



# Study on the Dispatch Scheme of Power Emergency Materials Considering Road Failure

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**Abstract.** In recent years, large-scale power outages caused by major natural disasters have occurred from time to time, posing a challenge to the power grid disaster emergency response system. As a key link in the emergency response of power grid disasters, power emergency material dispatching needs to consider various uncertainties in the emergency repair process, such as the uncertainty of transportation time caused by road failures. Combining the multidisciplinary theoretical knowledge of operations research, engineering project management and logistics engineering, this paper divides the power emergency material dispatching model into three parts: using the DC power flow to calculate the electrical mediator and determine the priority of fault recovery; considering the uncertainty of the road fault caused by the road section, the improved Dijkstra algorithm is used to calculate the shortest path optimization; combining the above two aspects, based on the utility function, the power emergency material dispatch model with the minimum delay loss value as the goal is established, and the branch demarcation method is used to solve it. Ensure priority distribution of important transmission lines and nodes.

**Keywords:** Power Emergency · Road Failure · Material Dispatch · Utility Function

## 1 Introduce

In recent years, power system accidents caused by natural disasters have occurred from time to time, which has brought great harm to the safe operation of various types of power equipment and power grids. According to the “2017 National Electricity Reliability Annual Report” released by the state, power grid faults and power outages caused by natural disasters account for 30% of the national fault blackouts. At the same time, the larger the scale of power outages in the power grid, the smaller the probability of triggering large-scale power outages [1], it can be seen that natural disasters have become the main factor affecting the reliable operation of the power grid, and once the power system suddenly occurs natural disasters and is not dealt with in time, it will bring huge economic losses to the country and the people.

The power grid is a system composed of many devices and complex structures composed of generation, transmission, transformation, distribution and use, and undertakes

the reliable power supply for the country, enterprises and people. Due to the power supply interruption caused by natural disasters is different from ordinary power outage accidents, its development speed is fast, destructive, long duration, large impact area, resulting in disaster points are often not single, the time required to restore normal power supply is long and the demand for power emergency materials is large. Therefore, in addition to doing a good job of monitoring and early warning before the disaster, when a natural disaster occurs, according to the storage of materials near the disaster and the distribution of rescue personnel, a fast and efficient power grid disaster emergency material dispatch plan is formulated, emergency rescue is implemented, and the power grid is repaired in the shortest possible time to minimize the impact of natural disasters on the power grid.

## 2 Failure Recovery Priority

Studies have shown that the power grid is a typical complex network with small-world characteristics and scale-free characteristics, so complex network theory can be used to quantify the importance of transmission lines and nodes. This chapter selects the electrical mediator index to measure the importance of transmission lines and nodes, which can reflect the topology of the power grid and the flow of the power grid, which can lay the foundation for the establishment of the power emergency material dispatch model.

### 2.1 Complex Networks

In 1998, Watts and his mentor proposed the concept of a “small world network” on Nature [2], validating the small-world characteristics of the western U.S. power grid. The following year, Professor Barabási and his PhD students [3] proposed a scale-free network with robustness and vulnerability in Science and proved that the U.S. power grid was a scale-free network. As soon as these two articles were proposed, research on the application of complex grid theory to power grids mushroomed. Later, many scholars have proved that power networks belong to small-world networks and scale-free networks, which are of great value for the study of node and line importance and cascade faults of power systems.

In graph theory, the basic parameters that describe the characteristics of complex network topology mainly include the following:

- 1) Average path length: The average of the shortest path length between any two nodes in the network;

$$L = \frac{1}{n(n-1)} \sum_{i \neq j} d_{ij} \quad (1)$$

- 2) Number of node degrees: the number of all edges connected to the node;

- 3) Aggregation coefficient of nodes: indicates the degree of tightness of the connection between nodes;

$$C_i = \frac{2t_i}{k_i(k_i - 1)} \quad (2)$$

- 4) Edges: Describes the number of times an edge appears in the shortest path between any two nodes;

$$C_B(e) = \sum_{i \neq j} \frac{\sigma_{ij}(e)}{\sigma_{ij}} \quad (3)$$

- 5) Node Mediator [4]: Describes the number of times the node appears in the shortest path between all node pairs;

$$C_B(v) = \sum_{i \neq j} \frac{\sigma_{ij}(v)}{\sigma_{ij}} \quad (4)$$

Where,  $n$  is the number of nodes;  $k_i$  is the number of nodes adjacent to the node  $i$ ;  $\sigma_{ij}(e)$  is the number of bars through which the shortest path between the node  $i$  and the node  $j$  passes through the edge  $e$ ;  $\sigma_{ij}(v)$  of bars through which the shortest path between the node  $i$  and the node  $j$  passes through the node  $v$ ;  $\sigma_{ij}$  is the number of bars through which the shortest path between the node  $i$  and the node  $j$ .

Mediators are often used in communication networks to measure the importance of edges and nodes. The definition of edge and node mediators is described in Eqs. (3) and (4), wherein the larger the value of the intermeter, the greater the importance.

## 2.2 Grid Topology Model Based on Electrical Mediator

In the early days, when complex network theory was applied to power networks, bus-bars, generators, and loads were abstracted as nodes in the network, and high-voltage transmission lines were abstracted into edges in the network, forming a directionless and authorityless diagram. The conclusions obtained by using the directionless and authorityless diagram have certain guiding significance, but with the continuous deepening of research, its limitations are becoming increasingly prominent, mainly reflected in: (1) complex network theory believes that the functions of each node are equivalent, but in the power system, the functions of each node are different, there are power generation nodes, transmission nodes and load nodes; (2) electric energy can only flow from the power generation node to the load node, so it cannot simply use the undirectional graph to represent the power network; (3) In the actual power network, the electric energy does not only flow along the shortest path [5]. Instead, it follows Kirchhoff's law to flow through the entire network; (4) the weights of each edge in the grid topology are not the same, but are determined according to the actual situation, and there are two main common electrical quantities: branch impedance and power flow state. Therefore, in view of the above four deficiencies, this paper proposes the concept of electrical mediator based

on DC power flow, and uses directed weighted diagram to establish the corresponding grid topology model.

DC power flow is a non-precise power flow, which is characterized by not considering the size of reactive power, the nonlinear AC power flow of the power system is simplified to a linear DC circuit problem, so the voltage scale value of each node is 1, the operation speed is fast, but the accuracy is poor, suitable for due to the power system transmission line and node importance ranking and vulnerability assessment. The DC power flow matrix is expressed as follows:

$$P = B\theta \quad (5)$$

Where,  $B$  is the electric nano matrix of the power network nodes;  $\theta$  is the node voltage phase angle;  $P$  is the difference between the generated power and the load power. The above is a matrix with nodes as the main body, in order to directly find the size of the active power of each branch, it is necessary to transform the above formula as follows:

$$F = B_l \Phi \quad (6)$$

$$\Phi = A^T \theta \quad (7)$$

$$F = B_l A^T \theta = B_l A^T B^{-1} P = CP \quad (8)$$

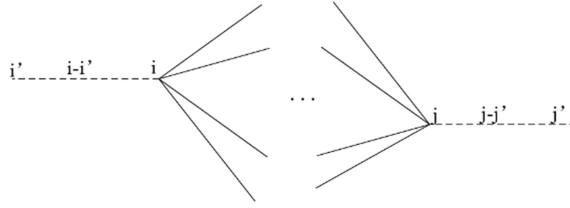
$$C = B_l A^T B^{-1} \quad (9)$$

Where,  $F$  is the active power column vectors for each branch;  $B_l$  is the branch conductive matrix;  $\Phi$  is a branch phase angle difference column vector converted by the phase angle of the node. The relationship between the  $\Phi$  and  $\theta$  can be derived from the correlation matrix  $A$ , as shown in Eq. (7). Therefore, Eq. (6) can be transformed to the Eq. (8)–(9). Matrix  $C$  are non-sparse computable constant matrices, as shown in Eq. (9).

Let the set of power generation nodes constitute  $G$ , the set of load nodes is  $L$ , through the above formula derivation, all possible power generation nodes and load nodes are performed the above operations, calculate the active power of each branch flow, and sum it, that is, the electrical mediator of the line, as shown in Eq. (10):

$$B_e(m, n) = \left| \sum_{i \in G, j \in L} w_{ij} P_{mn}(i, j) \right| \quad (10)$$

$$w_{ij} = \min(S_i, S_j) \quad (11)$$



**Fig. 1.** Added graph of virtual branches

$G$  is the set of power generation nodes;  $L$  is the set of load nodes;  $P_{mn}(i, j)$  is power generation-load node's share of the active power flowing on the line  $m$ - $n$ ; When the above operation is performed on different generation-load nodes, the flow direction of active power on the line may be different, and after summing, part of the active power will be offset, so the sum is first summed and then the absolute value is taken to conform to the flow of power in the power system.

Similar to the undirected and undecided diagram, in the directed sovereign diagram, for an intermediate transmission node, the magnitude of the power flowing into the node is equal to the size of the power flowing out of the node, so the electrical mediator of the transmission node is also half of the sum of the electrical media of the branch circuits connected to it [6, 7]. For power generation nodes and load nodes, the same as above also adopts the method of adding virtual nodes, as shown in Fig. 1.

After adding virtual nodes, the power generation node and the load node can be considered as intermediate nodes, so the electrical media number of all nodes is shown in Eq. (12):

$$B_e(k) = \begin{cases} \frac{1}{2} \left( \sum_{l \in F(k)} B_e(k, l) + \sum_{i \in L} w_{ki} \right), & k \in G \\ \frac{1}{2} \left( \sum_{l \in F(k)} B_e(k, l) + \sum_{i \in G} w_{ik} \right), & k \in L \\ \frac{1}{2} \sum_{l \in F(k)} B_e(k, l), & k \notin G, k \notin L \end{cases} \quad (12)$$

### 3 Shortest Path Optimization

Considering that in the actual distribution process of power materials, road failures may lead to uncertainty in transportation time, this chapter improves the traditional Dijkstra algorithm, and defines the shortest circuit time weight based on the three-point estimation method to find the shortest path of power emergency materials, laying the foundation for material scheduling.

### 3.1 Three-Point Estimation

Since natural disasters may cause partial road failures, resulting in uncertainty in the time of power emergency material transportation, this section introduces the three-point estimation method in “Engineering Project Management” to calculate the power emergency material dispatch time expectation, and uses it as the weight of the traffic network map to solve the shortest path of power material dispatch under the condition that the transportation time is uncertain due to road failure.

The three-point estimation method is an abbreviation for the full name of the Program Evaluation and Review technique. In the form of a network diagram, this method introduces the most optimistic, most pessimistic and most likely time to estimate the duration of the work, which can improve the accuracy of the event duration estimation. The three types of time are defined as:

- $t_o$ —The best estimated duration
- $t_p$ —The worst estimated duration
- $t_m$ —The most possible estimated duration

Based on the above three times, the available formula (13) estimates the duration of the activity:

$$t_e = \frac{t_p + 4t_m + t_o}{6} \quad (13)$$

### 3.2 Improved Dijkstra Algorithm

In addition to the three-point estimation method, this paper considers the complex scenario of road failure and emergency repair process to take into account that the topology of the distribution network and the shortest path change over time.

Due to the severity of the disaster and the different traffic environment, the roads in the affected area will be damaged to varying degrees, so this paper divides the road failure sections into normal road sections, partially failed road sections and completely failed road sections according to the degree of road failure. Normal road section refers to the normal road that has not been affected by the disaster; partially failed road section refers to the road less affected by the disaster, if the road section is driven to the two vertices of the road section, the repair team has not yet finished the repair, then it will move slowly at a certain speed; the completely invalid road refers to the entire road section is greatly affected by the disaster, and must wait at the apex to complete the repair before continuing to move forward. When considering a road fault condition, you need to change the time update rule in the traditional Dijkstra algorithm [8], is shown in Fig. 2.

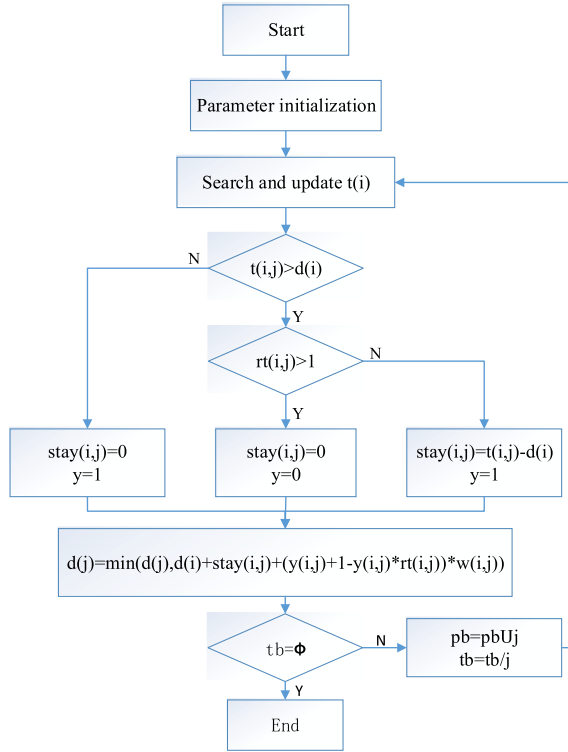


Fig. 2. Improved Dijkstra algorithm flowchart

## 4 Power Emergency Material Dispatch Model

The calculations in Sects. 2 and 3 provide the priority of fault recovery and the shortest path from the point of supply of emergency supplies to the disaster site. In addition, the establishment of emergency plans for power systems also needs to solve the problem of how to reasonably dispatch emergency materials at supply points. In order to solve the above problems, this chapter combines the utility function in economics with the power system nodes and line priorities based on electrical mediators calculated in Sect. 2, and calculates the shortest path based on Sect. 3, establishes a power emergency material dispatch model [9] with the goal of minimizing time delay loss, and solves the power system emergency dispatch scheme.

### 4.1 Variable Definitions and Constraints

- $i$ : the supply point of emergency supplies
- $j$ : the demand point for emergency supplies
- $S_i$ : the quantity of goods stored at the point of  $i$
- $D_j$ : the demand points  $j$  of emergency supplies
- $t_{ij}$ : the time from supply point  $i$  to demand point  $j$

$t_0$ : the emergency limit time

$x_{ij}$ : the quantity of goods transported from the point of supply to the point of demand

In the above variable definition, the following constraints are included:

$$\begin{cases} \sum_j x_{ij} \leq S_i, \forall i \in I \\ \sum_i x_{ij} \leq D_j, \forall j \in J \\ \sum_i \lambda_{ij} \cdot x_{ij} > 0, \forall j \in J \\ x_{ij} \geq 0, x_{ij} \in Z, \forall i \in I, j \in J \end{cases} \quad (14)$$

## 4.2 Delay Consequence Model Based on Utility Functions and Priorities

“Utility” is one of the most commonly used concepts in economics and is often used to measure the maximum satisfaction of a decision maker’s needs. For the specific scenario of emergency material dispatch of power system, “utility” refers to the quantification of the decision-maker’s satisfaction with the power emergency material dispatch plan. In general, in the process of dispatching power emergency materials, the two goals of time and cost of materials from the supply point to the disaster site are mainly considered. After the occurrence of major natural disasters, due to the urgency of the emergency time of the power system, the cost is not worth mentioning relative to the time, so only the time is considered.

The literature has established an exponential utility function to describe the consequence severity model of the delay of material transfer, because the difference between the data is too large, resulting in inaccurate results, so this paper selects the power function to construct the utility function, as shown in Eq. (15),  $\beta$  is a reduced factor, which can reflect the decision maker’s avoidance of the scheme of large scheduling delay, and can avoid the data error caused by too large data difference.

$$\alpha(t_{delay}) = \beta t_{delay}^2 = \beta (t_{ij} - t_0)^2 \quad (15)$$

In order to distribute power emergency supplies to more important nodes in a faster and more timely manner, introduces the normalized electrical mediator  $\chi_j$  calculated earlier, so formula (15) can be improved to:

$$S(t_{ij}, \chi_j) = \chi_j \beta (t_{ij} - t_0)^2 \quad (16)$$

For specific power emergency materials, the amount of material distribution from the material supply point to the disaster point and the actual transfer time also have an impact on the delay loss value of the transfer, and the objective function can be defined as:

$$\begin{aligned} R(\xi) &= \sum_i \sum_j S(t_{ij}, \chi_j) \cdot \lambda_{ij} \cdot x_{ij} \\ &= \sum_i \sum_j \chi_j \cdot \beta \cdot (t_{ij} - t_0)^2 \cdot \lambda_{ij} \cdot x_{ij} \end{aligned} \quad (17)$$



When the material transportation time is less than the emergency limit time, it means that it will not cause delay losses,  $\lambda_{ij} = 0$ ; otherwise,  $\lambda_{ij} = 1$ .

In summary, the power emergency material dispatch model is as follows:

$$\begin{aligned} \min R(\xi) &= \sum_i \sum_j \chi_j \cdot \beta \cdot (t_{ij} - t_0)^2 \cdot \lambda_{ij} \cdot x_{ij} \\ s.t. &\begin{cases} \sum_j x_{ij} \leq S_i \\ \sum_i x_{ij} \leq D_j \\ \sum_i \lambda_{ij} \cdot x_{ij} > 0 \\ x_{ij} \geq 0, x_{ij} \in Z \end{cases} \end{aligned} \quad (18)$$

### 4.3 Study Analysis

This study abstracts the disaster points, transit points and power reserve points as nodes, and the roads between the three as edges, as shown in Fig. 3, if the nodes are directly connected, it means that they can be reached directly, otherwise they need to go through the intermediate nodes to reach.

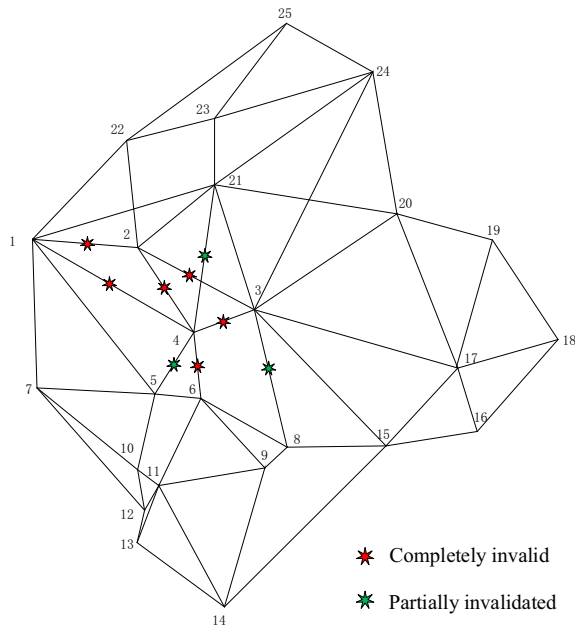
According to the disaster situation and road failure situation in various places, nodes 1 to 5 are selected as disaster points, nodes 14, 18 and 25 are selected as power emergency material reserve points, and the remaining nodes are transit nodes, regardless of their material needs. The shortest path optimization model based on road fault established in Sect. 3 is now used to solve, and the road fault situation and the required repair time are shown in Table 1.

Using the IEEE-14 node standard study in Sect. 2, the failure recovery priority factor of each node is used as the initial condition, and 5 of the nodes are selected to normalize them, as shown in Table 1. In addition, the material requirements for each node can also be obtained in Table 2.

Natural disasters caused a total of nine roads to varying degrees, including three partially failed sections and six completely failed sections. This example considers that the road fault repair time and the delivery time of power supplies start at the same time. When the power material dispatch vehicle transport materials arrive at a faulty road section, if the arrival time is greater than the road section repair time, it means that the faulty road section has returned to normal state, and the driving time of the road section is not affected; on the contrary, if the arrival time is less than the road section repair time, it means that the road section is in a fault state, for the completely failed road section, the degree of damage is large, the vehicle is not allowed to move forward slowly, and it can only wait for the end of the emergency repair at the node to continue to move forward, for some of the failed road sections, the degree of damage is small, Allow the vehicle to move slowly at  $rt(i, j)$  the original speed.

Table 3 shows the shortest travel path and time from each material reserve point to each disaster point obtained using the improved Dijkstra algorithm.

As known from Table 3, for the disaster point 1, the minimum travel time from the material reserve point 25 to the disaster point via the 22 transit point is 506 min; for the



**Fig. 3.** Transportation network topology diagram

**Table 1.** Road failure conditions

path	Repair time	Degree of failure	rt(i,j)
1-2	400	Completely invalid	1
1-4	600	Completely invalid	1
2-3	500	Completely invalid	1
2-4	500	Completely invalid	1
3-4	400	Completely invalid	1
3-8	400	Partially invalidated	2
4-5	600	Partially invalidated	2
4-6	450	Completely invalid	1
4-21	400	Partially invalidated	2

disaster point 2, the material reserve point 25 is the shortest travel time to the disaster point via route 23-21, which is 430 min; for the disaster point 3, the travel time from the material reserve point 18 and 25 to the disaster point is equivalent, 478 and 477 min, respectively; for the disaster point 4, the above three material reserve points 14, 18, The driving time of 25 to reach the disaster point through the transit point is not much different, of which 14 reserve points take the shortest time; for the disaster point 5, the minimum travel time from the material reserve point 14 to the disaster point via

**Table 2.** Priority and material requirements of each disaster point

disaster point	Priority	material requirements
1	0.6490	90
2	0.3264	60
3	1	120
4	0.9046	100
5	0.4289	80

**Table 3.** Shortest driving path

Material reserve points	disaster point	Shortest driving path	Minimum travel time
14	1	14-11-10-5-1	663
14	2	14-11-6-4-2	703
14	3	14-15-3	630
14	4	14-11-6-4	550
14	5	14-11-10-5	365
18	1	18-19-20-21-1	838
18	2	18-17-3-2	700
18	3	18-17-3	478
18	4	18-17-3-4	576
18	5	18-17-15-8-6-5	688
25	1	25-22-1	506
25	2	25-23-21-2	430
25	3	25-23-21-3	477
25	4	25-23-21-3-4	575
25	5	25-23-21-3-4-6-5	745

11-10 transit is 365 min. It can be seen that the minimum driving time from each power emergency material reserve point to each disaster point varies greatly. In order to make the material dispatch more efficient, it is necessary to combine the fault recovery priority of the second chapter solution to efficiently distribute the power supply.

The reserves of each power emergency material reserve point can be found in Table 4.

According to the power material dispatch model established in Sect. 4, and the branch demarcation method is used to solve it, the quantity of emergency materials dispatched from each power material reserve point to each disaster point can be obtained as shown in Table 5.

Without considering the priority of fault recovery, using the branch demarcation method to solve it, the quantity of emergency materials dispatched by each power reserve point to each disaster point can be obtained as shown in Table 6.

Comparing the two cases, considering the failure recovery priority, the delay loss value  $R(\xi_1) = 6.6718e5$ , without considering the priority  $R(\xi_1) = 8.0973e5$ , the two comparison, considering the failure recovery priority can greatly reduce the delay loss and accelerate disaster recovery.

Comprehensive Tables 3 and 5, it can be obtained that the power supply comprehensive emergency plan for the occurrence of the above specific accidents in the power grid is shown in Table 7, first considering the disaster point 3 with the largest fault recovery priority, which can be distributed by 18 and 25 reserve points, and the driving time difference is only 1 min. Since the travel time from material reserve point 25 to disaster points 1 and 2 is the shortest, but the disaster point 1 is higher than 2 fault recovery priority, so the power emergency materials of the disaster point 1 are all distributed by

**Table 4.** Reserves of each power material reserve point

Supply points	14	18	25
Material reserves	120	200	130

**Table 5.** The number of power emergency material dispatches when the fault priority is considered

$x_{ij}$	1	2	3	4	5
14	0	0	0	40	80
18	0	20	120	60	0
25	90	40	0	0	0

**Table 6.** The number of dispatched power emergency materials when failure priority is not considered

$x_{ij}$	1	2	3	4	5
14	20	0	0	20	80
18	0	0	120	80	0
25	70	60	0	0	0

**Table 7.** Electricity Emergency Supplies Program

Material points	14		18		25	
Failure point	Shortest driving path	Number	Shortest driving path	Number	Shortest driving path	Number
1	14-11-10-5-1	0	18-19-20-21-1	0	25-22-1	90
2	14-11-6-4-2	0	18-17-3-2	20	25-23-21-2	40
3	14-15-3	0	18-17-3	120	25-23-21-3	0
4	14-11-6-4	40	18-17-3-4	60	25-23-21-3-4	0
5	14-11-10-5	80	18-17-15-8-6-5	0	25-23-21-3-4-6-5	0

the reserve point 25, and the disaster point 2 is distributed by the reserve point 18 and 25, so the size of the delay loss value is comprehensively considered, and the materials at the disaster point 3 are distributed separately by the reserve point 18. The minimum travel time difference between each material reserve point and the disaster point 4 is small, so consider the disaster point 5 first, and its power emergency materials are distributed by the reserve point 14, and finally, the emergency materials at the disaster point 4 are selected to be distributed by the 14 and 18 reserve points at the same time. It can be seen that the power emergency material scheme ensures the priority distribution of important transmission lines and node failures when considering road failures.

## 5 Conclusion

Combining the multidisciplinary theoretical knowledge of power system analysis, operations research, engineering project management and logistics engineering, this paper divides the solution of power emergency material dispatch scheme into three processes: the determination of fault recovery priority, the optimal path of road fault is considered, the power emergency material dispatch model is established based on the utility function with the minimum delay loss value as the goal, and the branch demarcation method is used to solve it to ensure the priority distribution of important transmission lines and nodes.

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