Optimal dispatching strategy for power emergency supplies distribution considering the cooperation of supply reserve points

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Abstract. Power accidents in extreme conditions have seriously threatened the safe operation of the power system. Therefore, the research on optimal dispatching strategy for power emergency supplies in extreme conditions is the focus of power companies. According to the strong timeliness and weak economy of extreme conditions, this paper puts forward a two-layer optimization model of power emergency supplies distribution: according to the reserve and demand of supplies supply point and distribution point, an optimal dispatching model of power emergency supplies is put forward at the bottom level considering the time factor. At the same time, considering the time sequence evolution of extreme conditions, the optimal dispatching model of power emergency supplies is proposed to ensure that the power emergency supplies can still meet the demand after the extreme conditions deteriorate. Finally, the comprehensive learning particle swarm optimization algorithm is used to solve the problem, and the example results show that the model is effective and reasonable.

1. Introduction

Electric power has become an indispensable energy source in life and production. Large-area power failure accident will cause personal safety, equipment damage and heavy loss of production, which will have a huge impact on power supply enterprises and public safety. Maintaining the safe and reliable operation of the power system is not only to reduce the power outage loss, but also the foundation of the stable and healthy development of the whole society.

Among many electric power accidents, the proportion of electric power accidents caused by extreme conditions such as earthquakes, typhoons, debris flows, snow and ice disasters is as high as 50%, which seriously threatens the safe and stable operation of the power grid. Therefore, the distribution requirement of power emergency supplies is getting higher and higher.

The occurrence of extreme conditions usually has strong randomness and uncertainty, so the electric power accidents caused by extreme conditions often have strong time-varying, making the demand of power emergency supplies time-varying. Therefore, the general power supplies dispatching model cannot meet the dispatching requirements of electric power accidents caused by extreme conditions.

At present, there are some literatures on the optimal distribution of power emergency supplies [1]. Literature [2] gave the optimal logistics path under the condition of given logistics time limit considering the load importance and other indicators. Literature [3] studied the multi-objective...
optimization problem to minimize the number of power outages and the resources waste under different emergency power supply conditions. Literature [4] put forward the reference suggestions for the emergency supplies dispatch of power system by comprehensively considering the objective and task factors. Literature [5] used particle swarm optimization algorithm to solve the problem of optimal power repair path.

In this paper, an optimal dispatching model for power emergency supplies distribution is proposed to cope with extreme conditions, and the heterogeneous comprehensive learning particle swarm optimization with enhanced exploration and exploitation (HCLPSO) is used to solve the model, and the optimal dispatching strategy is formulated. Finally, an example is given to verify the feasibility and rationality of the method. After the occurrence of the extreme conditions, the research content solves how to make the optimal dispatching scheme of power emergency supplies in the first time, to meet the demand for power emergency supplies in the area where the power accident occurs as far as possible, that is, to deliver the power emergency supplies required to the area where the accident occurs in the shortest time from the supply reserve point. At the same time, considering the time sequence evolution of the future development of extreme conditions, the unbalanced distribution problem of power emergency supplies will be solved in the future, to minimize the loss caused by power accidents in the above two aspects.

This paper is divided into five parts, the first part introduces the background and significance of optimal dispatching strategy research for power emergency supplies distribution, the second part sets up a corresponding optimal dispatching model for power emergency supplies distribution according to the characteristics of the extreme conditions, the third part introduces the heterogeneous comprehensive learning particle swarm optimization with enhanced exploration and exploitation (HCLPSO), the fourth part illustrates the rationality and feasibility of the proposed method through the example analysis, and the final part proposes summary and prospect.

2. Optimal dispatching model for power emergency supplies distribution

In extreme conditions, the basic characteristic of emergency supply dispatching scheme is strong timeliness, and economic considerations take a secondary place. In addition, while taking timeliness into account, the development trend of extreme conditions should be considered, to obtain an optimization scheme of resource sharing considering the time sequence evolution of extreme conditions.

When the extreme conditions lead to the occurrence of power accident, the power emergency supplies distribution should meet the quantity and time requirements at the distribution point. Assume that $t_{ij}$ is the time from the supply reserve point $i$ to the distribution point $j$, where $i = 1, 2, ..., n$, $j = 1, 2, ..., m$, and in general, $n > m$. $\tau$ is the emergency time margin of supplies at the distribution point, and $\tau$ is determined by the characteristics of specific supplies. $x_{ij}$ is the quantity of supplies provided from the supply reserve point $i$ to the distribution point $j$, and $x_{ij}$ is the decision variable. $y_i$ is the quantity of supplies at the supply reserve point $i$. $z_j$ is the demand of supplies at the distribution point $j$. $\lambda_{ij}$ is a time parameter, if $t_{ij} > \tau$, $\lambda_{ij} = 1$, otherwise $\lambda_{ij} = 0$. Correspondently, $\alpha$ is the penalty coefficient of power loss caused by the supply transport time exceeding the time margin ($t_{ij} > \tau$). The optimal dispatching for power emergency supplies shall meet the quantity and time requirements at the distribution points, that is, the loss caused by exceeding the time margin shall be minimized. The optimal dispatching model is as follows:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} \alpha \lambda_{ij} (t_{ij} - \tau) x_{ij}$$

s.t. \( \sum_{j=1}^{m} x_{ij} \geq y_i \)

\[ \sum_{j=1}^{m} x_{ij} \geq z_j \]
\[
\sum_{i=1}^{n} (1 - \lambda_{ij}) x_{ij} \geq 0
\]

Where, the first constraint indicates that the supply demand of each distribution point can be met, the second constraint indicates that the supply reserve points have enough supply reserves to meet the quantity requirements, the third constraint indicates that there is at least one supply reserve point that can reach the distribution point \( j \) within the time margin.

With the development of extreme conditions, the demand for emergency supplies at each distribution point may change (increase or decrease), and the overall supplies distribution will also change, then emergency supplies should be distributed from the supply reserve point where the extreme condition is alleviated to the supply reserve point where the extreme condition is worsened. Therefore, on the premise that each supply reserve point can meet the demand of the local distribution points, this paper will comprehensively analyse the layout change of the whole supply demand and calculate the optimal dispatching scheme between supply reserve points according to the time sequence evolution of extreme conditions.

At a certain time section \( T \), suppose that \( M_i \) is the reserve of emergency supplies at the supply reserve point \( i \), and \( N_i \) is the demand of emergency supplies at the supply reserve point \( i \). At time \( T \), the power emergency supplies at the supply reserve point have the following two situations:

1. If \( M_i - N_i > 0 \), then the supply allowance at the supply reserve point \( i \) is \( M_i - N_i \);
2. If \( M_i - N_i < 0 \), then the supply allowance at the supply reserve point \( i \) is \( N_i - M_i \);

\( \phi_i^+ = \max\{0, M_i - N_i\} \) is used to represent the supply allowance at the supply reserve point \( i \) at time \( T \), and \( \phi_i^- = \max\{0, N_i - M_i\} \) is used to represent the shortage of emergency supplies at the supply reserve point \( i \) at time \( T \). Considering the time sequence evolution of extreme conditions, at time \( T + \Delta T \), the whole supply demand layout will change. \( \chi_{ij} \) is used to represent the quantity of supplies to be distributed from the supply reserve point \( i \) to the supply reserve point \( j \), and \( \chi_{ij} \) is the decision variable at this stage. The optimal dispatching model of the supply reserve point is as follows:

\[
\min \sum_{i=1}^{n} \sum_{j=1}^{m} \chi_{ij} C_j L_j + \beta \max\{0, N_j - M_j - \chi_{ij}\} \\
\text{s.t.} \quad \sum_{j=1}^{m} \chi_{ij} \leq \phi_i^+ \\
\sum_{i=1}^{n} \chi_{ij} \leq \phi_j^-
\]

Where, \( C_j \) represents the unit outage loss at the supply reserve point \( j \); \( L_j \) represents the outage load at the supply reserve point \( j \); \( \beta \) is the penalty coefficient of the power loss caused by the supply shortage \( (N_j - M_j - \chi_{ij}) \) in this period. The first constraint means that the sum of supplies distributed by each supply reserve point to other supply reserve points cannot exceed the supply allowance. The second constraint means that each supply reserve point should receive supplies from other supply reserve points in quantities greater than the shortages.

3. Heterogeneous comprehensive learning particle swarm optimization

Particle swarm optimization algorithm (PSO) was first proposed by professors Kennedy and Eberhart et al. in 1995 and achieved rapid development [6-7]. It is a method to solve optimization problems by simulating social behaviour. PSO algorithm was originally designed to simulate the unpredictable movement mechanism of birds. Through the observation of birds’ social behavior, it was found that there was social sharing of information in the group, which was used as the basis for the development of the algorithm. PSO algorithm has a good global search capability and is widely used in power system, wireless network and machine learning.

Particle swarm optimization (PSO) simulates birds by designing a massless particle with two properties: speed and position. Firstly, each particle searches for the optimal solution in the search
space separately, and it is recorded as the current individual extreme value, and the individual extreme value is shared with other particles in the whole particle swarm to find the optimal individual extreme value as the current global optimal solution of the whole particle swarm. Then, all the particles in the particle swarm adjust their speed and position according to the current individual extreme value found by themselves and the current global optimal solution of the whole particle swarm, the specific adjustment method is as follows:

\[
V_i' = V_i + \lambda_1 \times \text{rand} \times (I_i - X_i) + \lambda_2 \times \text{rand} \times (G_i - X_i)
\]

(3)

\[
X_i = X_i + V_i'
\]

(4)

Where, \(V_i\) and \(X_i\) represent the speed and position of particles respectively, \(V_i'\) represents the last speed, \(\lambda_1\) and \(\lambda_2\) represent the learning factors, \(I_i\) represents the current individual extreme value, \(G_i\) represents the current global optimal solution. In Formula 3, the first part is the memory item, which represents the influence of the size and direction of the last speed, the second part is the self-cognition item, which represents the influence of own experience on the speed, the third part is the group cognition item, which reflects the cooperation and knowledge sharing among particles.

In this paper, the comprehensive learning particle swarm optimization (CLPSO) [8] is used to solve the optimal dispatching problem of power emergency supplies. In this method, all particles are divided into two subgroups, which are respectively responsible for exploration and development. The comprehensive learning strategy is used to generate a "Canon" for particles in two subgroups: in the subgroup responsible for exploration, the "Canon" is mainly based on the best experience of particles themselves; In the subgroup responsible for development, the "Canon" is mainly based on the best experience of all the particles in the subgroup. Because there is no information communication between particles of two different subgroups, the diversity of particles in the exploration subgroup will not be affected even if the particles in the development subgroup converge prematurely.

4. Example

It is assumed that there are 5 supply reserve points that meet the emergency requirements of power supplies in extreme conditions, and 8 distribution points. The paths between supply reserve points and distribution points are shown in Figure 1, and the unit of path is kilometres.

![Figure 1. Supply distribution path](image)

The reserve at the supply reserve points is as follows: 1 million pieces for supply reserve point 1, 1.2 million pieces for supply reserve point 2, 800,000 pieces for supply reserve point 3, 700,000 pieces for supply reserve point 4, and 1.5 million pieces for supply reserve point 5. The speed of material distribution is 70km/h. Assuming that this area is affected by extreme conditions, the demand for emergency supplies of each distribution point and its timing changes are shown in Table 1.
According to the model (1), the optimal dispatching scheme of power emergency supplies can be obtained as shown in Figure 2, that is, 450,000 emergency supplies will be delivered from the supply reserve point 1 to the distribution point 1, 470,000 emergency supplies to the distribution point 2, and 140,000 emergency supplies to the distribution point 3. 420,000 emergency supplies will be delivered from the supply reserve point 2 to the distribution point 4. 110,000 emergency supplies will be delivered from the supply reserve point 3 to the distribution point 5. 110,000 emergency supplies will be delivered from the supply reserve point 4 to the distribution point 6, 360,000 emergency supplies to the distribution point 7, and 380,000 emergency supplies to the distribution point 8. 530,000 emergency supplies will be delivered from the supply reserve point 5 to the distribution point 3, 230,000 emergency supplies to the distribution point 5, and 670,000 emergency supplies to the distribution point 6.

As can be seen from Table 1, with the development of extreme conditions, the extreme conditions in the local areas of distribution points 1, 2, 3 and 4 have weakened, and the demand of emergency supplies has weakened. However, the extreme conditions in the local areas of distribution points 5, 6, 7 and 8 fluctuated, as did the demand of emergency supplies. With the time sequence evolution of extreme conditions, Model (2) is used to optimize resource allocation to ensure that there is no supply shortage at each supply reserve point, to meet the demand for power emergency supplies at each distribution point. The optimal dispatching scheme of supply reserve points is shown in Table 2. Each row in the table represents the quantity of supplies distributed by the supply reserve point represented by this row to other supply points, that is, the positive direction of optimal scheduling of supply reserve points. A positive number indicates delivery in the forward direction, and a negative number indicates delivery in the opposite direction.

Table 1. Demand of power emergency supplies at distribution points

| distribution point | 0  | 1  | 2  | 3  |
|--------------------|----|----|----|----|
| 1                  | 45 | 37 | 31 | 25 |
| 2                  | 47 | 26 | 11 | 2  |
| 3                  | 67 | 42 | 39 | 26 |
| 4                  | 42 | 33 | 28 | 21 |
| 5                  | 34 | 33 | 45 | 27 |
| 6                  | 78 | 51 | 105| 99 |
| 7                  | 36 | 31 | 24 | 19 |
| 8                  | 38 | 31 | 24 | 22 |

Figure 2. Optimal dispatching scheme of power emergency supplies
Table 2. Optimal dispatching scheme of supply reserve points

|   | 1  | 2  | 3  | 4  | 5  |
|---|----|----|----|----|----|
| 1 | -  | 0  | 11 | 7  | 37 |
| 2 | 0  | -  | 4  | 46 | 31 |
| 3 | -11| -4 | -  | 0  | 0  |
| 4 | -7 | -46| 0  | -  | 0  |
| 5 | -37| -31| 0  | 0  | -  |

With the development of the extreme conditions, in order to guarantee the demand of emergency supplies at distribution points, supplies need to be distributed from the supply reserve point where the extreme condition is relatively weakened to the supply reserve point where the extreme condition is relatively fluctuated: the supply reserve point 1 without carrying supplies to the supply reserve point 2, carrying 110000 emergency supplies to the supply reserve point 3, carrying 70000 emergency supplies to the supply reserve point 4, carrying 370000 emergency supplies to the supply reserve point 5. The supply reserve point 2 without carrying supplies to the supply reserve point 1, carrying 40000 emergency supplies to the supply reserve point 3, carrying 460000 emergency supplies to the supply reserve point 4, carrying 310000 emergency supplies to the supply reserve point 5.

5. Conclusion

To meet the optimal allocation of power emergency supplies in extreme conditions, a two-layer optimal dispatching model of power emergency supplies considering the time sequence evolution of extreme conditions is proposed, and the comprehensive learning particle swarm optimization is used to solve the optimal dispatching scheme, to ensure that the demand of emergency supplies at distribution points can be met. Finally, the example results show that the model can effectively ensure the demand of power emergency supplies at distribution points.

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