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Optimal Resources Dispatching Technology of Distribution Network Rush-Repairing

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Abstract

Confronted with the requirement of higher efficiency and higher quality of distribution network fault rush-repair, the subject addressed in this paper is the optimal resource dispatching issue of the distribution network rush-repair when single resource center cannot meet the emergent resource demands. A multi-resource and multi-center dispatching model is established with the objective of "the shortest repair start-time" and "the least number of the repair centers". The optimal and worst solutions of each objective are both obtained, and a "proximity degree method" is used to calculate the optimal resource dispatching plan. The feasibility of the proposed algorithm is illustrated by an example of a distribution network fault. The proposed method provides a practical technique for efficiency improvement of fault rush-repair work of distribution network, and thus mostly abbreviates power recovery time and improves the management level of the distribution network.

Keywords

Distribution Network; Rush-Repairing; Multi-Objective and Multi-Resource Dispatching; Proximity Degree Method

1. Introduction

The power recovery efficiency of the power grid depends on the matching degree between the damage of the power grid and the rush-repair capability. The rush-repair capability of the power gird depends on the repair resource reserves, field circumstance and the dispatching capability. The resource reserves are fundamental to the rush-repair work. And the resources dispatching technology is critical for the fast recovery to meet with the requirement of the distribution network fault rush-repair [1]-[5].

When the power grid is facing with the continuous or extensive attack, such as severe weather or geological disaster, rush-repair crew will be very busy and the repairing resource might not be able to meet with the emergency resource demands.

In a rush-repair work, when the repair resources are insufficient in local resource center, the decision-maker relies on his previous experience to command. It might be very difficult for them to make an optimal decision under the condition that there are various kinds of resource demands form distributed resource centers, which

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implies that it is hard to make an optimal decision. Besides, there is not evaluation criterion for the decision made by the commander until the rush-repair work is done. In this paper, a reasonable evaluation criterion and corresponding techniques for the decision making are studied to figure out the optimal resource dispatching plan.

2. Modelling for Resource Dispatching

2.1. The Resource Dispatching Process

When a power outage event happen in the power grid, the rush repairing command center analyzes the outage cause based on the information from DSCADA, electricity usage data acquisition system, 95,598 customer service system, and etc.. According to the fault analysis, the command center recognizes the needed type and amount of the repair resources and then sends dispatching order to the resource centers. The dispatching process is shown in **Figure 1**.

2.2. Resource Dispatching Modelling

Sufficient repair resources are the fundamental requirement for the distribution network rush-repairing. In a rush-repair work, there will be n involved resource centers, which are notated as $A_1, A_2, \cdots, A_n$. Meanwhile, there will be m (m > 1) types of repair resources needed in fault location A. The types of resources are notated as $X_1, X_2, \cdots, X_{\mathrm{m}}$, and the amount needed for every resource is $x_1, x_2, \cdots, x_m$, respectively. x_{ij} and x'_{ij} is assumed to be the resource reserve and supplying amount of the j^th^ type of resource from the i^th^ resource center, in which $1 \le i \le n$, $1 \le j \le m$ and $\sum_{i=1}^{n} x_{ij} \ge x_j$. The delivery time from A_i to A is t_i ($t_i > 0$), assuming $t_1 \le t_2 \le \cdots \le \mathrm{t}_n$. The optimal resource dispatching plan implies that the start-time of the rush-repairing work is shortest and the number of involved resource centers is minimized.

Assuming the optimal plan is φ, which is specified as

$$\varphi = \{\varphi_1, \varphi_2, \cdots, \varphi_m\} \tag{1}$$

where, $\varphi_j = \left\{\left(A_{\mathrm{d}_1}, x'_{\mathrm{d}_1 j}\right), \left(A_{\mathrm{d}_2}, x'_{\mathrm{d}_2 j}\right), \cdots, \left(A_{\mathrm{d}_\mathrm{k}}, x'_{\mathrm{d}_\mathrm{k} j}\right)\right\}$ represents the rush-repairing plan for the j^th^ resource.

If the selected resource center $d_1, d_2, \cdots, d_k$ from all of n centers satisfy the demand of the j^th^ resource, we have

$$\sum_{i=1}^{k} x'_{d_i j} = x_j, \ (j = 1, 2, \cdots, m) \tag{2}$$

where, $x'_{\mathrm{d}_1 j}, x'_{\mathrm{d}_2 j}, \cdots, x'_{\mathrm{d}_k j}$ are the supplying amount of the j^th^ resource from the selected resource centers, separately. The set of all the dispatching plans is Ω.

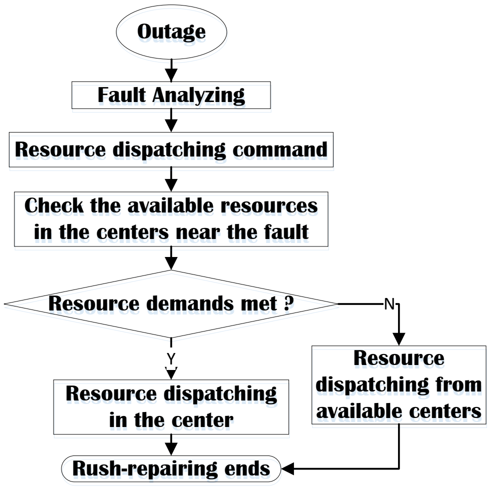

Figure 1. Rush-repair process.

Definition 1: The number of the selected resource centers is $N(\varphi)$ and the start-time of the rush-repair work is $T(\varphi)$, which implies that all the needed repair resources arrive at the fault location in $T(\varphi)$ with their demand satisfied. Thus,

$$T(\varphi) = \max(t_i), \quad i = d_1, d_2, \cdots, d_k \tag{3}$$

The objective of the resource dispatching is to minimize the start-time of the rush-repair work and the number of the resource centers involved. That is

$$\left.\begin{array}{l} \min(T(\varphi)) \\ \min(N(\varphi)) \\ st.\varphi \in \Omega \end{array}\right\} \tag{4}$$

The Equation (4) is a multi-target decision-making problem which can be solved by the technique of order preference by similarity to ideal solution. Therefore, the positive distance and the negative distance to the ideal solution can be worked out from the two following objective functions.

$$\left.\begin{array}{l} \min(T(\varphi)) \\ st.\varphi \in \Omega \end{array}\right\} \tag{5}$$

$$\left.\begin{array}{l} \min(N(\varphi)) \\ st.\varphi \in \Omega \end{array}\right\} \tag{6}$$

Assume $\underline{\varphi}''$, $\overline{\varphi}''$ is the best and worst solution of the Equation (5), separately. And $\underline{\varphi}'$, $\overline{\varphi}'$ is the best and worst solution of the Equation (6), separately. The proximity degree between a dispatching plan φ_v and the best solution can be expressed as:

$$R_v = \omega_1 \frac{N(\underline{\varphi}')}{N(\varphi_v)} + \omega_2 \frac{T(\underline{\varphi}'')}{T(\varphi_v)} \tag{7}$$

Similarly, the proximity degree between the plan φ_v and the worst solution can be expressed as:

$$r_v = \omega_1 \frac{N(\varphi_v)}{N(\overline{\varphi}')} + \omega_2 \frac{T(\varphi_v)}{T(\overline{\varphi}'')} \tag{8}$$

In the Equation (8), ω_1 and ω_2 are the weight of "the number of the resource center" and "the start-time of the rush-repair work", separately, and $\omega_1 + \omega_2 = 1$. The specific value can be obtained by specialists. In this paper, both of them are 0.5. The relative proximity degree between the plan φ_v and the ideal solution can be expressed as follows:

$$\varepsilon_v = \frac{R_v}{R_v + r_v}, \quad 0 \le \varepsilon_v \le 1 \tag{9}$$

Therefore, the multi-objective decision-making problem can be translated to the proximity degree problem between the suggested solution and the ideal solution. The solution which obtains the maximal proximity degree ε_v is optimal [6].

3. The Solution to the Resource Dispatching Problem

$N(\underline{\varphi}''), N(\overline{\varphi}'')$ and $T(\underline{\varphi}''), T(\overline{\varphi}'')$ should be solved firstly for the Equations (7)-(9).

3.1. The Solution to the $T(\underline{\varphi}''), T(\overline{\varphi}'')$

The resource centers involved should be near enough to make sure that the start-time of the rush-repair work is as earlier as possible.

Assume the resource centers $A_1, A_2, \cdots, A_n$ are ranked by the delivery time to the fault location from shortest to longest.

If

$$\sum_{p=0}^{q_j-1} x_{pj} < x_j \le \sum_{p=0}^{q_j} x_{pj},$$

where $x_{0j} = 0$, the optimal dispatching plan for the j^{th} resource with the objective of the shortest delivery time can be expressed as:

$$\varphi'_j = (A_1, x_{1j}), (A_2, x_{2j}), \cdots, (A_{q_j}, x_j - \sum_{p=0}^{q_j-1} x_{pj}) \tag{10}$$

Thus, t_{q_j} which is the delivery time of the j^{th} resource from the resource center A_{qj} to the fault location, is the shortest delivery time for the j^{th} resource.

Similarly, the shortest delivery time for the other resources can be obtained. And the best solution to the Equation (5) is $\varphi' = \{\varphi'_1, \varphi'_2, \cdots, \varphi'_m\}$.

Therefore

$$T(\underline{\varphi}'') = \max(t_{q_1}, t_{q_2}, \cdots, t_{q_m}) \tag{11}$$

And

$$T(\underline{\varphi}'') \le T(\varphi) \le t_n \tag{12}$$

Notice that the longest delivery time is t_n, that is:

$$T(\overline{\varphi}'') = t_n \tag{13}$$

3.2. The Solution to the $N(\underline{\varphi}'), N(\overline{\varphi}')$

Similar to Section 3.1, assume the resource centers $A_1, A_2, \cdots, A_n$ are ranked by the resource reserve of the j^th^ resource from least to most.

The optimal dispatching plan for the j^{th} resource with the objective of the least number of the involved resource centers can be expressed as:

$$\varphi_j = \left\{ (A_{k_1}, x_{k_1 j}), (A_{k_2}, x_{k_2 j}), \cdots, (A_{k_{p_j}}, x_j - \sum_{i=1}^{p_j-1} x_{k_i j}) \right\} \tag{14}$$

where, p_j is least number of the involved resource centers for the j^{th} resource.

Therefore, the least number of the involved resource centers of the rush-repair work is

$$N_{\max} = \max(p_1, p_2, \cdots p_m) \tag{15}$$

And for every dispatching plan φ,

$$N_{\max} \le N(\varphi) \le n \tag{16}$$

3.3. The Solution to the Dispatching Problem

In the resource dispatching optimization problem, not only the number of the involved resource centers is considered to be as small as possible, but also the start-time of the rush-repair work should be as early as possible. Therefore, the dispatching plan whose relative proximity degree ε_v is the biggest is taken as the optimal solution.

The calculation steps of the ε_v are as follows:

Step 1: Work out $N_{\max}$, $T(\underline{\varphi}''), T(\overline{\varphi}'')$;

Step 2: Let the set R = { $A_1, A_2, \cdots, A_n$ } be the group of the repair centers, $n' = N_{\max}$ and the serial number y = 0;

Step 3: Select combinations of n' centers from the set R. If there is not a combination feasible, go to step 9;

Step 4: Let y = y + 1, Select the combination φ_v whose start-time $T(\varphi_v)$ is shortest from all of the available feasible combinations;

Step 5: Let $N(\varphi_v) = n'$, and if y = 1, let $N(\underline{\varphi}') = N(\varphi_v)$ and $N(\overline{\varphi}') = n$;

Step 6: According to the Equation (7) and (8), calculate the proximity degree of between φ_v and the ideal solution;

Step 7: Obtain the ε_y by Equation (9), and figure out the dispatching plan φ_y^*;

Step 8: Modify the set R by deleting the repair centers whose start-time t_i is longer than $T(\varphi_v)$;
Step 9: Let $n' = n' + 1$;
Step 10: If the length of the set R is larger than n', go to step 3; or else, go to step 11;
Step 11: Compare the obtained ε_y, and the largest one is optimal
The flow chart of the algorithm is shown in **Figure 2**.

4. Case Study

In this study case, the distribution power grid was affected by storm. Based on GIS technology, the rush-repairing center confirmed that the fault location is A. The dispatching plan of the required repair resources should be optimized to ensure the efficient of the rush-repair work.

In this rush-repairing, 32*insulator (XPW-7)\25*pole (18 m) and 36*Cross Arm (1 meter) are required.

There are eight available resource centers near fault location A, and their resource reserves are shown in **Table 1**.

The weights ω_1 and ω_2 are set to be 0.5. As is shown in **Table 2**, the biggest relative proximity degree is 0.6364 (y = 3). Therefore, the third dispatching plan whose start-time is 15 minutes is the optimal one.

The delivery time for every center is 10, 12, 14, 15, 20, 22, 25 and 30 minutes, separately.

Follow the algorithm proposed in this paper, the calculation results are shown in **Table 2**.

The details of the optimal plan are shown in **Table 3**.

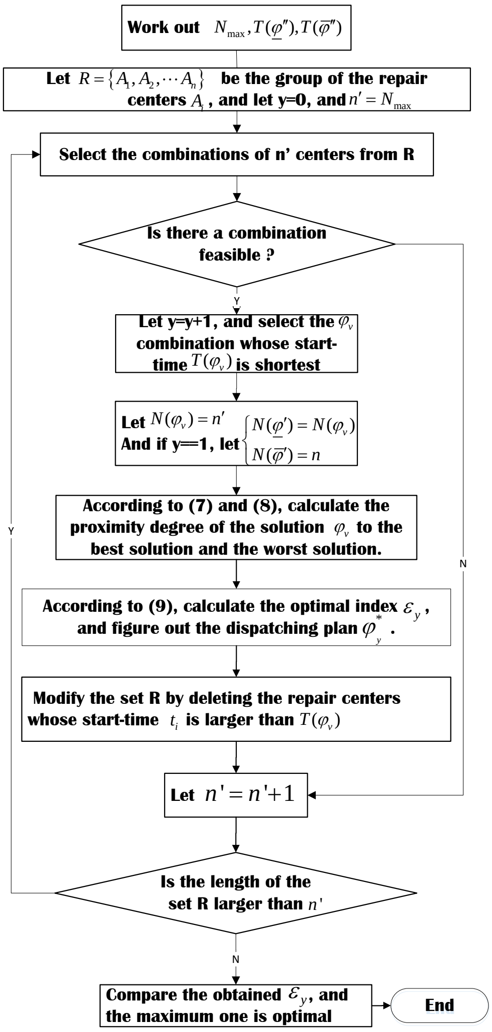

Figure 2. The flow chart of the resource dispatching.

Table 1. The resource reserves.

Resource	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Insulator	12	5	10	9	9	6	24	7
Pole	10	8	4	12	4	15	10	5
Cross Arm	12	16	5	7	9	12	20	14

Table 2. Calculation results.

y	R	N'_y	ϕ_y	n'	t	ε_y
1	$A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8$	unfeasible		2		
2	$A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8$	A_1, A_2, A_7	$(A_1, 12), (A_2, 5), (A_7,15)$ $(A_1, 10), (A_2, 8), (A_7,7)$ $(A_1, 12), (A_2, 16), (A_7, 8)$	3	25	0.5697
3	$A_1, A_2, A_3, A_4, A_5, A_6$	A_1, A_2, A_3, A_4	$(A_1, 12), (A_2, 5), (A_3, 10), (A_4, 5)$ $(A_1, 10), (A_2, 8), (A_3, 4), (A_4, 3)$ $(A_1, 12), (A_2, 16), (A_3, 2), (A_4, 6)$	4	15	0.6364
4	When the quantities of elements are smaller than n', the calculation ends.			5		

Table 3. The optimal resource dispatching plan.

Resource	A_1	A_2	A_3	A_4
Insulator (XPW-7)	12	5	10	5
Pole (18 m)	10	8	4	3
Cross Arm (1 m)	12	16	5	6

5. Conclusion

In this paper, the optimal resource dispatching issue of the distribution network rush-repair is studied. The dispatching model is established first with the objective of "the shortest repair start-time" and "the least number of the repair centers". And a "proximity degree method" is used to calculate the optimal resource dispatching plan. The feasibility of the proposed algorithm is illustrated by an example of a distribution network fault. The proposed method provides a practical technique for efficiency improvement of fault rush-repair work of distribution network, and thus mostly abbreviates power recovery time and improves the management level of the distribution network.

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