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Reliability Assessment of Distribution Network Considering Feeder Capacity Constraint

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Abstract

This paper studies the reliability evaluation algorithm considering feeder capacity. Based on feeder partition, the reliability assessment algorithm is combined with the minimum path algorithm to simplify the fault analysis process. By taking feeder transfer capacity into consideration, this algorithm fit the actual operation of the distribution network and can obtain accurate reliability assessment results.

Keywords

Reliability evaluation; simplified network; minimum path; capacity constraint.

1. Introduction

With the continuous development of the national economy, user load has increased year by year, and power users have higher and higher requirements for power system power supply capacity and power supply reliability. As the last link between the power transmission system and users , the operation status of the distribution network determines the power supply status of users, and directly affects the quality of users' power consumption. By evaluating the reliability of the distribution system, it is possible to find out the weak links in the network.

At present, domestic and foreign scholars have proposed a variety of algorithms in the research of distribution network reliability, such as analytical methods[1,2]and simulation methods[3]. However, most of the researches did not consider the equipment capacity constraints in the system. In fact, the load transfer process needs to consider feeder capacity constraints. Considering the feeder capacity constraints, this paper proposes a fast reliability calculation method based on the minimum path method to simplify the process of fault impact analysis.

2. Reliability index of distribution network

(1) System Average Interruption Frequency Index

This index describes the number of power outages for each user in the system per year:

$$SAIFI = \frac{\sum_i \lambda_i N_i}{\sum_i N_i} \tag{1}$$

(2) System Average Interruption Duration Index

This index describes the average duration of power outage suffered by each user in the power distribution system per year :

$$SAIDI = \frac{\sum_i U_i N_i}{\sum_i N_i} \tag{2}$$

(3) Average Service Availability Index

The ratio of the actual power supply time of the user in the power distribution system per year to the total power supply demand time:

$$ASAI = \frac{8760\sum_i N_i - \sum_i U_i N_i}{8760\sum_i N_i} \tag{3}$$

(4) Energy Not Supplied

The total power shortage of users in the power distribution system per year:

$$ENS = \sum_i L_a(i)U_i \tag{4}$$

3. Improved minimum path algorithm

3.1. Network simplification

In order to simplify analysis process, the network topology is simplified by using feeder partitions and equivalent load nodes. The concept of feeder area [4] is used here. If a component in the feeder area fails, other components in the same feeder area will also lose power. Taking the feeder area as the analysis object can achieve the purpose of simplifying the analysis of the failure mode of the distribution system. The network simplification process is shown in Figure 1.

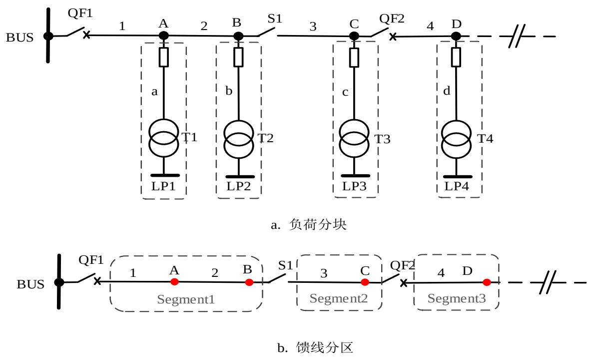

Figure 1 A radial distribution network

3.2. Minimum path

Based on the simplified network, this paper analyzes the impact of non-minimal path component failure on the load point. By passing the fault influence from the backward zone to the forward zone in turn upwards, the fault influence components of all non-minimum path components transmitted to the load point are obtained, and their fault parameters are assigned to the corresponding minimum path area; then the minimum path element is used to analyze the impact of power outage in the load area and calculate the corresponding reliability index. The specific analysis process is:

(1) equivalent of non-minimal path components:

The fault component of each area is transferred to its adjacent upper layer area. Through layer-by-layer transfer, the fault influence parameter of the non-minimum path element in the specified load can be obtained. The fault influence parameter is determined by switch type and the fault parameters of the lower-level regional components.

If the connecting switch of the two adjacent layers is a circuit breaker, since the circuit breaker quickly acts to disconnect the branch after a fault, the fault in the lower layer will not be transmitted to the upper layer.

If the switch between two adjacent feeder areas is a isolation switch, the fault in the lower layer area will be transmitted to the upper layer feeder area, and the fault component transmitted from the lower layer area to the upper layer area is

$$\Delta\lambda_{k-1} = \lambda^{'}_{k} = \lambda_k + \Delta\lambda_k = \lambda_k + \sum_{i\in\Omega_k} \lambda'_i \tag{5}$$

$$\Delta U_{k-1} = U^{'}_{k} = U_k + \Delta U_k = \lambda_k t_k + \sum_{i\in\Omega_k} U^{'}_{i} \tag{6}$$

In the formula, $\Delta\lambda_k$, Δr_k, ΔU_k are the reliability increments of area k, $\lambda^{'}_{k}$, $U^{'}_{k}$, $t^{'}_{k}$ are the fault components passed through area k to the upper layer, λ_k, U_k, t_k are the equivalent fault parameters of the internal components of area k, Ω_k are the collection of the next layer area connected to area k, t_k is the fault isolation time.

Using the formula above to obtain the equivalent parameter layer by layer from the end to the line upwards, the fault transmission component of the non-minimal path element in the uppermost area can be obtained.

(2) Analysis of the minimum path

Table 1 shows the components in the minimum path of the load block in the system of Figure 1. Since the minimum circuit element is located upstream of the load point, the power supply of the load point will be interrupted when the element fails. Therefore, the number of power outages of the load block is the sum of the minimum circuit element failure rate, but the power outage time needs to be further analyzed in conjunction with the load transfer situation.

If the system has no backup power supply or transfer path, each component in the minimum path faults, the power outage time of the load point is the repair time of the component.

If the system has a backup power supply or a transfer path, the load can be transferred under the condition of satisfying the constraints. Then the components before the segmentation device faults, the outage time of load behind is the maximum of switch isolation time and contact switch operation time. If the load is removed because it cannot meet feeder capacity constraint conditions, the power outage time of load block is the component repair time.

Table 1 The minimum path component set of load block

Number	Element in the minimum path	Non-minimum path parameter conversion node
1	QF1, segment 1	node 1
2	QF1, segment1, S1, segment2	node 2
3	QF1, segment1, S1, segment2, QF2, segment3	node 3

4. Analysis of the transfer situation

Due to the constraints of feeder transfer capacity, not all loads in non-faulty areas can be powered by other power sources. It needs specific analysis according to the fault conditions.

Assume that the total load to be transferred is S_{load}, and the remaining capacity of feeder is S_{line}:

If $S_{load} < S_{line}$, it indicates that the feeder transfer capacity constraint condition is met, and the load block can be transferred completely.

If it doesn't meet the above constraints, load shedding is required. The load blocks are removed one by one from the farthest point from the standby power supply, and a new S_{load} is obtained,

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which is substituted into the constraint condition until the condition is met. The fault time of the removed load block is still the component repair time, and the fault time of the load block transferred can be corrected to the fault isolation and contact switch switching time.

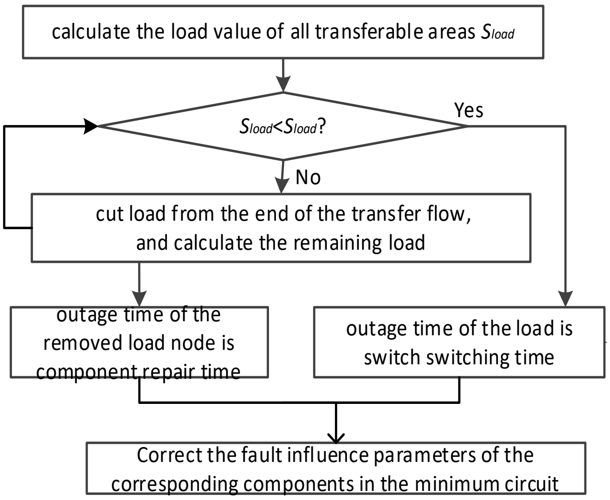

Figure 2 Analysis process of the transfer situation

5. Algorithm process

On the basis of simplification of the network, the fault uplink transmission component of the lower layer area is calculated. Then the failure parameters of non-minimum path components are converted to the minimum path, and finally the reliability index is calculated by analyzing the load transfer situation under the minimum path component failure. Specific analysis steps of the reliability evaluation method are as follows:

(1) Network simplification: search circuit breakers, section switches, load switches etc., and determine load blocks and feeder domains. Then mark the nodes connecting the load blocks and the main line as load nodes, delete the load blocks and obtain a simplified network only with feeder partition and switches.

(2) Calculating the equivalent fault parameters of the every feeder area: calculate the equivalent reliability parameters of the internal components of each feeder area and the equivalent reliability parameters of the load block according to the series-parallel formula.

(3) Uplink equivalent: combine switches from the most terminal area upwards, calculate the fault components transmitted upwards from each area, and assign the results to the connecting nodes of the two areas;

(4) Determine the minimum path: use the depth-first algorithm to traverse each area from the power point, obtain the minimum path of each load node, and record the bifurcation points in the minimum path in the minimum path list of the load node in order.

(5) Extract each simplified components in the distribution network as the faulty components, and analyze the situation of the components in the minimum path of the load block node. If the component is on the smallest path of a certain load block, store the load block in the set of load blocks to be transferred;

(6) Search for circuit breakers and isolating switches from both ends of the faulty component, and mark the traversed load nodes. Then disconnect the traversed switching components. Traverse the load nodes in the network from the contact switch, , and store them into the transferable load block collection;

(7) Find the intersection of the set of load blocks to be transferred and the set of transferable load blocks. These load blocks can actually be transferred;

(8) Invoke the load transfer analysis module, judge the actual transfer situation of the transferable load blocks, and record the reliability parameters of each load block;

(9) Parameter accumulate: sum the power outage time under all faults to get the power outage time of each load block. The flow chart is shown as in Fig. 3.

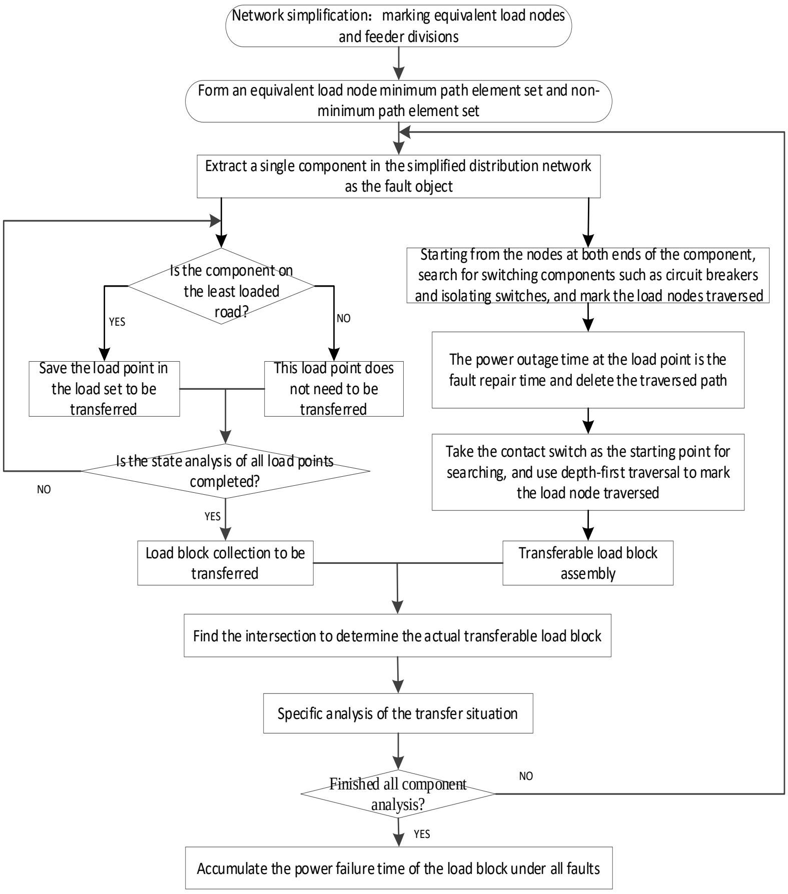

Figure 3 Algorithm flow chart

Case analysis

Use the algorithm in this paper to analyze the feeder of IEEE RBTS BUS6 system F1[5]. The system topology is shown in Figure 4. It is assumed that the circuit breaker and the fuse are 100% reliable, and the switch operation time is 1h. The calculated reliability indexes are shown in Table 2 and Table 3.

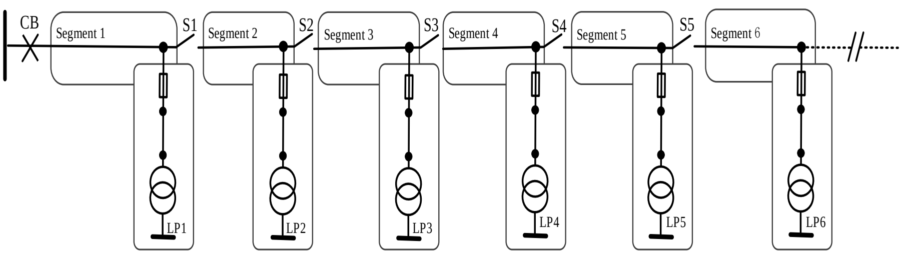

Figure 4 IEEE RBTS BUS6 system F1 topology

Table 2 Reliability parameters of load

Index		LP1	LP2	LP3	LP4	LP5	LP6
λ	-	0.36725	0.38025	0.377	0.36725	0.377	0.36725

U	no transfer	0.89025	1.12925	1.326	1.49025	1.713	1.87225
	Transfer capacity	0.89025	1.12925	0.939	0.89025	0.9	0.88525

Table 3 Reliability parameters of system

Index	SAIFI	SAIDI	EENS	ASAI
no transfer	0.3727	1.4035	14.78223	99.9840%
Transfer capacity	0.3727	0.939	9.3581	99.9893%

Because the load transfer is carried out for the power-loss load area after the fault, it cannot affect the failure rate. Therefore, the number of power outages at the load point is the same in the three cases. The reliability data of the feeder F1 also verifies this. It can be seen that in the case of no transfer, the power outage time of each load point is the accumulation of component repair time, so the power outage time is longer; when considering the line capacity constraint, although the load point LP2 can be transferred theoretically, but actually the total load to be transferred exceeds the capacity margin of the line, so it is cut off. The power outage time is equal to the corresponding time under the channel without transfer.

On the basis of simplifying the network, this paper uses the minimum path method to evaluate the reliability of the distribution system. By calculating the fault transmission, the non-minimum path influence is converted to the minimum path. The method reduces the amount of calculation, and considers line transmission capacity constraint to make the evaluation result fit actual operation.

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