Research on the Application of Artificial Intelligence Technology in Power System Intelligent Dispatching Automation

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Abstract. From the perspective of meeting the power quality requirements of users, the article analyses the characteristics of traditional voltage and reactive power control mode and the regional power grid reactive voltage optimization centralized closed-loop control mode (AVC system) based on the dispatch automation system (SCADA/EMS) from the perspective of technical management. Combining the reactive power/voltage real-time optimization control model, a real-time optimization control method of the regional power grid based on the improved differential evolution algorithm is proposed. The particle swarm algorithm is combined with the characteristics of reactive power/voltage control to improve the initial particle quality, reduce the optimization space, and introduce a crossover operator to improve the calculation speed and efficiency of the algorithm. Taking an actual regional power grid as an example, the simulation calculation of reactive power/voltage real-time optimization is carried out. The results show that the proposed algorithm and control strategy are feasible and effective.

Keywords: Artificial intelligence technology, power system, dispatch automation.

1. Introduction
The requirements for the operation of the power system are: safety, reliability, economy, and high quality. Among them, safety and reliability are the basic conditions and are the main problems faced by the power operation department. With the continuous development of the power grid, users have also raised questions about the quality of power. Therefore, in order to provide users with high-quality power under the premise of ensuring the safe and reliable operation of the system, the pursuit of operating economy has become an important task for voltage and reactive power optimization control. With the deepening and automation of the power system market with the improvement of the level, the real-time optimization control of the reactive power/voltage of the regional power grid has been paid more and more attention as an important and effective means to ensure the safety of the power grid, economic operation and high-quality power supply [1]. In the real-time optimization of reactive power/voltage, the transformer gear and compensation capacitor are expressed in integer form, and the generator terminal voltage is expressed in real number form, which is a typical nonlinear mixed
integer optimization problem. There are usually two kinds of methods to deal with such problems: one is analytical method, including gradient method, linear programming, quadratic programming and interior point method. These traditional optimization algorithms are simple and fast, but they need to rely on the convexity of the problem to find the optimal solution. At the same time, discrete variables are difficult to deal with directly.

Therefore, for reactive power/voltage optimization control problems with nonlinear and non-convex characteristics, it cannot guarantee to find the global optimal or sub-optimal solution. In addition, these algorithms cannot guarantee convergence when there is no feasible solution for the system. The second is evolutionary algorithms, including genetic algorithms, evolutionary programming, evolutionary strategies, etc., which overcome the above shortcomings of analytical methods, but their solution time is too long and easy to converge prematurely. For this reason, scholars from various countries have carried out a lot of research work, and in particular, have developed a wide range of interest in the interior point algorithm of linear programming with polynomial time solvability proposed by scholars [2]. The calculation time of this method is not sensitive to the scale of the problem, does not increase significantly with the increase of the scale of the problem, and has good convergence characteristics. However, although the interior point method shows broad application prospects, it has not yet achieved satisfactory performance in solving the voltage and reactive power optimization problems of large-scale power systems with a large number of constraints. The existing algorithm either only considers the variable inequality constraints and lacks effective methods to deal with the function inequality constraints, or the proposed model has the same defects as the quadratic programming method because the Hessian matrix and the constraint matrix are full matrices, namely the calculation time will increase too fast with the increase of the number of constraints. When dealing with the voltage and reactive power optimization problem of a large-scale power system with a large number of constraints, it is difficult to reflect the advantages of the original-dual interior point method in terms of speed. When it is not feasible, the current interior point method still appears powerless. The infeasible classic processing method based on least squares not only requires careful adjustment of the weight matrix, but also reduces the calculation speed when the number of infeasible constraints increases.

Based on the dynamic segmentation of the predicted load of the bus and the start and stop according to the start-up incremental control optimization program, this paper combines the characteristics of the reactive power/voltage control of the regional power grid to improve the basic differential evolution algorithm, and uses its fast random search ability to carry out "constraint guidance" and Group optimization, in order to quickly give an optimized solution for real-time reactive power/voltage control under the condition of meeting operating constraints [3]. The number of actions of the control equipment in a day is effectively controlled and reasonably allocated, which is more suitable for engineering applications. The simulation analysis of an actual regional power grid proves the feasibility, effectiveness and practicability of the method proposed in this paper.

2. Classification of voltage and reactive power control modes

At present, the most widely used voltage level control mode in the world includes three levels: first-level voltage control, second-level voltage control, and third-level voltage control.

2.1. Level 1 voltage control

The first-level voltage control is local control, and only local information is used. The controller is composed of an on-load voltage regulation tap and a capacitor that can be switched in this area. The control time constant is generally a few seconds. In this level of control, the control equipment compensate for rapid and random changes in voltage by keeping the output variable as close as possible to the set value.
2.2. Secondary voltage control
The time constant of the secondary voltage control is about tens of seconds to minutes. The main purpose of the control is to keep the central bus voltage equal to the set value. If the central bus voltage amplitude deviates, the secondary voltage controller will follow the predetermined control regularly change the set reference value of the first-level voltage controller. The second-level voltage control is a type of area control, and only the information in the area is used.

2.3. Three-level voltage control
The three-level voltage control is the highest level among them. It takes the economic operation of the whole system as the optimization goal, and considers the stability index, and finally gives the set reference value of the central bus voltage amplitude for the second-level voltage control. The coordination factor is fully considered in the voltage control, and the information of the entire system is used for optimization calculation. Generally speaking, its time constant is from ten minutes to hours.

In the above-mentioned voltage hierarchical control system, each layer has for their respective purposes, the lower-level control accepts the upper-level control signal as its own control purpose, and sends a control signal to the next level [4]. The three-level organizational structure of voltage control is shown in Figure 1.

![Figure 1. Three-level organizational structure of global voltage control.](image)

3. Reactive power/voltage real-time control model

3.1. Mathematical model of reactive power/voltage real-time control
The objective function of the reactive power/voltage real-time control of the regional power grid.

\[
\min F = P_{\text{loss}}(V_G, T, Q_C)
\]

In the formula: \(P_{\text{loss}}\) is the active power loss of the power grid, \(V_G\) is the terminal voltage, \(T\) is the transformer gear, and \(Q_C\) is the capacitor capacity. The constraints are power flow constraints and the following inequality constraints:

\[
\begin{align*}
T_{j,\text{min}} & \leq T_{j, t} \leq T_{j, \text{max}, t}, & j \in N_T \\
Q_{C_{\text{min}}} & \leq Q_{C_{k, t}} \leq Q_{C_{\text{max}, t}}, & Q_{C_k} = M_{C_k} D_{C_k}, & k \in N_C \\
V_{i, \text{min}, t} & \leq V_{i, t} \leq V_{i, \text{max}, t}, & i \in N \\
Q_{G_{\text{min}}} & \leq Q_{G_{r, t}} \leq Q_{G_{\text{max}, t}}, & r \in N_G \\
S_{w_{\text{min}, t}} & \leq S_{w, t} \leq S_{w_{\text{max}, t}}, & w \in N_w
\end{align*}
\]
Where: $N_T$, $N_C$, $N$, $N_G$, $N_l$ are the total number of transformers, the number of switchable capacitors, the number of system nodes, the number of generators and the number of transmission lines, respectively. $T_{j,t}$, $Q_{Ck,t}$, $M_{Ck,t}$, $V_{i,t}$, $Q_{Gr,t}$, $S_{lw,t}$ are respectively the gear position of transformer $j$ at time $t$, the input capacity of capacitor $k$, the total number of input groups, the voltage amplitude of node $i$, the reactive output of generator $r$ and the apparent power of transmission line $w$.

According to the principle of hierarchical and partitioned reactive power, the reactive power exchange between the regional power grid and the superior power grid should be restricted, so the following inequality constraints should also be added:

$$
\cos \varphi_{s,\min,t} \leq \cos \varphi_{s,t} \leq \cos \varphi_{s,\max,t}
$$

(3)

In the formula: $\cos \varphi_{s,t}$ is the gateway power factor and the upper and lower limits of the gateway power factor at time $t$, respectively.

Discrete control equipment is restricted by the number of operations in a day due to factors such as manufacturing technology. One of the problems with real-time reactive power/voltage optimization control of regional power grids is that the discrete control equipment operates too frequently [5]. However, this constraint is not strict, so this article proposes "limited number of actions" as a constraint, that is, the number of actions in a day must meet the following "soft constraint" conditions:

$$
\begin{align*}
\sum_{t=1}^{N_S}|M_{k,t} - M_{k,t-1}| & \leq M_{Ck} \\
\sum_{t=1}^{N_l}|T_{k,t} - T_{k,t-1}| & \leq T_{Tk}
\end{align*}
$$

(4)

In the formula: $N_S$ is the number of start-ups of the reactive power/voltage real-time control of the day, $M_{k,t}$ is the number of capacitor banks put into capacitor $k$ at time $t$, $M_{Ck}$ is the total number of allowed switching times of capacitor $k$ in a day, and $T_{k,t}$ is transformer $k$ at time $H$ transformer Gear position, $T_{Tk}$ is the total number of adjustments allowed for transformer $k$ in a day. "Soft constraints" make the reactive power/voltage real-time optimization control problem more complicated and become a nonlinear optimization problem with time and space complexity.

3.2. Incremental start-up strategy

The reactive node set is the set of the node where the capacitor is located and the nodes directly connected to it through the transformer. In Figure 2, the reactive node set of capacitors $C$ is $\{5,3\}$. The voltage node set is the set of nodes controlled by the transformer and the nodes connected to these nodes via non-transformer branches. For example, the voltage node set of the transformer $T$ is $\{5\}$. The incremental start strategy is to obtain the start increment of the response control equipment action frequency distribution and the load condition of each bus through the dynamic fusion of the load of each reactive node set, and control the start and stop of the optimization program according to the respective start increments [6]. When the reactive power load change of the reactive power node set exceeds the start increment, the optimization program is started.
3.3. Fuzzy control cost

Considering factors such as the load level at the time of optimization, the proportion of the action of the control equipment in the number of assigned actions, and the degree of oscillation of the action, the control cost is fuzzy through fuzzy reasoning, and the number of actions of the equipment is more reasonably limited and assigned. This paper adopts a fuzzy logic controller with the total load level, action ratio, and vibration limiting coefficient reflecting the degree of vibration of the action as the input and the fuzzy control cost as the output, as shown in Figure 3. Multiplying the unit fuzzy control cost and the number of actions into the objective function can reasonably limit and allocate the number of actions of the control equipment at each control point and each control period.

4. Improved differential evolution algorithm

4.1. Standard DE algorithm model

DE algorithm is a probabilistic search method that simulates biological evolution phenomena (selection, hybridization, mutation) to represent complex phenomena. The preferred method recommended by PriceK is to directly combine hybridization and mutation to form a concise and complete DE form, as shown in the following formula:
Although the propagation rule is simple, it gives the DE algorithm the ability to adaptively adjust and maintain rotation invariance. This article uses a simpler DE algorithm derived from the above formula, and its generation rule for generation $k$ is:

$$u_{i,j}[k] = u_{i,j}[k] + K(u_{\text{best},j}[k] - u_{i,j}[k]) + F(u_{i,j}[k] - u_{\text{best},j}[k])$$  \hspace{1cm} (6)$$

Where $r_1$, $r_2$, and are respectively the bus voltage, generator reactive power output, line power flow and threshold power factor over-limit penalty coefficient; $u_{\text{best},j}$ is the fuzzy control cost of the control equipment at time $t$; $x_{\text{lim},j}$ in the above formula is defined by the following expression:

$$\min F = P_{\text{loss}} + \lambda_1 \sum_{i=1}^{N} (U_{i,j} - U_{\text{lim},j})^2 + \lambda_2 \sum_{i=1}^{N} (Q_{i,j} - Q_{\text{lim},j})^2$$
$$+ \lambda_3 \sum_{i=1}^{N} (S_{i,j} - S_{\text{lim},j})^2 + \lambda_4 (\cos \phi_{i,j} - \cos \phi_{\text{lim},j})^2$$
$$+ \sum_{i=1}^{N} \sum_{j=1}^{N} (x_{ij} - \lambda_{ij} x_{\text{lim},j})^2 + \sum_{i=1}^{N} \sum_{j=1}^{N} F_{cc,i,j} (M_{ij} - M_{\text{lim},i,j})^2$$  \hspace{1cm} (7)$$

4.2. Fitness function

The quality of an individual in the DE algorithm is evaluated by fitness, so the selection of fitness function is very important. DE is an unconstrained search in the solution space. The control variables are automatically satisfied by the solution constraints, and the equality constraints are satisfied by the power flow equations. Bus voltage, gateway power factor, etc. are used as state variables, which are realized by adding a quadratic penalty function to the objective function. According to the requirements of the real-time optimization control of the reactive power/voltage of the regional power grid, while optimizing the network loss, the number of operations of the control equipment in a day should also meet the requirements of "soft constraints". Therefore, the fuzzy control cost, which characterizes the action cost of the control device, is added to the objective function, and the new objective function is

$$\min F = P_{\text{loss}} + \lambda_1 \sum_{i=1}^{N} (U_{i,j} - U_{\text{lim},j})^2 + \lambda_2 \sum_{i=1}^{N} (Q_{i,j} - Q_{\text{lim},j})^2$$
$$+ \lambda_3 \sum_{i=1}^{N} (S_{i,j} - S_{\text{lim},j})^2 + \lambda_4 (\cos \phi_{i,j} - \cos \phi_{\text{lim},j})^2$$
$$+ \sum_{i=1}^{N} \sum_{j=1}^{N} (x_{ij} - \lambda_{ij} x_{\text{lim},j})^2 + \sum_{i=1}^{N} \sum_{j=1}^{N} F_{cc,i,j} (M_{ij} - M_{\text{lim},i,j})^2$$  \hspace{1cm} (7)$$
In the DE solution, DE searches for the solution with the maximum fitness. Therefore, the minimum objective function is converted into a maximum fitness function

\[ f = K / F \]  \hspace{1cm} (9)

In the formula: \( K \) is a large constant, used to amplify the usually small \( 1/F \) so that the individual’s fitness value is within a larger range.

4.3. Population selection

4.3.1. Customize the initial population. The DE algorithm initializes the population using a completely random method. In this paper, mixed coding is used, and the action amount of the control device is taken as the individual component. Any action at this moment occurs on the basis of the previous period, which is equivalent to memorizing the state of the control device in the previous period. Therefore, 0 as an initial individual can make DE memorize the excellent information of the control equipment in the previous period. In order to speed up the convergence speed of the DE algorithm, based on the idea of reactive power in-situ balance, the difference between the time period before and after the reactive power load of the reactive node set is assigned to the individual capacitor components to obtain an initial individual. In the reactive power/voltage control of the regional power grid, the transformer gear is generally required to be adjusted at no more than 3 gears at a time. At the same time, it is hoped that the number of actions should not be too many [7]. The remaining individuals are initialized randomly using the DE method.

4.3.2. Individual evaluation. The regional power grid belongs to the medium and high voltage distribution network, and generally does not meet the conditions, so it is not suitable for the active and reactive power decoupling algorithm of the high voltage transmission network; it does not fully meet the characteristics of the low voltage distribution network such as the radiation grid, and the low voltage distribution network is forwarded. The later generations and other algorithms are not suitable for power flow calculation of regional power grids, so this paper recommends using Newton’s method for power flow calculation. The power flow calculation time accounts for most of the time of the intelligent algorithm. In order to improve the efficiency of the algorithm, each individual is briefly evaluated. If it is qualified, it will enter the next step, otherwise it will be regenerated according to the formula.

1) According to the requirements of reactive power hierarchical and zoning, the gateway is not allowed to send a large amount of reactive power to the superior grid, and qualified individuals should meet the power factor constraint of the gateway, that is, the following formula:

\[ Q_{\text{slack min}} \leq \sum_{k=1}^{N_c} Q_{Ck} \leq Q_{\text{slack}} \]  \hspace{1cm} (10)

In the formula: \( Q_{\text{slack min}} \) is the amount of reactive power compensation that must be provided to meet the lower limit of the power factor of the gateway, \( Q_{Ck} \) is the input capacity of the capacitor \( k \), and \( Q_{\text{slack}} \) is the reactive power of the gateway.

2) Pre-estimate the bus voltage based on the experience that has the greatest impact on the local area after the action of the control equipment.
As shown in Figure 1, if the incoming reactive power of the substation C is \( Q_3 \), the compensation capacity of the capacitor is set to \( \Delta Q \), \( V_3 \), which is approximately unchanged, ignoring the transformer excitation circuit, then \( V_3 \) and \( V_3' \) before and after compensation are shown in equations (11) and (12) shown

\[
V_3 = (V_3 - \frac{P_3R_{T3} + Q_3X_{T3}}{V_3^2}) / K_3' \tag{11}
\]

\[
V_3' = (V_3 - \frac{P_3R_{T3} + (Q_3 - \Delta Q_3)X_{T3}}{V_3}) / K_3' \tag{12}
\]

In the formula: \( R_{T3} \) and \( X_{T3} \) are the resistance and reactance of the transformer branch, \( K_3' \) is the adjusted transformation ratio of the transformer, and \( V_3' \) is the adjusted low-voltage busbar estimated value. A qualified individual should meet

\[
V_{i\text{min}} - \varepsilon < V_i' < V_{i\text{max}} + \varepsilon \tag{13}
\]

In the formula: \( \varepsilon \) appropriately relax the margin of the voltage limit in order to take into account the error of the voltage estimated value.

(3) Assuming that the single group capacity of capacitor \( i \) is \( D_C \), the amount of action at the last time is \( x_{i,t-1} \), the reactive load of the reactive node set at this time is \( Q_{L,i} \), and the predicted load at the next time is \( Q_{L,i+1} \). Generally, the increment of reactive load is mainly determined by the local Compensation, so the estimated number of compensation groups at the next moment is

\[
\Delta Q_{C,i+1} = \left( Q_{L,i+1} - Q_{L,i} \right) / D_C \tag{14}
\]

If formula (15) is established, it indicates that there is a large oscillation in the action of the capacitor, so that the individual is deemed unqualified.

\[
\text{sgn}(x_{i-1}) \times \text{sgn}(x_i) = -1 \text{ and } \text{sgn}(x_i) \times \text{sgn}(\Delta Q_{C,i+1}) = -1 \tag{15}
\]

(4) In the middle and late stages of DE evolution, the individual differences become smaller. When the individuals appear in the same position or the degree of difference is less than \( \varepsilon_i \), the chaos operator with ergodic and randomness is used to directly initialize the individual.

4.4. "Constrained Guidance" Optimization

Due to the random distribution of a large number of individuals in the early stage of DE evolution, many individuals are in an infeasible solution position. In order to avoid too many individuals searching in the invalid space, a "constraint guide" is introduced in equation (6) for individuals that cause state variables to exceed the limit. The components are shown in equation (16). If the node voltage in the reactive node concentration is too high, a group of capacitors will be removed according to the principle of local control. If the node voltage in the voltage node concentration is too high, the transformer gear will be reduced by one gear, and vice versa. The constraint guidance component quickly pulls the individual back into the feasible solution space and accelerates the convergence of DE.
\[ u^*_{i,j}[k] = u^*_{i,j}[k] + \text{round}(\text{rand}) \times \text{sgn}(dx_j) \]  

(16)

In the formula: \text{round} is the rounding function, \text{rand} is the random number in [0,1], \text{sgn} is the sign function, and \( dx \) is the "constraint guidance" component.

4.5. Group optimization

In order to better solve the convergence of the algorithm and truly give a definite solution in various situations, this paper designs a method for solving hierarchical constraints grouping, that is, the constraint conditions are divided into three levels, namely strict constraint level, constraint level and Relaxation level, if the node voltage is between 1 and 1.05pu, it is a strict constraint level. On this basis, the voltage value of 0.02pu is expanded to be the constraint level. Outside the range of the constraint level, it is the relaxation level, as shown in Figure 4 below.

![Figure 4. Schematic diagram of clustering.](image)

This article adopts different strategies according to different groups to reduce the amount of tidal current calculation. For the strictly constrained level, use high-precision power flow calculations such as the calculation error; for the constrained level, consider low-precision power flow calculations such as the error; and for the slack level, use the sensitivity algorithm. Taking into account that the sensitivity calculation is a linear approximation calculation, there may be a large voltage deviation at some nodes, so the output node voltage results are simply evaluated using equation (12), and the voltage values close to the constraint level are taken. By applying sensitivity calculations to individuals belonging to the slack group, a large amount of power flow calculations is reduced, and the speed of the algorithm for solving reactive power/voltage optimization problems is improved.

It can be seen from the DE reproduction rules that the difference item is composed of the difference between two individuals selected at random in the current population, and the mutation direction of each individual is limited, so DE lacks true random mutation operations in reproduction. By directly using the chaos function to reinitialize the worst individual in the slack group, the ergodicity and irregularity of chaos are used to introduce new individuals into the group, bringing new “differences” and overcoming the direction of DE algorithm variation.

5. Automatic dispatching system design

5.1. Main process

Realize the comprehensive optimization of the whole network voltage qualified and the network loss as small as possible. The core of the centralized automatic control of the on-load tapping gear
adjustment and the capacitor switching is based on the state and the state of the reactive power compensation equipment and the voltage regulating equipment of the whole network. The comprehensive coordination of the operating parameters of the power grid forms related instructions, which are executed by the operation control system. First, collect data from the dispatch automation system, send it to the voltage analysis module and the reactive power analysis module for comprehensive analysis, and form the main transformer substation adjustment command, the substation capacitor switching command, and the multi-main transformer economic operation command. The control system of the dispatch centre, centralized control centre, and distribution centre is executed. After that, it goes back and forth.

5.2. Main functions
(1) Real-time monitoring of data in the power grid. It can monitor 10kV bus voltage, current, reactive power, transformer tap position and capacitor switch status in the power grid on one screen. (2) Voltage limit control. When the 10kV bus voltage exceeds the limit, the system will issue a corresponding instruction to adjust the on-load tap or switch the capacitor, and automatically execute the operation instruction. (3) Unreasonable control of reactive power flow. When the flow direction of the reactive power flow of the grid is unreasonable, the system issues instructions to switch the relevant capacitors, and automatically execute the operating instructions. (4) Centralized automatic control. There is no need for the intervention of on-duty personnel to meet the requirements of unattended stations and realize the "four remotes" function. (5) Economic operation of the main transformer. When the power grid is in low load operation, the economic operation mode is proposed for 2 or more main transformers in each substation, and the staff on duty decides whether to execute the operation instructions. (6) Reverse pressure regulation. In the voltage qualified range, the voltage is above the upper limit operation at peak load, and the voltage is below the lower limit operation at low load. (7) Voice report. There is a voice report on the success or failure of any operation in the system to remind or notify the duty personnel to grasp the adjustment of the main transformer tap and the capacitor switching action of a certain substation. (8) Record printing. After each operation command is issued, the program has a record of the control operation, saves and analyses, and automatically counts the number of times of each substation's main variable tap and capacitor switching on a monthly and daily basis. These records can be simulated and displayed on the screen, and can also be printed and archived for management.

5.3. Practical treatment in system software
In order to realize the practicality of the system, in the process of developing the system, the author does not perform pure power flow calculation of the whole network, but establishes optimization and control judgment rules that conform to the minimum network loss and qualified voltage of the whole network. Deal with the problem of data and instruction interface between this system and the original dispatch automation system, and ensure that the operation instructions are reliably executed in the corresponding components. The following examples illustrate several implementation technical solutions to lay the foundation for the practical processing of system software.

(1) Assuming that the reactive power flow of the power grid is reasonable, when the voltage of the low-voltage side busbar of a substation deviate from the qualified range, analyse the voltage of the same voltage level substation and the upper substation with the same power supply, and determine by yourself to adjust the substation The main transformer tap or adjust the main transformer tap of the superior power substation. Assuming that the voltage is within the qualified range, first consider whether the reactive power flow in the substation is reasonable, and then consider whether the reactive power flow in the same-level power grid is reasonable. Realize part of the reactive power reverse transmission between the substations in the same level of power grid to achieve the balance of reactive power flow in the power grid of this level.

(2) On the premise of making the capacitor input and the main transformer tap adjustment as small as possible, coordinate the relationship between the main transformer tap adjustment and the voltage...
(3) In order to realize the operation mode that the voltage of each node runs at the upper limit and the capacitors of each substation are put into reasonable operation, the comprehensive operating conditions of the main transformer tap and capacitor are: \( U_1 - A \times X + \Delta U \leq U_2 \). Among them, \( U_1 \) refers to the actual value of the voltage before the capacitor is put in; \( U_2 \) refers to the upper limit of the allowable voltage; \( \Delta U \) refers to the voltage increase value caused by the capacitor input; \( A \) is the main variable tap adjustment and converted to the voltage difference of each gear on the low-voltage side, often taking 0.25kV or 0.125kV; \( X \) is the number of operating gears of the main variable tap. \( \Delta U \) is obtained from the actual measurement of the voltage rise caused by the first input of the capacitor.

6. Example analysis

In order to verify the feasibility and effectiveness of the proposed method, an actual 40-node system in a certain area is used as a test system. The system includes a 220kV pivot substation and six 110kV substations. The control range is from the 220kV inlet end of the substation to the 10kV outlet end. The upper and lower limits of the bus voltage are 1.07 and 0.95 respectively, and the reference value is 100MV·A. The program is written in VB language, and it is simulated and analysed on a Pentium 3G computer with 512M memory. The active power loss of the system before optimization control is 34.40MW. The standard PSO algorithm and the improved PSO algorithm are used to calculate the reactive power/voltage real-time optimization control. After running for 20 consecutive times, the following typical operating results are given. The optimization results are compared as shown in Table 1.

It can be seen from Table 1 that the improved PSO algorithm reduces the network loss by 1.04MW more than the standard PSO algorithm, and the average calculation time is greatly shortened, which is less than 20s, which can basically meet the needs of real-time operation control. The number of capacitor and transformer gear actions in a day has been reduced from hundreds to ten or twenty, effectively suppressing unnecessary actions of control equipment. After optimized control, the over-limit voltage is all restored to the required level. Figure 5 shows the voltage value of a bus 24 before and after optimization.

| Table 1. Comparison of optimization results. |
|---------------------------------------------|
| Method                                      | Before optimization | DE              | MDE             |
| Voltage limit times (times/day)             | 28                 | 0               | 0               |
| Power factor limit violation times (times/day) | 1             | 0               | 0               |
| Network loss reduction rate (%)             | -                  | 12.48%          | 16.42%          |
| The maximum number of actions of the capacitor (times/day) | 0             | 34              | 4               |
| Total number of actions of capacitor (times/day) | 0             | 172             | 17              |
| Maximum operating times of transformer (times/day) | 0             | 78              | 4               |
| Total number of actions of capacitor (times/day) | 0             | 405             | 15              |
| Calculation time (S)                        | -                  | 28.40           | 15.33           |
Figure 5. Voltage comparison chart at 24 hours.

7. Conclusion
Incremental starting strategy solves the problem of inconsistent load between buses. Adding fuzzy control cost to the objective function limits the number of actions of the control equipment, and at the same time it is more reasonable in time and space allocation. The algorithm considers the correlation of time to a certain extent, but how to make full use of historical and forecast data for optimization calculations, further shorten the algorithm time, and more reasonable distribution of the number of actions will be studied in the future for reactive power/voltage real-time optimization control One of the directions.

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