The allocation scheme of distribution network’s emergency service stations based on feeder fault prediction results

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Abstract. In order to solve the problems of low efficiency and long time consuming to determine the location scattering of distribution network emergency service stations on account of geometric shortest path method, this paper proposes an optimal allocation scheme of distribution network emergency service stations based on feeder fault prediction results. In this method, the weight of feeder fault level is fully considered by constructing the optimization model of emergency service station in accordance with the prediction results of feeder fault, and the process parameters such as path congestion factor, path obstacle factor, feeder bending and twisting factor, weather influence factor and average speed of rush repair vehicles are applied to the location optimization model of emergency service station. Compared with the original method, this model can obtain the total time which significantly shortens the road time of rush repair, and leaves as much free time as possible for the subsequent fault repair stage.

1. Introduction

Nowadays, there are more equipment connected with the distribution network, and its topology structure is also various, which can easily lead to the occurrence of user power failure. If the distribution network fault cannot be removed in time, it will lead to a larger range of blackouts. The importance of distribution network, the complexity of its network structure and load, and the probability of multiple fault events make the task of distribution network fault repair more challenging and practical [1-3]. The effect and efficiency of distribution network fault repair work directly affects the power supply reliability and the service quality of State Grid. Choosing the appropriate location of emergency service station can effectively improve the efficiency of emergency repair and reduce the loss caused by power failure [4-6].

At present, the main methods which are to optimize the allocation of fault repair work, reasonable allocation of repair resources, optimization of repair path, increase fault recovery rate and so on. For example, the distribution network emergency repair model coming from the fuzzy evaluation method is used to predict the future emergency repair data based on the historical repair data, and establish the emergency repair plan. Then the fuzzy evaluation method is used to summarize each repair plan, which provides theoretical support for the construction of distribution network emergency repair data platform. According to the characteristics of the road network, the number of fault points and the demand for repair are analyzed; in this scheme, the mode of multi warehouse coordination is established for 10kV distribution network instead of for 380V low-voltage power grid. The above research content provides some constructive ideas for the research of emergency repair resource allocation strategy, but the actual operability is quite limited due to the limitation of determining the
location of distribution network emergency repair stops connected with geometric shortest path method [7-9].

In this paper, the establishment of a distribution network emergency service station location’s allocation scheme based on the feeder fault prediction results has been suggested.

2. Establishment of optimization model for location of emergency service stations

2.1. Calculation method of distance between emergency service stations and feeders

In order to quantitatively express the interval between the emergency service station \( P_\eta \) and each feeder line, each feeder line can be regarded as a particle \( F_\mu \) with the same utility in two-dimensional coordinate system, then the interval between the emergency service station and the feeder is equivalent to the interval utility between the emergency service station and the feeder particle; according to the monthly failure rate of the feeder predicted by the historical data, the fault coordination factor \( f_\mu \) of the feeder line is determined [10]. In order to reduce the total time spent on rush repair and save enough time for follow-up repair. For a definite scope of emergency repair, if it is necessary to set \( m \) emergency service stations, the number of feeder equivalent points is defined as \( n \), and denotes the number of emergency service station and feeder equivalent point respectively, where \( \eta = 1, 2, 3, 4... m \), \( \mu = 1, 2, 3, 4... n \). \( P_\eta = (x_\eta, y_\eta) \) and \( F_\mu = (\varphi_\mu, \upsilon_\mu) \) are the geographical location coordinates of the emergency service station and the fault point in the two-dimensional space, and \( G_{\eta\mu} \) represent the geometric interval from the first fault point \( \mu \) to the first emergency service station \( \eta \). Thus, the calculation method to obtain the feeder from the emergency service station is as follows,

\[
G_{\eta\mu} = f_\mu \sqrt{(x_\eta - \varphi_\mu)^2 + (y_\eta - \upsilon_\mu)^2}
\]

(1)

Where, \( \sqrt{(x_\eta - \varphi_\mu)^2 + (y_\eta - \upsilon_\mu)^2} \) means Euclidean measure between \( P_\eta \) and \( F_\mu \).

2.2. Calculation of rush repair travelling time

According to the process of emergency repair, the congestion factors are \( \sigma \); path obstruction factor \( \varsigma \); feeder bending and twisting factor \( \rho \); weather influence factor \( \delta \); the average speed of rush repair vehicle is \( v \). In this way, the calculation method of the time spent in rush repair of the feeder line from the stationary point is obtained,

\[
T_{\eta\mu} = \frac{G_{\eta\mu} \cdot \sigma \cdot \varsigma \cdot \rho \cdot \delta}{v}
\]

(2)

2.3. Calculation of the maximum time for rush repair

The time of rush repair along the way shall meet the promise time \( T_{\text{max}} \) range of the power grid to the society, and its range is 40mins in the urban area and 60mins in the suburb. If the fault report acceptance time of State Grid Dispatching Center is \( T_1 \), the management scheduling and troubleshooting time is \( T_2 \), the attendance preparation time of motor vehicles is \( T_3 \), and the addressing time of maintenance team is \( T_4 \), then the calculation method of the maximum time \( T_{\text{big}} \) spent along the emergency service station to the feeder is determined [11].

\[
T_{\text{big}} = T_{\text{max}} - T_1 - T_2 - T_3 - T_4
\]

(3)

2.4. Optimization model of emergency repair service stations

Assuming that the geometric interval between the feeder line \( \mu \) and the emergency service station \( \eta \) meets the time allowed by the State Grid, then \( R_{\eta\mu} = 1 \), if not \( R_{\eta\mu} = 0 \), then the responsible feeder line is divided for the emergency service station, and the relevant feeder area of the emergency service
station is determined. If any emergency service station corresponds to a single feeder line, a
mathematical model for optimizing the location of emergency service station can be established.

\[ \text{MinG} = \sum_{\eta=1}^{n} \sum_{\mu=1}^{m} D_{\eta\mu} \cdot R_{\eta\mu} \]  

(4)

The eigenvalue function \( \text{MinG} \) shows that the sum of the intervals of the emergency service
stations arriving at their respective areas of responsibility is the minimum.

The constraints (4) of the optimal plan for the location of emergency service station are as follows:
1) Time limit

\[ T_{\eta\mu} \leq T_{\text{Big}} \]  

(5)

Formula (5) shows the restraint time of repairing workers along the way to the failure point.
2) Feeder is subject to the limit of emergency service station.

\[ \sum_{\eta=1}^{n} \sum_{\mu=1}^{m} R_{\eta\mu} = m \]  

(6)

Where, \( m \) is the number of feeders and \( n \) is the number of emergency service stations. Equation (6)
is the binding condition of feeder repair tasks accepted by \( n \) emergency service stations.

3. Application results and discussion

3.1. Longitude and latitude of feeder utility equivalent point and monthly fault frequency

Firstly, the midpoint of each feeder is determined as the utility equivalent point, and then the
monthly fault frequency of each feeder is predicted according to the historical data. In each random
experiment, 70% of the data set was randomly selected as training samples and 30% as test samples.
All experiments were carried out in Python environment, and the longitude and latitude of each feeder
and the predicted monthly fault classification (more than 5 times for class A, 2-5 times for class B, 0-1
time for class C) were filled partially in Table 1.

Figure 1 is the longitude and latitude distribution diagram of feeder utility equivalent points in the
area of the service station according to Table 1, and is represented by three different symbols of A, B
and C according to different fault levels. As can be seen from Figure 1, type A faults are mainly
distributed in the lower right part of the service station area, type B faults are mainly distributed in the
middle part, and type C faults are more evenly distributed in the whole service station of responsible
area.

| Feeder | Longitude | Latitude | level | Feeder | Longitude | Latitude | level |
|--------|-----------|----------|-------|--------|-----------|----------|-------|
| 1      | 121.51817 | 31.32856 | A     | 5      | 121.51782 | 31.31078 | B     |
| 2      | 121.52385 | 31.32675 | A     | 6      | 121.52468 | 31.33691 | C     |
| 3      | 121.51352 | 31.36930 | C     | 7      | 121.52328 | 31.31584 | C     |
| 4      | 121.53461 | 31.31480 | B     | 8      | 121.51776 | 31.33922 | C     |

3.2. Optimize the location of emergency service station

Figure 2 is a mathematical model and its eigenvalue function for optimizing the location
of emergency service stations. According to figure 2, the location optimization method based
on feeder fault prediction results makes the new emergency service station more close to the
utility equivalent point of the feeder with high fault level in recent months, so the new
emergency service station is more effective than the original service station (geometric center).
The emergency repair efficiency has been significantly improved. In the calculation example,
the total monthly rush repair time of the urban area before and after the optimization is
2212.75mins and 1885.26mins respectively, which means that the total monthly time spent on
rush repair is reduced by 14.8%.
4. Conclusion

In this paper, according to the geographical distribution of power fault points and the historical situation of fault repair, the address of emergency service station is optimized to improve the efficiency of emergency repair, so as to restore power supply as quickly as possible. In this method, the weight of feeder fault level is fully considered by constructing the optimization model of emergency service station based on the prediction results of feeder fault, and the process parameters such as path congestion factor, path obstacle factor, feeder bending and twisting factor, weather influence factor and average speed of rush repair vehicles are applied to the location optimization model of emergency service station.

By comparing with the distribution network emergency service station’s location allocation scheme without fault prediction results, it is proved that the location optimization based on feeder fault prediction results can greatly shorten the average arrival time from service station to fault point, and leave as much free time as possible for the subsequent fault repair stage, so as to improve the work efficiency of distribution network fault repair and optimize the resource allocation.

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