Dynamic Optimal Configuration Method for Distribution Network Based on Multidimensional Reliability Improvement

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Abstract. The power supply company has invested a lot of money to enhance the reliability of the distribution network by improving the grid structure, increasing the level of distribution automation, and increasing the coverage of live operations. However, blind investment will cause a lot of waste of assets. In view of the current situation, this article firstly constructs a reliability calculation model based on the minimum path method, which considers the mutual influence of multiple methods. Then, from the perspective of the life cycle, a corresponding life cycle cost (LCC) model is established. Next, based on grid search, a multi-dimensional dynamic optimal configuration method of distribution network considering the full life cycle is presented. Finally, this paper takes a regional distribution network as an example, and verifies the validity of the model through simulation calculations. The research results can provide a theoretical basis for the investment of distribution network assets.

Keywords: Power grid asset management, distribution network, life cycle cost, dynamic programming.

1. Introduction

The distribution network is the key link between the transmission grid and users, and its reliability and economy are the most important indicators of the power system, which are directly related to the benefits of the enterprise. At present, in order to improve the reliability of power supply, each department of the power supply enterprise mainly focus on three kinds of methods, including network structure optimization, distribution automation construction, and on-line maintenance. Since the reliability improvement capabilities of those methods are time-dependent, how to coordinate the order and volume of these three sequences in power grid planning to meet the reliability with the minimum cost needs to be further studied.

Thus, aiming at the demand of reliability improvement during distribution network renovation, a collaborative optimization method of reliability improvement equipment configuration is proposed in this paper. First of all, taking the addition of feeders (to optimize the structure of the grid), the allocation of automation equipment on the whole line, and the improvement of coverage rate of live...
maintenance as discrete transformation variables, the cost and apportion model of unit transformation variable is established. Then, considering the impact of various improvements on reliability parameters, a reliability calculation model based on variable parameters is established.

On this basis, with reliability as the constraint and economic optimization as the goal, from the three dimensions of "grid structure equipment", "distribution automation equipment" and "live working equipment", a dynamic optimization of the reliability improvement equipment of the distribution network is established, and the grid search method is used to solve the scheme. The research results of this paper can provide a new method for the planning and transformation of distribution network, which is beneficial to guarantee the reliability of power supply for users with the most economical scheme and help the sustainable development of enterprises.

2. Dynamic optimization configuration model for reliability improvement

The user reliability level is closely related to the grid structure, the automation level, the maintenance method and the length of the maintenance time. Among them, optimizing the grid structure can provide load transfer capabilities, reduce the scope of power outages, and reduce the probability of failure. The configuration of automated equipment can quickly locate faulty equipment, which greatly reduces the time required for fault isolation and load transfer [1]. In the operation phase, the use of live working can shorten the fault repair time and avoid power outages caused by planned maintenance [2]. The relationship between different reliability improvement methods and reliability influencing factors is shown in Figure 1.

![Figure 1. The Effect of Distribution Network Optimization Approach on Reliability.](image)

Moreover, the order of adding the three types of equipment has a greater impact on the reliability index. Under different basic conditions of the distribution network, the effects of investing the same cost and using different promotion methods are very different.

2.1. Optimal configuration model of multi-dimensional equipment based on reliability constraints

2.1.1. Configuration scheme set. By analyzing the impact of adding feeders, configuring automation equipment, and increasing the proportion of live work on reliability, it can be known that the order and the quantity of equipment configuration have a greater impact on the final cost and reliability benefits, so this problem belongs to dynamic planning. This paper takes the increase of a single line (power supply line or tie line) as the optimization variable for the grid structure, and takes the implementation of distribution automation transformation on a single feeder as configuration variable of the distribution automation equipment, and takes the live inspection coverage rate and the live
maintenance coverage rate as live maintenance configuration variables, construct Set X (G, DA, LW) to be selected for equipment optimization configuration.

The grid structure transformation plan set \( G(G_1, ..., G_t) \) is to select optional tie lines and new feeders in the area according to the line load and load growth. The distribution automation configuration plan set \( DA(DA_1, ..., DA_t) \) is to select the feeder to be automated according to the failure duration index and load demand. Any feeder has three states: no distribution automation configuration plan, "one remote" configuration and "three remote" configuration \[3\]. The plan set \( LW(lr, li) \) is based on the proportion of planned power outage time and the time of failure to establish a live repair coverage improvement plan and a live inspection coverage improvement plan. The upper and lower limits of the live repair coverage are 0.1 and 0.8, respectively. Set the search step size to 0.1, and there are 8 states. The upper and lower limits of the coverage rate of the live check are 0 and 0.9 respectively. Set the search step to 0.1, there are 10 states.

2.1.2. Objective function. Due to the difference in the service life of various equipment and the difference in the duration of each stage of dynamic planning, the planning is divided into multiple stages. This article takes the lowest overall life cycle cost of configuring multiple devices within the planning period as the objective function:

\[
\min F = \sum N_n \times f(x_n)
\]  

(1)

In the formula: \( N_n \) is the duration of the n-th stage; \( f(x_n) \) is the annual value of the LCC of the n-th stage of plan \( x_n \), and the calculation method is as in formula (2).

\[
\begin{align*}
    f(x) &= C_g + C_{da} + C_i \\
    C_g &= \sum C_{G}(G_i) \\
    C_{da} &= \sum C_{DA}(DA_i) \\
    C_{lw} &= C_{lr}(lr) + C_{li}(li)
\end{align*}
\]  

(2)

In the formula: \( C_g \) is the equivalent annual cost (EAC) of the life cycle cost (LCC) of the grid structure transformation; \( C_{da} \) is the EAC of the distribution automation system; \( G_i \) is the EAC of live maintenance; \( C_{G}(G_i) \) is the EAC of the i-th line of the grid structure according to plan \( G_i \); \( C_{DA}(DA_i) \) is the EAC of the j-th line of the distribution automation system according to plan \( DA_i \); \( C_{lw}(lw) \) is the additional cost of live repair, and \( C_{li}(lm) \) is the additional cost of live inspection.

2.1.3. Transfer equation. The basis of dynamic programming is the optimality theory: the sub-strategies contained in the optimal strategy must be the optimal sub-strategy \[4\]. In the dynamic programming sequential solution method, starting from the initial state, according to the initial condition (3) and the n-th stage recursive equation (4), the optimal path of all the alternatives at each stage is calculated from forward to backward, as shown in Figure 2.

\[
\begin{array}{cccc}
\vdots & \vdots & \vdots & \\
\bullet & \bullet & \bullet & \bullet \\
\vdots & \vdots & \vdots & \\
1 & n-2 & n-1 & n \quad N \\
\end{array}
\]

Figure 2. Optimal path for dynamic programming.
Until the optimal path of all the options at the final stage is obtained, and the optimal solution of the objective function is obtained by comparing each scheme.

\[ F_0 = 0 \]  

\[ F_n(x_n) = \min_{x_{n-1} \in D(x_{n-1})} (F_{n-1}(x_{n-1}) + N_n \times f(x_n)) \]  

In the formula: \( D(X_{n-1}) \) is the set of allowed schemes for the (n-1)-th stage determined by the n-th stage scheme \( x_n \).

2.1.4. Restrictions. Since different stages have different requirements for reliability, there are reliability constraints:

\[ ASAI_n \geq S_n \]  

In the formula: \( ASAI_n \) is the average power supply availability rate of the n-th stage of the distribution network optimization plan; \( S_n \) is the average power supply availability target of the n-th stage.

2.2. Equipment configuration cost model based on the LCC

2.2.1. Grid equipment configuration cost model. Increasing the cost of feeder or tie line for network structure adjustment mainly considers the cost of adding equipment, and the EAC is as follows.

\[ C_{G}(G_i) = \sum n_{ik} \cdot C_k \]  

In the formula: \( C_{G}(G_i) \) is the EAC corresponding to the reconstruction of the i-th line's grid structure, \( n_{ik} \) is the number of k type equipment added to the i-th line reconstruction, \( C_k \) is the EAC of the k type equipment, and its calculation method is shown in formula (7).

\[
\begin{align*}
C_k &= C_A + C_R + C_M + C_{RA} \\
C_A &= \frac{C_i(1+\alpha)^n\alpha}{(1+\alpha)^n-1} \\
C_{RA} &= C_A \cdot \lambda_{IR}
\end{align*}
\]  

In the formula: \( C_A \) is the EAC for equipment investment, \( C_R \) is the annual operating cost, \( C_M \) is the annual failure disposal cost, and \( C_{RA} \) is the EAC for decommissioning disposal. \( C_i \) is the initial investment value, \( n \) is the service life, \( \alpha \) is the discount rate, and \( \lambda_{IR} \) is the decommissioning loss coefficient of the i-th equipment.

2.2.2. Distribution Automation Cost Model. The distribution automation system is mainly composed of the main distribution station, the distribution terminal, the distribution electronic station and the communication channel, which can realize the operation monitoring and automatic control of the distribution network. The cost of distribution automation is calculated based on the line, as shown in equation (8).
\[
\begin{align*}
C_{DA}(DA_j) &= C_{jA} + C_{jM} + C_{jRA} \\
C_{jA} &= \frac{C_{MS}}{N_1} + \frac{C_S}{N_2} + \sum n_{jl} \cdot C_l + L_j \cdot c_c \\
C_{jM} &= \frac{C_{AC}}{N_3} \\
C_{jRA} &= C_{jA} \cdot \lambda_{jR}
\end{align*}
\]  

(8)

In the formula: \(C_{DA}(DA_j)\) is the EAC of the distribution automation system for the jth line; \(C_{jA}\) is the EAC of the distribution automation system investment for the jth line; \(C_{jM}\) is the annual operation and maintenance cost of the j-th line distribution automation system; \(C_{jRA}\) is the EAC of the decommissioning cost of the distribution automation system of the j-th line. \(C_{MS}\) is the EAC invested by the distribution automation main station, \(N_1\) is the number of lines controlled by the main station; \(C_S\) is the EAC of the investment cost of the distribution automation substation, and \(N_2\) is the number of lines controlled by the substation; \(n_{jl}\) is the number of l-th type terminal on the j-th line, \(C_l\) is the EAC of the kl-th type terminal; \(L_j\) is the length of the communication channel of the j-th line, and \(c_c\) is the EAC of the unit-length communication channel. \(C_{AC}\) is the fixed operation and maintenance fee charged by the communication company, and \(N_3\) is the number of lines controlled by the communication company. \(\lambda_{jR}\) is the decommissioning loss coefficient of the distribution automation system.

2.2.3. Live maintenance cost model. Since the live work replaces the maintenance work that should have been carried out originally, the difference between the live maintenance cost and the ordinary maintenance cost is used for the calculation of the single live work cost. The calculation method is shown in formula (9).

\[
\begin{align*}
C_{lr}(lr) &= \sum lr \cdot n_k \cdot \lambda_k^r \cdot C_{lrk} \\
C_{li}(li) &= \sum li \cdot n_k \cdot \lambda_k^i \cdot C_{lik}
\end{align*}
\]  

(9)

In the formula: \(lr\) is the live repair coverage rate, \(n_k\) is the number of the k-th device, \(\lambda_k^r\) is the failure rate of the k-th device, and \(C_{lrk}\) is the average additional cost of the k-th device on-line repair; \(li\) is live inspection coverage rate, \(\lambda_k^i\) is the planned outage rate of the i-th device, and \(C_{lik}\) is the average additional cost of live inspection of the k-th device.

2.3. Distribution network reliability model

In order to judge whether the optimization scheme meets the reliability requirements, it is necessary to calculate the benefits of various equipment configurations to improve reliability. The distribution network has a variety of reliability indicators, among which the average power supply availability index (ASAI) can comprehensively reflect the actual reliability level of the system, as follows (10).

\[
ASAI = \frac{\sum 8760N_x + \sum (U_x + U_x^p)N_x}{\sum 8760N_x}
\]  

(10)

In the formula: \(N_x\) is the number of users at the load point, \(U_x\) is the annual outage time of the load point, and \(U_x^p\) is the annual planned outage time of the load point.

In the paper, the minimum road method is used to calculate the outage time of each load point, and the model is as (11).
In the formula: \( \lambda_s \) is the failure rate of the load point, \( \lambda_i \) is the failure rate of the i-th component, \( r_s \) is the repair time of the load point, \( r_i \) is the repair time of the i-th component, and \( U_s \) is the annual failure outage time of the load point. \( \lambda_s^p \) is the planned outage rate of the load point, \( \lambda_i^p \) is the planned outage rate of the i-th element, \( r_s^p \) is the planned outage time of the load point, \( r_i^p \) is the average planned outage time of the i-th element, and \( U_s^p \) is the annual planned outage time of the load point.

\[
\begin{align*}
    \lambda_s &= \sum \lambda_i \\
    r_s &= \frac{\sum \lambda_i r_i}{\sum \lambda_i} \\
    U_s &= \sum \lambda_i \cdot r_i
\end{align*}
\]
\[
\begin{align*}
    \lambda_s^p &= \sum \lambda_i^p \\
    r_s^p &= \frac{\sum \lambda_i^p \times r_i^p}{\sum \lambda_i^p} \\
    U_s^p &= (1 - l_i) \times \sum \lambda_i^p \times r_i^p
\end{align*}
\] (11)

In the formula: \( \lambda_s \) is the failure rate of the load point, \( \lambda_i \) is the failure rate of the i-th component, \( r_s \) is the repair time of the load point, \( r_i \) is the repair time of the i-th component, and \( U_s \) is the annual failure outage time of the load point. \( \lambda_s^p \) is the planned outage rate of the load point, \( \lambda_i^p \) is the planned outage rate of the i-th element, \( r_s^p \) is the planned outage time of the load point, \( r_i^p \) is the average planned outage time of the i-th element, and \( U_s^p \) is the annual planned outage time of the load point.

**Figure 3.** Troubleshooting process.

When a component fails, the actual processing flow is shown in Figure 3. It can be seen from the figure that only the \( r_i \) cannot accurately reflect the actual grid action. Therefore, this paper adopts the partition method, and considers the benefits of grid structure improvement, distribution automation and live work, and revises the model. In formula (11), the planned power outage time has been revised through the live inspection rate.

For each load point, the related components can be marked into three categories: the first type of component \( a=1 \) is in the same isolation interval as the load point or the isolation interval is located upstream of the load point in the irrelevant function; the second type of component \( a=2 \) is the isolation interval located downstream of the load point; the third type of component \( a=3 \) is the isolation interval located upstream of the load point with transfer capacity. \( r_i \) is calculated as formula (12).

\[
r_i = \begin{cases} 
    t_L + t_l + t_R & a = 1 \\
    t_L + t_l & a = 2 \\
    t_L + t_l + t_T & a = 3 
\end{cases}
\] (12)

In the formula: \( t_L \) is the fault location time, \( t_l \) is the fault isolation time, \( t_R \) is the component maintenance time, and \( t_T \) is the load transfer time.

Furthermore, After the implementation of power distribution automation transformation, the automatic processing of fault location, isolation, transfer and recovery can be realized, so the fault location time, fault isolation time, and load transfer time are all reduced \([5, 6]\). Considering that the power distribution automation level at the location of the component is "none", "remote sensing" or "remote control" \( b=0, 1, 2 \), and considering the coverage of live work, the time of each action after the fault occurs is corrected according to the formula (13-16).
\begin{equation}
t_L = \begin{cases} L \cdot T_L \cdot (1 - \eta) + T^2_L \cdot \eta & b = 1, 2 \\ L \cdot T_L & b = 0 \end{cases}
\end{equation}
(13)

\begin{equation}
t_1 = \begin{cases} T^1_1 \cdot (1 - \eta) + T^2_1 \cdot \eta & b = 2 \\ T^1_1 & b = 0, 1 \end{cases}
\end{equation}
(14)

\begin{equation}
t_R = T^1_R \cdot (1 - lw) + T^2_R \cdot lr
\end{equation}
(15)

\begin{equation}
t_T = \begin{cases} T^1_T \cdot (1 - \eta) + T^2_T \cdot \eta & b = 2 \\ T^1_T & b = 0, 1 \end{cases}
\end{equation}
(16)

In the formula: \(L\) is the total line length of a single outgoing area of the substation, \(T_L\) is the line location time per unit length, \(T^2_L\) is the average fault location time in the distribution automation area obtained by statistics, and \(\eta\) is the reliability rate of the distribution automation terminal, \(T^1_1\) is the average fault isolation time in areas without remote control, \(T^2_1\) is the average fault isolation time in the remote control area, \(T^1_R\) is the component repair time, \(T^2_R\) is the preparation time for live work, \(T^1_T\) is the transfer time in areas without remote control, \(T^2_T\) is the transfer time in the remote control area.

3. Dynamic optimization model solving method based on grid search

Grid search (GS) is a mathematical method for finding nonlinear extremums with constraints [7]. The grid search method divides the feasible interval of each parameter to be optimized into a grid according to a certain step length, so that the parameter value is within a certain range. The objective function value is at the intersection point, and all intersection points are searched according to the traversal method, and each intersection point representing the optimal objective function is found, and each parameter represented by the intersection point is the optimal parameter. The grid search method is relatively intuitive. When there are few optimization parameters, the search time is shorter and the optimal fitness is higher. It can solve the problem that most optimization algorithms are difficult to converge when processing discretized variables and nonlinear objective functions.

At the same time, due to the limitation of the optimization principle in dynamic programming, the solution at each stage must be the global optimal solution. Therefore, the shortcomings of other search algorithms that are easy to fall into the local optimum will be further magnified in the process of dynamic programming, so this paper adopts the grid search algorithm to solve the model. The dynamic optimization process based on grid search is shown in Figure 4. The specific steps are:

1) Enter the raw data of the distribution network.
2) Initialize the parameters of each stage.
3) Calculation scheme EAC and reliability.
4) Judge whether the program meets the reliability requirements. If yes, search for the optimal front path of the scheme, calculate \(F_n(x_n)\), and include the scheme in the set of optional schemes for the nth stage.
5) Judge whether to traverse all the plans at this stage: if yes, go to 6); if not, go to the next plan, and return to 3).
6) Judge whether all stages of planning are completed: if yes, search for \(\min F_n\), and output the planning results: if not, go to the next stage and return to 3).
Enter the raw data

Initialize the parameters

n=1, F_0=0, k=1

Calculation scheme EAC and reliability

k=k+1

Meets the reliability requirements?

N

search for the optimal front path of the scheme, calculate F_n, and include the scheme in the set of optional schemes for the nth stage.

N

traverse all the plans?

N

all stages of planning are completed?

N

search for min F_n, and output the planning results

Y

Y

n=n+1

k=1

Figure 4. Optimization process of distribution network based on grid search.

4. Case Study

Figure 5. 19-node distribution network system diagram.
Basic data this paper uses the 19-node point distribution network system shown in Figure 5 to analyze the calculation example. The seven-stage dynamic optimization reliability constraints are 0.99935, 0.99962, 0.99977, 0.99984, 0.99988, 0.99990, and 0.99992 respectively. The total planning time is 5 years, and the time of each stage is equal.

4.1. Cost and reliability data
The cost data for the optimization of the grid structure in the optimal configuration model is shown in Table 1, and the cost unit is 10,000 yuan per year.

| device | $C_A$ | $C_R$ | $C_M$ | $C_{TA}$ | $C_k$ |
|--------|-------|-------|-------|----------|-------|
| transformer | 0.3383 | 0.65  | 0.12  | 0.0101   | 1.1184 |
| breaker   | 0.0453 | 0.02  | 0.06  | 0.0026   | 0.1279 |
| line      | 1.1264 | 0.87  | 0.15  | 0.0035   | 2.1499 |

After investigation, there are 246 distribution automation lines in a certain area, including 1 main distribution station and 16 distribution electronic stations. $C_{JM}$ is 498,000 yuan. The decommissioning loss factor is 0.01; $N_1$, $N_2$, and $N_3$ are 246, 15.7, and 246 respectively. The investment cost of distribution automation equipment is shown in Table 2. In the table, FTU means Feeder Terminal Unit, and RTU means Remote Terminal Unit.

| device | Master Station | Station | Communication Channel | FTU | RTU |
|--------|----------------|---------|-----------------------|-----|-----|
| EAC    | 90.6532        | 1.1549  | 0.4382                | 0.0693 | 0.1617 |

4.2. Calculation results and analysis
The grid search is used to solve the multi-dimensional dynamic optimization model, and the improvement strategies at each stage of the planning cycle are obtained. The total cost is at least 804,300 yuan, as shown in Table 6.
Table 6. Multi-dimensional reliability improvement, dynamic optimization, optimal configuration.

| ASAI       | G     | DA | LR | LI | $f(x)$ (10,000 yuan/year) |
|------------|-------|----|----|----|--------------------------|
| 0.99935    | 00000 | 000| 0.2| 0  | 1.3716                   |
| 0.99962    | 00000 | 000| 0.7| 0  | 4.6876                   |
| 0.99977    | 00001 | 000| 0.8| 0.3| 9.8968                   |
| 0.99984    | 00001 | 000| 0.8| 0.9| 16.1908                  |
| 0.99988    | 00001 | 200| 0.8| 0.9| 21.5709                  |
| 0.99990    | 01101 | 200| 0.8| 0.9| 26.2411                  |
| 0.99992    | 01101 | 210| 0.8| 0.9| 32.6448                  |

In the table, ASAI is the reliability requirements of each stage, G is the grid structure transformation plan, DA is the distribution automation transformation plan, LR is the live maintenance coverage configuration plan, LI is the live inspection coverage configuration plan, and $f(x)$ is the EAC of the current plan. It can be seen from Table 6 that the coverage rate of live inspection was increased in the first and second stages, the contact line was added at the end of the A3 area in the third stage, and the coverage of live inspection was increased in the fourth stage. In the fifth stage, the "remote control" distribution automation transformation was implemented in the A1 area. In the sixth stage, tie lines were added in the A1 and A2 areas respectively, and in the seventh stage, the "remote sensing" power distribution automation transformation was implemented in the A2 area.

Based on the objective function, the equipment with the lower unit reliability improvement cost should be invested first. At the same time, in the face of different power grid characteristics, the impact of different reliability improvement equipment on reliability has certain differences. The unit price of live maintenance is low and has a good input-output ratio, and it is selected first in the optimization process until its coverage growth is restricted by the operating environment and reaches the upper limit of the coverage rate under safe operation conditions. Since the construction cost of optical fiber communication channels is relatively large in the configuration process of power distribution automation equipment, its life cycle cost is positively related to the line length. Therefore, in areas similar to the A1 area with short lines and high load density, increase the distribution level of electrical automation can achieve good results. Similar to the area of A3, where the line is longer and the load density is small, the cost-effectiveness of improving the level of power distribution automation is lower.

In the multi-stage (non-dynamic) optimal allocation strategy, only the current stage of economic optimization is considered, and the optimal cost in the entire planning cycle is not considered. The minimum cost in the multi-stage optimization strategy planning cycle is 827,400 yuan, and the results are shown in Table 7.

Table 7. Reliability improvement, dynamic optimization, optimal configuration.

| ASAI       | G     | DA | LR | LI | $f(x)$ (10,000 yuan/year) |
|------------|-------|----|----|----|--------------------------|
| 0.99935    | 00000 | 000| 0.2| 0  | 1.3716                   |
| 0.99962    | 00000 | 000| 0.7| 0  | 4.6876                   |
| 0.99977    | 00001 | 000| 0.8| 0.3| 9.8968                   |
| 0.99984    | 00011 | 000| 0.8| 0.7| 16.0712                  |
| 0.99988    | 00011 | 200| 0.8| 0.9| 23.1787                  |
| 0.99990    | 01101 | 200| 0.8| 0.9| 26.6287                  |
| 0.99992    | 01111 | 210| 0.8| 0.9| 34.0012                  |

Comparing with Table 6, it can be seen that when the multi-stage optimization strategy in the fourth planning stage selects the current stage optimization plan, because only the lowest cost of the current stage is considered and the total cost optimization in the planning cycle is not considered, the
increase of feeders is selected. This is less cost-effective in the subsequent stages. Then it caused an increase in the cost of the subsequent stage. Compared with multi-dimensional dynamic planning, multi-stage planning cannot consider the timing impact of planning schemes, and it is easy to fall into local optimum in the planning, which causes the total cost to rise during the entire planning cycle.

5. Conclusions
This paper studies the dynamic optimal configuration method of multi-dimensional equipment to improve the reliability of distribution network. Taking the addition of feeders (to optimize the structure of the grid), the allocation of automation equipment on the whole line, and the improvement of coverage rate of live maintenance as discrete transformation variables, the cost and allocation model of unit transformation variables are established. At the same time, considering the impact of various improvements on reliability parameters, a reliability calculation model based on variable parameters is established. On this basis, with reliability as the constraint and economical optimization as the goal, three types of reliability-improving equipment dynamic optimization configuration models are established, and a solution method based on grid search is proposed.

Finally, through the analysis of a typical distribution network, the difference between multi-dimensional dynamic optimization and multi-stage optimization is compared, and the optimal solution is obtained. Through analysis, it is found that multi-dimensional dynamic optimization can save a lot of cost compared with single-dimensional optimization, and it avoid falling into a local optimum, which verifies the feasibility and effectiveness of the proposed method for dynamic optimization of multi-dimensional equipment in the distribution network.

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