor expansion of the objective function and constraints at the equilibrium point. The LP method only retains the constant term and the first term, and approximates the original nonLP problem with a series of LP problems[17]. In the establishment of LP model, we need to divide the control variables and state variables of the system[18]. Therefore, we need to recalculate the sensitivity matrix at each new equilibrium point. LP has clear physical concept and mature algorithm theory, which can be solved by simplex or IP method. The simplex method is to find the optimal solution on each vertex of the feasible region according to the basic principle of LP. Starting with a vertex, we can check its optimality[19]. Therefore, the number of iterations of the simplex method will increase significantly with the increase of the system size[20].

3.1.4. Interior point (hereinafter referred to as IP)

The IP method is proposed to solve the problem of iteration times of simplex method in solving LP, which can solve the problem that the number of iterations increases exponentially with the increase of variable size[21]. It is different from the simplex method in searching the optimal points along the feasible region[22]. Starting from the initial IP, the IP method directly seeks the optimal solution from the interior of the feasible region along the steepest descent direction[23]. Therefore, the number of iterations will not increase significantly with the scale of system variables and constraints. Therefore, the IP method is also suitable for large-scale power system calculation. The IP method was originally born in LP problems[24]. Later, the IP method was extended to quadratic programming and direct non-LP. After years of development, the IP method has developed into three branches: projection scale method, affine scale method and primal dual path tracking method. By constructing the augmented Lagrangian function, we can use Newton method to solve the problem according to KKT condition. Primal dual IP method has polynomial complexity, which has been widely used to solve large power system optimization problems.

3.2. Artificial intelligence algorithm

3.2.1. Genetic algorithm

Genetic algorithm is a random search optimization method which simulates the evolution of the survival of the fittest in nature. Genetic algorithm encodes the feasible solution, which will reflect the fitness function of the optimization objective. Genetic algorithm can generate a set of initial solutions. Then, according to the fitness function, we can judge whether the fitness function is good or bad. Only the population with high fitness is retained. Then, through the operation of heredity, crossover and mutation, we will form a new population, which will reach the optimal solution through circulation. The principle of genetic algorithm is simple, which can solve the problem of

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discrete variables. Genetic algorithm can find the global optimal solution with a large probability.

3.2.2. Particle swarm optimization (hereinafter referred to as PSO)

PSO algorithm is evolved from the foraging behavior of birds. Each particle in the search space represents a feasible solution. Similar to genetic algorithm, PSO is also based on random solution, which is to judge the advantages and disadvantages of solutions by fitness. There are no crossover and mutation operations in PSO, which makes the rules simpler. According to their own and companion's flying experience, particles can adjust their flight in the search space. By following the current optimal particles, we can finally achieve the goal of searching the optimal solution from the whole space. PSO can deal with discrete variables well, which does not require that the objective function is differentiable. However, PSO is a stochastic search method, and the optimal solution is different from each other.

4. OPF model based on LP

4.1. Steady state model of converter station

Through the connection of converter station, the high voltage side bus of converter transformer can be regarded as the dividing point between AC and DC systems. AC system is generally composed of generators, transformers and AC lines. DC system includes converter transformer, converter and DC line. Each converter station is called one end of the DC system. The requirements of DC circuit breaker are higher than that of AC circuit breaker, and most of the systems that have been put into operation are double ended systems. According to the positive and negative polarity of DC conductors, DC transmission system can be divided into three types: single stage, bipolar and homopolar. In the actual operation, in order to reduce the loss, we usually adopt the bipolar operation mode. The model of AC / DC transmission system is shown in Figure 2.

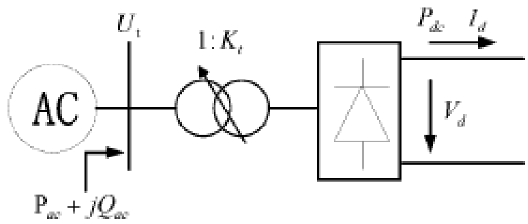

Figure 2. Schemes of the converter station.

The converter bridge of DC transmission is composed of three-phase bridge converter circuit. In order to reduce the voltage of each converter valve, we can generally use multi bridge series converter. The DC voltage drop of the converter is as shown in the formula 1.

$$V_d = \frac{3\sqrt{2}}{\pi} n_t k_t V_t \cos\delta_d - \frac{3}{\pi} n_t X_c I_d \tag{1}$$

Among them, n_t is the number of converter bridges, k_t is the transformation ratio of converter transformer, V_t is the primary side voltage of converter transformer, δ_d is the control angle of converter, X_c is equivalent reactance of converter transformer, I_d is DC current.

Without considering the loss of converter transformer, the active power of AC fundamental wave is equal to DC power, and the voltage relationship between AC and DC side is shown in formula 2.

$$V_d = \frac{3\sqrt{2}}{\pi} k_\gamma n_t k_t V_t \cos\varphi \tag{2}$$

Among them, k_γ is a parameter reflecting the influence of commutation pressure drop, which is related to the control angle and commutation angle of the converter. Generally, $k_\gamma = 0.995$. $\cos\varphi$ is the power factor of the converter.

4.2. Linearization of objective function

The generation cost of a generator is generally expressed as a binomial function of the active power of each generator.

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According to the characteristics of power system, network loss is a nonlinear function of control variables P_G, V_G, T_k and Q_c. The linear model can be shown in Formula 3.

$$\min \Delta f(\Delta x) = \left[\frac{\partial f}{\partial V_G}\right]_{(k)} \times \Delta V_G + \left[\frac{\partial f}{\partial T_k}\right]_{(k)} \times \Delta T_k + \left[\frac{\partial f}{\partial Q_c}\right]_{(k)} \times \Delta Q_c \quad (3)$$

Among them, $f(x)$ is the active power loss of the system or the active power generation cost of the generator; V_G is the terminal voltage of the reactive adjustable generator; T_k is the transformation ratio of the adjustable transformer; Q_c is the power of the reactive power compensation power supply; P_G is the active power output of the active power adjustable generator. $[\ ]_{(k)}$ is the sensitivity coefficient of the objective function to each control variable at the current iteration point. As shown in formula 4.

$$\min \Delta f(\Delta x) = C\Delta x\Big|_{x=x^{(k)}} \quad (4)$$

Among them, C is the sensitivity coefficient of the objective function to each control variable at the current iteration point, as shown in formula 5.

$$\left[\frac{\partial f}{\partial V_G} \quad \frac{\partial f}{\partial T_k} \quad \frac{\partial f}{\partial Q_c} \quad \frac{\partial f}{\partial P_G}\right] \quad (5)$$

4.3. Linearization of network operation constraints

In this paper, the distance between the upper limit and the lower limit is used to indicate that the network operation constraint is a function inequality constraint, as shown in formula 6.

$$\begin{aligned}
\Delta V_{G\min} &= V_{G\min} - V_G; \\
\Delta V_{G\max} &= V_{G\max} - V_G; \\
\Delta P_{G\min} &= P_{G\min} - P_G; \\
\Delta P_{G\max} &= P_{G\max} - P_G; \\
\Delta T_{k\min} &= T_{k\min} - V_G; \\
\Delta T_{k\max} &= T_{k\max} - V_G; \\
\Delta Q_{C\min} &= Q_{C\min} - V_G; \\
\Delta Q_{C\max} &= Q_{C\max} - V_G; \\
\Delta V_{G\min} &= V_{G\min} - V_G \\
\Delta V_{G\max} &= V_{G\max} - V_G
\end{aligned} \quad (6)$$

In order to ensure the high accuracy of the linear model, we can limit the step size of each step of the control variable. Therefore, we can obtain formula 7

$$\max(\Delta x_i, -\Delta x_{step}) \le \Delta x\Big|_{x=x^{(k)}} \le \min(\Delta x_u, \Delta x_{step}) \quad (7)$$

Among them, Δx_i is the difference between the lower limit of all control variables minus the current value, Δx_u is the difference between the upper limit of all control variables minus the current value, and step represents the limit on the step size of all control variables.

Because the properties of function constraints and objective functions are unknown, the linear performance at each iteration point is also different. Therefore, we should determine the validity and feasibility of the next iteration point, which will ensure a certain calculation accuracy and speed. In the iteration process, we still need to adjust the step size.

Therefore, we can linearize the objective function, which is a function of all control variables, as shown in formula 8.

$$\begin{aligned}
&\min \Delta f(\Delta x) = C\Delta x\Big|_{x=x^{(k)}} \\
s.t. \quad &\Delta h_1 \le h(\Delta x) = B\Delta x\Big|_{x=x^{(k)}} \le \Delta h_u \\
&\max(\Delta x_i, -\Delta x_{step}) \le \Delta x\Big|_{x=x^{(k)}} \le \min(\Delta x_u, \Delta x_{step})
\end{aligned} \quad (8)$$

4.4. OPF calculation flow based on LP algorithm

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The basic process of solving OPF based on LP algorithm is an iterative process. First, we need to give the initial iteration point and initial step size. At the initial iteration point, we can linearize the function constraints and objective functions, which will form a LP problem and solve it. By returning to the effective and feasible iteration point of the original nonLP problem, we can linearize the solution again at the new point, which can reach the optimal point. The flow chart of OPF calculation based on LP algorithm is shown in Figure 3.

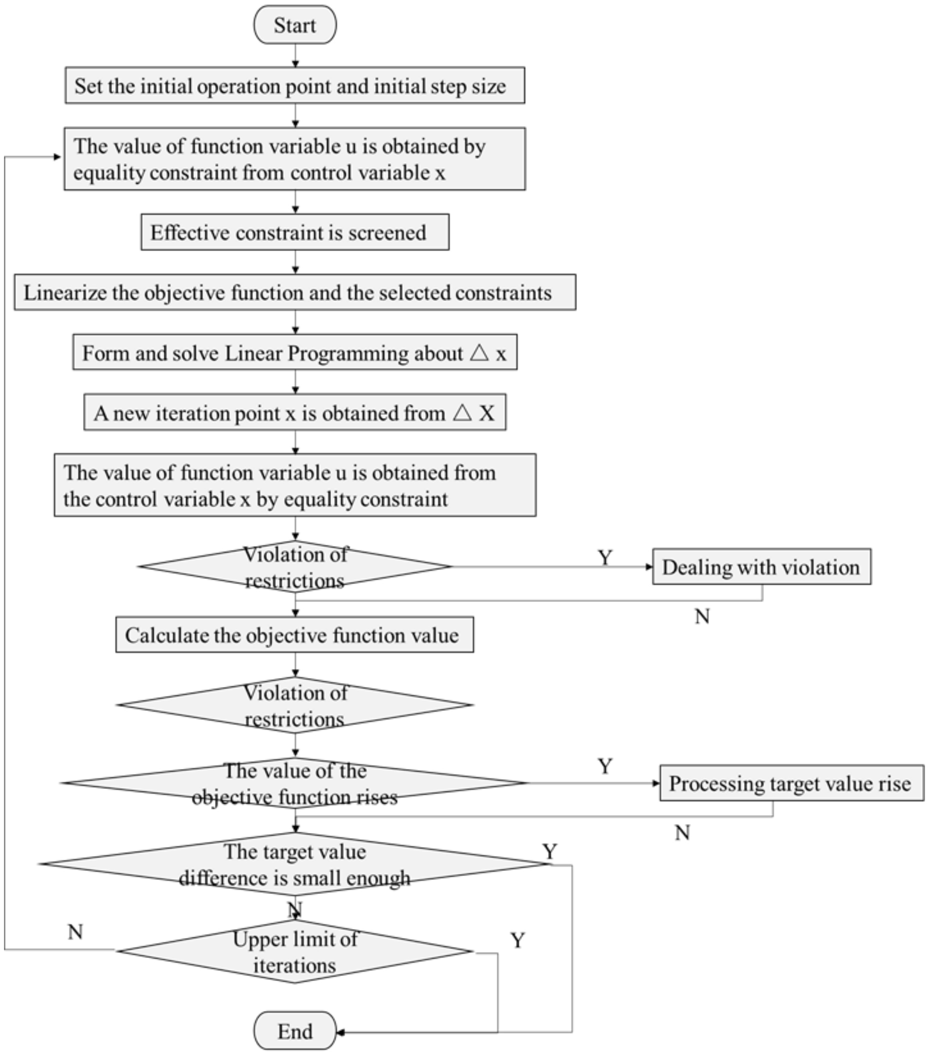

Figure 3. OPF calculation flow based on LP algorithm.

The OPF of LP method is calculated by approximate optimal LP model. By using the mature algorithm of LP, we can solve the problem of nonLP, which will avoid some difficulties in the solution of nonLP. By selecting the function inequality constraints, we can greatly reduce the scale of the LP model, which will make the LP problem easier to solve. However, the LP method still brings some problems to the algorithm. For example, the new iteration point deviates makes the target rise some function inequality constraints.

5. Optimal calculation and analysis of reactive power based on linear rule algorithm

5.1. Original information of example

In this paper, three typical test cases are WSCC-9 node, IEEE-30 node and a practical example (109 nodes). Among them, the 109 node example is the reactive power optimization example provided by the user, which is only used to test the reactive

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power optimization. The number of elements in each example is shown in Table 1.

Table 1. The number of elements in the example.

	WSCC-9	IEEE-30	109
Bus bar	9	30	109
Alternator	3	6	16
Load	3	21	43
AC line	6	37	60
Two winding transformer	3	4	17
Three winding transformer	0	0	17
Controllable transformer	3	6	19
(No power) Controllable generator	3	6	3
No power compensation equipment	3	10	10
(With power) Controllable generator	3	6	0

This paper draws a single line diagram of WSCC-9 node system, as shown in Figure 4. This paper draws a single line diagram of WSCC-30 node system, as shown in Figure 5.

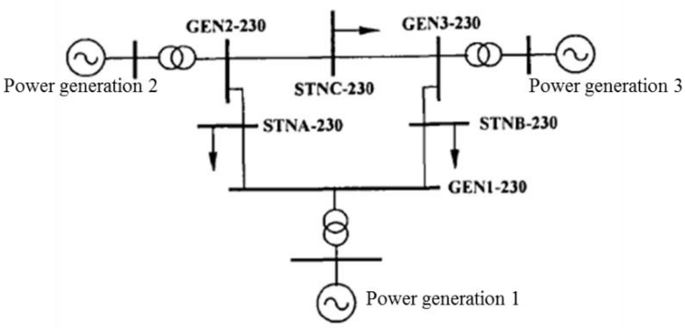

Figure 4. Single line diagram of WSCC-9 node system.

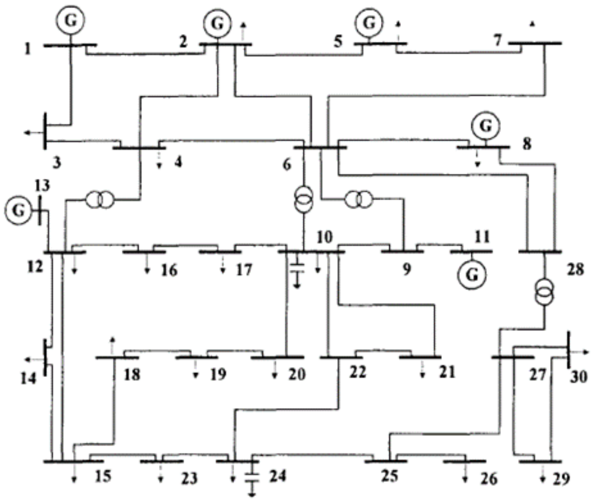

Figure 5. Single line diagram of WSCC-30 node system.

The single line diagram of 109 bus system is passed through MATLAB's Matlab software package, which is not listed in this paper.

5.2. Example results of reactive power optimization

Three examples are used to test reactive power optimization: WSCC-9, IEEE-30 and 109 bus. Each example contains three types of control variables: controllable transformer, reactive power adjustable generator and reactive power compensation. In the example test, the optimization is carried out by adjusting the three variables and the combination of

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the three variables. Where a represents the active power of the system balancing node and B represents the number of iterations. The initial active power of each balance node is shown in Table 2.

Table 2. The initial active power of each node is balanced.

	WSCC-9		IEEE-30		109	
	A	B	A	B	A	B
T_k	71.145	6	109.292	5	192.439	6
Q_G	71.010	3	108.760	5	192.268	4
Q_c	71.602	3	109.197	3	192.673	3
T_k, Q_G	71.010	5	109.041	10	192.066	4
T_k, Q_c	71.116	6	109.235	6	192.077	4
Q_G, Q_c	70.993	3	108.615	11	192.138	9
T_k, Q_G, Q_c	70.995	4	109.003	12	Abnormal termination	/

The variable column indicates the adjustment variables set in the optimization, for example, T_k means only the transformer transformation ratio is adjusted; T_k, Q_G means simultaneous adjustment of transformer transformation ratio T_k and generator reactive power Q_G. T_k, Q_G, Q_c refer to adjust the three at the same time.

In the iterative process of each example, we verify that it is necessary and effective to select constraints in LP method.

6. Conclusion

Practice has proved that LP technology can be used in power system transmission planning. In particular, the dual solution pair planning and design will determine the installed capacity, location and load point size of the power point, which is an effective method for power supply analysis. Through the auxiliary sensitivity analysis, we can study the upper and lower limits of the installed capacity, load variation and relative position, which will be very helpful to determine the reasonable transmission system planning scheme.

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