

## Fault ergodicity algorithm for reliability evaluation of distribution system

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**Keywords:** Distribution network, reliability evaluation, fault algorithm, depth-first search, breadth-first search.

**Abstract.** A practical and fast fault ergodicity algorithm for the reliability evaluation of distribution system is proposed on the basis of a large number of analysis of the distribution network structure. The algorithm uses breadth first search and depth first search and the minimum path set for the load point to the power point in the graph theory, respectively to determine the fault of circuit breaker or fuse isolating switch action and fault isolation scope and load point fault type, the reliability index of the system is calculated according to the type of the fault of the load point. The calculation example shows that the algorithm can effectively implement the reliability evaluation of the complex distribution system, and it is a more practical algorithm for reliability evaluation.

### Preface

As a subsystem of the whole power system in direct contact with the end users in distribution system is an important part of the system's safety and economic operation, once the distribution system failure or maintenance, users of the system will inevitably lead to power outages, and the distribution system with radio network structure, is sensitive to the fault, the outage fault mostly caused by the fault in the power distribution system. At the same time, due to the current user requirement of power supply reliability of distribution system more and more high, the reliability of distribution systems has become an important part of the study of the reliability of power system, which has attracted many domestic and foreign experts attention.

Domestic and foreign scholars have put forward various algorithms in the research of distribution system reliability, including Monte Carlo sampling method [1], network reliability equivalence method [2], network planning method [9] and so on. However, with the increasing power system and the complexity of distribution network structure, the modeling and calculation of its reliability have become more difficult. Therefore, how to balance between the accuracy and the amount of calculation and how to find fast and effective methods are all problems to be explored further. In view of this, this paper chooses fault traversal network topology algorithm, using the breadth search algorithm, depth search algorithm and the minimal path set of each load point to the power point, and combining the results of the distribution network power flow distribution, to achieve the reliability evaluation of distribution network.

### Reliability index of distribution system

The reliability of distribution system (distribution system reliability) refers to the supply point to the user, including the measurement of substation, high and low voltage lines and grounding wire, the whole distribution system and equipment according to the accepted standard and the expected number of power and power quality to meet user demand ability.

In this paper, the reliability of the whole distribution system is characterized by two kinds of indexes, the reliability index of load point and the reliability of the system.

## Reliability index of load point

The reliability index of load point includes: load point fault rate,  $\lambda$  (unit: times/a), average power outage duration for each fault of load point,  $r$  (unit: H times) and load point average annual outage time  $U$  (unit: h/a) for  $n$  series repairable components, the following formula can be used for this calculation:

$$\sum_{i=1}^n \lambda_i \quad (1)$$

$$r = \frac{\sum_{i=1}^n r_i}{\sum_{i=1}^n \lambda_i} \quad (2)$$

$$U = \sum_{i=1}^n \lambda_i r_i \quad (3)$$

For two parallel repairable components, the following formula is used to calculate:

$$\lambda = \lambda_1 \lambda_2 (r_1 + r_2) \quad (4)$$

$$r = \frac{r_1 + r_2}{\lambda_1 + \lambda_2} \quad (5)$$

$$U = \lambda r \quad (6)$$

## System reliability index

System reliability index Includes: System Average interruption frequency index (System Average interruption frequency index, SAIFI), system average interruption duration index (System average interruption duration index, SAIDI) and average service availability index (Average service availability index, ASAI), expected energy not served (Expected energy not served, EENS). The formulae for each index are as follows:

$$\text{SALTI} = \frac{\sum_{i=1}^n N_i \lambda_i}{\sum_{i=1}^n N_i} \quad (\text{times household} \cdot \text{year}) \quad (7)$$

Among them:  $N_i$  is the number of users of load point  $i$ ;  $\lambda_i$  is the failure rate of the load point  $i$ .

$$\text{SAIDI} = \frac{\sum_{i=1}^n N_i U_i}{\sum_{i=1}^n N_i} \quad (\text{hours/household} \cdot \text{year}) \quad (8)$$

Among them,  $U_i$  is the average annual fault time of the load point  $i$ .

$$\text{ASAI} = \frac{\text{Total } \sum_{i=1}^n N_i - \sum_{i=1}^n N_i U_i}{\text{Total } \sum_{i=1}^n N_i} \quad (9)$$

## Principle analysis

Based on the idea of enumerating fault, this algorithm develops a reliability evaluation method by using ergodicity technology of DFS and BFS. Through the establishment of analysis list of effect of fault mode, it identifies each enumeration fault event and its influence, it takes the power flow calculation of distribution network as the check basis, to determine the fault types of all load points caused by various kinds of fault enumeration, and then make a comprehensive analysis to calculate reliability index, therefore, this paper firstly classifies the load point of the network, makes a comprehensive analysis on this basis, so as to calculate the required reliability assessment index.

## Classification of fault types of load points

Any failure event (this paper mainly considers components failures of lines, transformers, circuit breakers, disconnecting switches and combinatorial components failures), and divides the load points into 4 categories according to the duration of power outage:

Class I: power failure duration is component repair time;

Class II: the correct action of the switch after the occurrence of the fault is not affected by the fault.

Class III: power outage duration is isolated operation time;

Class IV V: power outage duration is isolated operation time and switching operation time.

### **The minimum path set of the load point**

For each branch of the system, all the anterior branch of the system can be obtained by the structure chain list of the system respectively. Therefore, the shortest path from the power point to the load point can be obtained by the recursive algorithm. First, we build a stack to stack the load point branch and traverse the previous branch. If the branch doesn't have a forward branch or a branch leads to a path cycle, the path is deleted. Otherwise, the branch stack will traverse the other preceding branches. If we traverse the output branch, we will terminate the calendar. Then, the branch that is stored in the stack is the shortest path. The shortest path set of the load point is formed by traversing each load branch.

### **Determination of the type of load point fault**

According to the classification standard of the load point proposed in this paper, the following methods are used to determine the types of each load point in the actual system.

#### **Determination of class I load point**

When a component in the network fails, the breadth first search (BFS) sequence is used to search the parent node backwards until the first time there is a circuit breaker, fuse or disconnecter. Circuit breaker, fuse or vibration isolation switch to remove the debt branch line to search, changing the topology of distribution network, and then from the source node start depth first search (DFS) traversal of the distribution network, so that those who do not have to traverse the load node is class load node, namely the node outage duration of repair the repair time for a component.

#### **Determination of class II load point**

When a fault occurs on a component in the network, by taking the branch of the component as the starting node, then it backward searches the parent node by using the order of breadth first search (BFS), until the first time occurring of the breakers and fuses, is the feeder for the circuit breaker or fuse branch is removed, the topological changes of distribution the grid, then from the source node start depth first search traversal (DFS) distribution network, you can traverse to the load node is class III load node, node failure that occurred after the correct switch action and not affected by the failure of the.

#### **Determination of class III and V load points**

The circuit breaker, fuse and isolator are determined by searching for the range of the fault and the influence scope of the component fault. It lays the foundation for the next step to determine the load nodes of class V and class IV. In addition to the above identified 1, I load, the remaining load node is, NV load node, they can be determined by the following methods: the grid topology on the component fault range traverse, those directly connected with the power supply load node (not by contact switch or contact knife smell) is class II the rest of the load node, left is IV V load node.

### **Flow calculation in Power distribution**

The load change caused by the fault outage in the distribution system must be considered. Under the condition of neglecting line capacitance and load and reactive power, DC power flow method and Z matrix method can be used to solve the distribution of power flow in distribution network under line fault or load point load reduction.

### **The Process of Algorithm Implementation**

Read the original data, through the adjacency list stored, dynamic representation of topological structure of distribution network, the formation of system topology information; 2. depth search (DFS), the formation of the load path set; fault enumeration 3. events; 4. with a breadth first traversal

search method (BFS) to determine the scope of the fault and determine the fault the action of breakers and fuses: 5. using breadth first search method (BFS) is to determine the fault influence, determine the fault circuit breaker, fuse action and vibration isolation knife 6. according to the fault distribution network topology structure, calculate the power flow distribution, the implementation of system fault recovery, system reconstruction, the formation of the subsystem; 7. by depth first search algorithm (DFS) traversal of each subsystem, identify load fault types; 8. according to the network load point fault types and load of reliability index calculation; check whether the 9. failure events after enumeration If completed, unfinished, go to step 3; 10. calculation results output, provide reference for system operation, management and planning departments and users.

To sum up, the flowchart of the program implementation is shown in Figure 1:

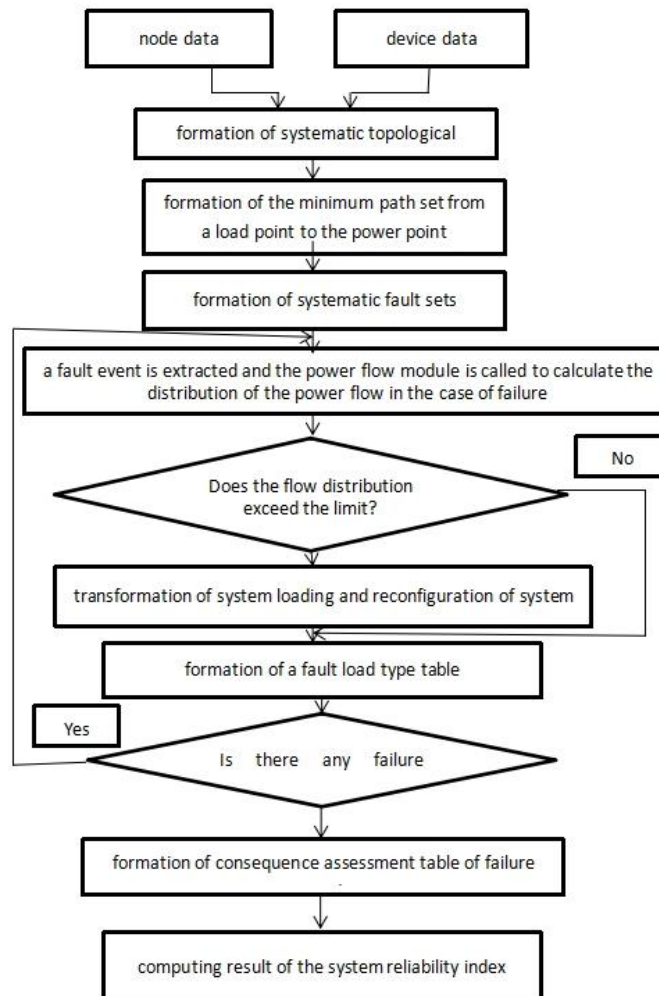


Figure 1 Program flow chart of distribution network reliability evaluation

## Test example

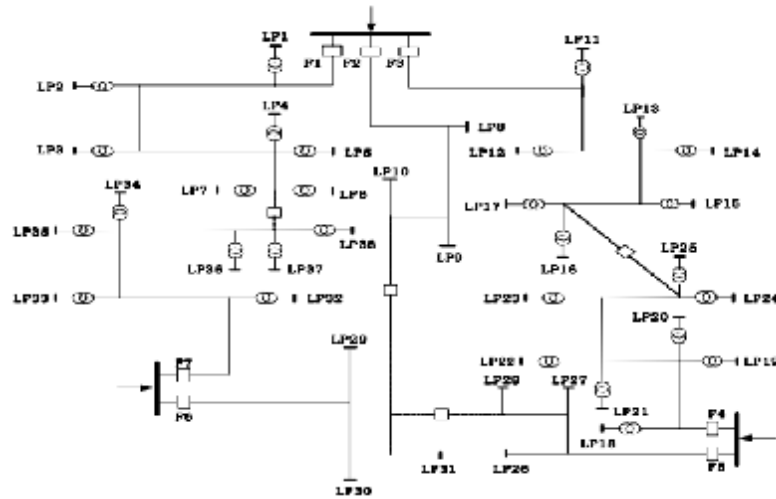


Figure 2 wiring diagram of 10kV distribution system in a certain planning area

This paper uses the 10kV distribution system of a planning area as a test example, the connection is as shown in Figure 2: the system has 7 main feeder lines (F1, F2, F3, F4, F5, F6, F7), F1 as one of main feeder lines, comes with 7 load points, F2 comes with 3 the load point, F3 comes with 7 load points, F4 comes with 8 load points, F5 with 3 load points, F6 comes with 3 load points, F7 comes with 5 load points. The reliability parameters of each component, the reliability index of the system and the cost of investment are shown in the following tables:

Table 1 User data

Load point number	Load point(M/W)	Load	Users
15	1-4 , 11-13 , 18-21 , 32-35	0.8869	220
7	5,14 , 15 , 22 , 23 , 36 , 37	0.81378	200
7	8,10,26-30	1.6300	1
2	9,31	2.445	1
7	6,7,16,17,24,25,38	0.6714	10
Total		40	4779

Table 2 Component data

Componet	$\lambda/a^{-1}$	R/h	Unit price(Dollars)
Transformer 10/0.4	0.015	120	52,857
Circuit breaker 10	0.006	2	4,286
Fuse 10	0.013	0.3	286
Force sluice 10	0.010	1.5	857
Lines 10kV electric cable	0.004	8	114,286

Table 3 Feeder lines data

Feeder lines type	L/km	Feeder lines number
1	0.60	2,6,10,14,17,21,25,28,30,34,38,41,43,46,49,51,55,58,61,64,67
2	0.75	35,37,40,42,45,48,52,53,56,60,63,65
3	0.80	36,39,44,47,52,54,57,59,62,66

Table 4 System reliability and cost investment results

Type	System Average interruption frequency index (SAIFI)/a <sup>-1</sup>	System average interruption duration index(SAIDI)/ h*a <sup>-1</sup>	Average service availability index (ASAI)	Expected energy not served( EENS)/ MW*H *a <sup>-1</sup>	Investment cost of power grid(Dollars)
I	0.469786	15.9402	0.99818	443.507	1,883,143
II	0.297286	3.44871	0.999606	138.253	1,894,000
III	0.347669	2.65629	0.999697	113.609	1,916,857
IV	0.109939	2.48948	0.999716	108.638	2,006,000

The fault isolation time for the system is taken for 0.5 hours, and the power supply time of the load is 0.7 hours. The reliability and cost analysis of the system are divided into 4 types:

Class I: calculated according to the wiring diagram of the distribution system in Figure 1.

Class II: adding a fuse in the load branch of Figure 1;

Class III: adding a fuse in the load branch of Figure 1, and a contact knife switch in the main feeder lines branch.

Class IV: Adding a fuse in the load branch of Figure 1, and a connection switch in the branch of main feeder lines.

As can be seen from table 4, as the system configuration changes, the system reliability index rises as well as the investment cost of the system. This phenomenon is reasonable and scientific. According to the average electricity price conversion multiple method, if the average electricity price is 0.35 RMB kW / h and the conversion ratio is 25, taking class I as the comparison standard, then the relationship of the annual power outage loss and the additional investment for improving the reliability level is shown in Table 5.

Table 5 Results of systematic economic investment analysis

Type	Investment cost of power grid(Dollars)	Annual Power outage loss of the system(Dollars)	Increase the reliability of additional investment(Dollars)	Power outage loss plus additional investment(Dollars)
I	1,883,143	554,384	0	554,384
II	1,894,000	172,816	10,857	183,672
III	1,916,857	142,011	33,714	175,726
IV	2,006,000	135,797	122,857	258,654

As can be seen from table 5, according to the power outage loss and the minimum investment cost added by the system to increase the reliability level, the third option in the four investment plans is the best investment plan.

## Conclusion

Through the discussion above, we can draw the following conclusions:

1.The method proposed in this paper is calculated by an example. The results show that the method is feasible, and the correctness of the model is verified.

2.The assessment takes into account the actual conditions of the distribution system, such as sub branch protection, isolation switch, the configuration of the segmented circuit breaker and the influence of the standby power supply.

3.According to the principle of power outage loss and the minimum investment cost for increasing the reliability level, by comparing the different schemes,this article gives the best investment strategy. The engineering verification is feasible, reasonable and scientific.

4.The reliability level of the distribution system is closely related to the wiring mode of the distribution system. In the case of permitting of economic conditions, a circuit breaker, a fuse, a load

switch or, isolation switch and other sectionings can be set up to improve the reliability of the distribution system. Since this method increases investment, the coordination of economy and reliability should be considered in practical application.

5. The reliability of equipment components directly affects the overall reliability level of the system. The reliability index of the system can be improved effectively by reducing the failure rate and the fault time.

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