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A DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT APPROACH CONSIDERING MULTI-FAULTS BY IMPACT INCREMENT BASED MONTE CARLO

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ABSTRACT
The reliability evaluation of distribution network is an important part of power system. In the extreme situation caused by aging or weather, the multi-fault affect the distribution network reliability. There are only few reliability assessment approach considered the impact of multi-faults. It's necessary to have a method that can ensure both accuracy and efficiency. The impact increment method based on Monte Carlo sampling (IIMC) can meet the requirements in transmission network. After improving the independent faults identification by distribution network structure, the RBTS Bus6 system is used as an example to test the effectiveness of IIMC. Compared with traditional Monte Carlo sampling. When the failure rate of components is high for the aging and other reasons, the result can show the advantage of IIMC.
Keywords: Distribution system; Multi-faults; Impact increment; Monte Carlo sampling;

1. INTRODUCTION

According to the statistics of power companies, most of the blackouts are caused by distribution network faults, so the reliability evaluation of distribution network is of great significance [1]. In the operation of large-scale distribution network, the possibility of multiple faults will be improved due to the influence of operation, aging and weather conditions [2,3]. In this case, the reliability index of distribution network considering only single fault will be quite different from the actual situation[4].Whether multiple faults should be added to the reliability evaluation of distribution network has not been a unified result by scholars for many years. At present, only a few articles consider the impact of multiple faults on distribution network reliability. Literature [5] analyses the impact of multiple faults on Reliability Evaluation under different conditions. Literature [6] presents a method to construct the random function of distribution system reliability index based on the frequency distribution and probability distribution of occurrence times of multiple faults. Literature [7] uses coded Markov cut set method to evaluate the reliability of network distribution system, and truncates some low probability high dimension overlapping faults to reduce the computational complexity. In literature [8], a Markov cut set method based on DC-OPF is proposed to evaluate the reliability of composite power systems. This method uses DC-OPF method to determine the minimum cut set to reach the predetermined order, and then applies Markov process to calculate its reliability index. It's necessary to have a method that can not only considering the impact of multi-faults, but also ensure both accuracy and efficiency.

The impact increment method can meet the requirement in principle. The impact increment method is a reliability index calculation method which was initially applied in transmission network [9]. The calculation formula is obtained by improving the availability and state in the reliability index formula of the state enumeration method. In reference [10], the expression of impact increment algorithm based on Monte Carlo method (IIMC) is proposed, and the formula of impact increment method is modified according to the probability of Monte Carlo sampling.

2. IMPACT-INCREMENT BASED MONTE-CARLO SAMPLING

The expression of reliability index and Impact-increment by Impact-increment based on state enumeration is

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$$R=\sum_{k=1}^{N}\sum_{s\in\Omega_A^k}\left(\prod_{i\in s}u_i\right)\Delta I_s \quad (1)$$

$$\Delta I_s=I_s-\sum_{k=1}^{n_s-1}\sum_{u\in\Omega_s^k}\Delta I_u \quad (2)$$

In these two formula, the R is reliability index, N is the total number of state, $\Omega^k{}_A$ is the subset of all elements, S is the fault state, u_i is the unavailable rate of element, n_s is the number of fault elements. In the formula (1), the system probability is not applicable to Monte-Carlo. For Monte-Carlo sampling, sampling probability of system state S is considered as unbiased estimation of its probability, so some part of the formula should be changed [10]. After changing the probability, the stability index calculating formula of 3 elements system is

$$\begin{aligned}R=&u_1a_2a_3(\frac{a_1}{P_\phi})\Delta I_{\{1\}}+u_2a_1a_3(\frac{a_2}{P_\phi})\Delta I_{\{2\}}+u_3a_1a_2(\frac{a_3}{P_\phi})\Delta I_{\{3\}}\\&+u_1u_2a_3(\frac{a_1a_2}{P_\phi})\Delta I_{\{1,2\}}+u_1u_3a_2(\frac{a_1a_3}{P_\phi})\Delta I_{\{1,3\}}\\&+u_2u_3a_1(\frac{a_2a_3}{P_\phi})\Delta I_{\{2,3\}}+u_1u_2u_3(\frac{a_1a_2a_3}{P_\phi})\Delta I_{\{1,2,3\}}\end{aligned} \quad (3)$$

In the formula, a_i is the available rate of element,P_φ is the total number of sampling.The Impact-increment expression is

$$\begin{cases}\Delta I'_{\{i\}}=\dfrac{a_i}{p_\phi}\Delta I_{\{i\}}\\ \Delta I'_{\{i,j\}}=\dfrac{a_i}{p_\phi}\Delta I_{\{i,j\}}\\ \Delta I'_{\{i,j,k\}}=\dfrac{a_i}{p_\phi}\Delta I_{\{i,j,k\}}\end{cases} \quad (4)$$

The system probability in this form has been changed to the sampling frequency P_s of the system state S, so the Monte Carlo method can be applied to this formula. The formula (3) and (4) extended to N elements system are

$$\Delta I'_s=\frac{\prod_{i\in n_s}a_i}{P_\phi}\Delta I_s=\frac{\prod_{i\in n_s}a_i}{P_\phi}(I_s-\sum_{k=1}^{n_s-1}\sum_{u\in\Omega_s^k}\Delta I_u) \quad (5)$$

$$R=\sum_{k=1}^{N}\sum_{s\in\Omega_A^k}P_s\Delta I'_s \quad (6)$$

3. IMPACT-INCREMENT BASED MONTE-CARLO RELIABILITY ASSESSMENT IN DISTRIBUTION SYSTEM

According to the formula (5), the Impact-increment of high order fault can be calculated by all lower order faults. Some high order faults can be divided into two subsets, S1 and S2, and the elements in S1 and S2 are independent of each other. The Impact-increment is

$$\Delta I_s=I_s-I_{\{s_1\}}-I_{\{s_2\}}=o \quad (7)$$

So the Impact-increment of this kind of fault can be calculated quickly. The quickly identification of Independent fault can improve the efficiency.

3.1 Reduction of High Order Fault

Due to the large actual area of distribution network, when multiple faults occur, different fault elements may be far away from each other, resulting in the independent load curtailment of fault elements.

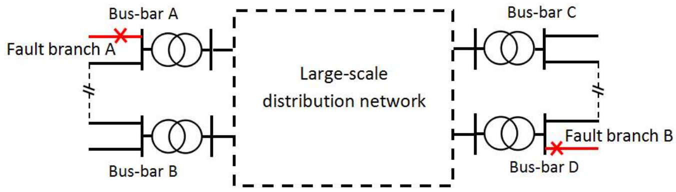

Figure1. Independent fault diagram

So as long as the fault element are in distribution system structure which are not directly connected and have no transfer relationship in current voltage level and lower voltage level, it can be identified as independent multiple faults, like the Bus-bar A and Bus-bar D.

For a group of medium-voltage redial structures distribution network, the starting nodes of these redial branches can be recorded, and they can be separated from the main branch starting from the power point. This can be used to determine which kind of faults can be divided into independent faults.

3.2 The Application of Segment

In the large scale distribution system, there will be over hundreds even thousands of basic elements like lines and transformers. The identification of independent faults for all elements will highly influence the total efficiency. The Application of segment can solve this problem. A segment is a set of components with common entry components [11]. The entry components are switches or protective devices. Components in segment cause the same fault effects to other components and the impact of the elements in other segments on this segment is the same. It can high decrease the number of basic components from lines and transformers to segment.

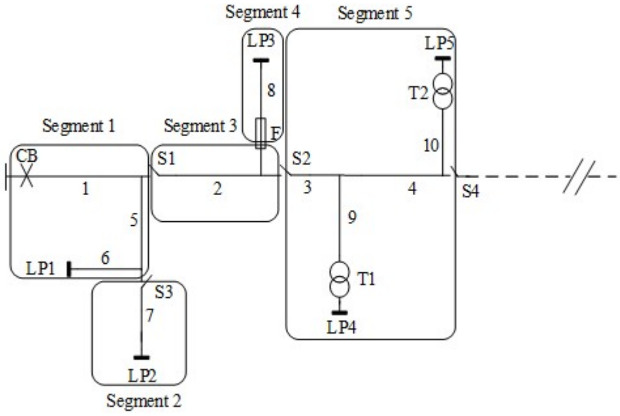

Figure 2. The structure of segment

The figure of segment is shown below. In this figure, there are over 10 elements that can have faults. If use the segment, there are only 4 segments that can highly increase the efficiency.

3.3 Convergence Criterion of Assessment

Coefficient of variation(COV) of EENS is used to judging whether the algorithm converges or not. The formula of COV is

$$COV = \sqrt{\frac{V(I)}{N \times E^2(I)}} \tag{8}$$

In the formula, V(I) is the variance of sampling results, N is the total sampling number, E(I) is the average value of the sampling results.

3.4 Algorithm Flow Diagram

The diagram of Impact-increment based on Monte-Carlo sampling in distribution system is in figure 3.

4. CASE STUDY

The case used in this paper is the IEEE RBTS Bus 6 system [12]. The system structure is shown in figure, including 1 10kV bus bar and 4 feeders (F1, F2, F3, F4). There are 64 feeder sections, 38 distribution transformers and 40 load points (LP1-LP40).In this case, there are 3 non connected parts which are F1&F2, F3 and F4. The average failure rate of lines and transformers are 0.07 times/year.km and 0.5 times/year, the average repair time of line is 5h, the average replace time for transformer is 15h.

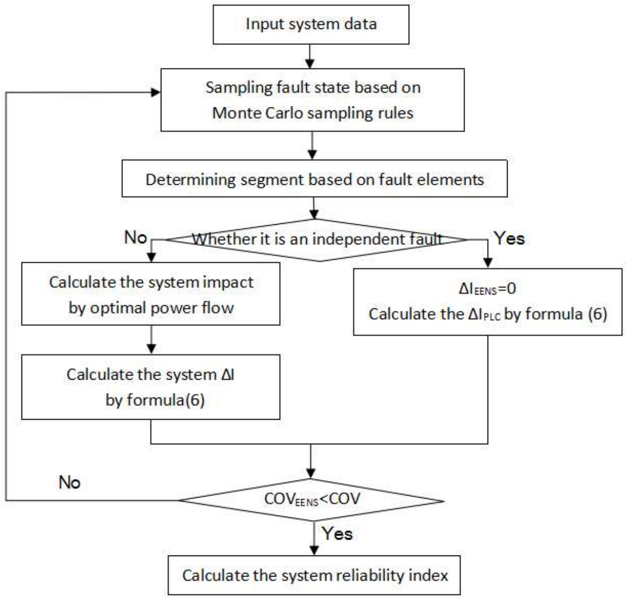

Figure 3. Algorithm flow diagram

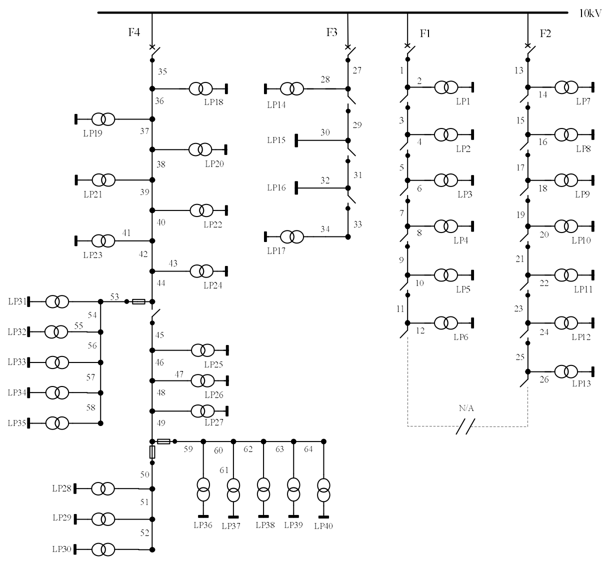

Figure 4. The RBTS Bus6 wiring diagram

5. RESULT AND DISCUSSION

The result of 5×10^6 times Monte Carlo sampling is seen as the reference, the COV of result is 0.0055. The result of 10^5 times Monte Carlo based impact-increment method with segment used and 10^5 times Monte Carlo sampling without segment are shown in table1.

Table1. The result of IIMC (with segment) and MCS (without segment) in normal situation

	EENS	PLC	COV	Time
Reference	526.8	0.0069	0.0055	1517.3
MCS	535.4	0.0068	0.0385	34.3
IIMC	525.9	0.0071	0.0388	29.3

From the result, it can be seen that the accuracy of EENS by IIMC is a little higher than the MCS, which is 1.6% to 0.1%. In the PLC and Cov, the result of these two method is almost same. The operation time of IIMC is quicker than MCS for about 5s.

When the cables are in extreme situation (aging and weather) that failure rate rise from 0.07 f/yr.km to 0.2f/yr.km. The result of 10^5 times Monte Carlo based impact-increment method and 10^5 times Monte Carlo sampling are shown in table2. The result of 10^6 time Monte Carlo sampling is seen as the reference, the COV of result is 0.00078.

Table2. The result of IIMC (with segment) and MCS (without segment) in extreme situation

	EENS	PLC	COV	Time
Reference	1272.5	0.0171	0.0078	770.6
MCS	1315.2	0.0169	0.0385	120.3
IIMC	1279.2	0.0171	0.0252	75.4

From the result, all the index by IIMC is more accurate than MCS in extreme situation. The error of EENS by IIMC is only 0.5%, the error of PLC is almost 0, the COV is smaller.Time is the most significant index which is quicker than MCS for 38%(45s).

The comparison result is not as obviously as the result in large scale transmission network in normal situation. There are two main reasons, the first one is the unavailable rate of elements in distribution network is much more lower than the unavailable rate of elements in transmission network. This will cause the probability of high order faults is much lower, so the advantage of IIMC is not so obvious in distribution network. The result of second situation show when probability of high order faults is higher, the advantage of IIMC is more obviously.

The second reason is in this case study, the high order fault in F3 and F4 will not cause positive impact-increment. This is because in the F4, some of the high order faults are independent faults, the impact-increment is 0, the impact-increment of others high order faults in F4 and all kinds of high order faults in F3 are negative. This means that the load curtailment high order faults is equal to one of the lower order fault. Only the high order faults in F1 and F2 have positive impact increment. This is because the F1 and F2 have a transfer switch to connect them, the single elements fault can only cause one segment’s load curtailment. But the high order fault will case all segments between fault element power off. This means the IIMC will be more suitable for the microgrid, Integrated Energy System and large scale distribution with transfer.

6. CONCLUSION

In this paper, IIMC, a reliability analyze method designed for large-scale transmission network, is tried to be used in distribution network. There are some improvements has been made in independent fault identification method to adapt to the distribution network situation. The application of segment can also improve the efficiency for the decrease of number of basic elements. The RBTS Bus6 system is used to test the IIMC, when the failure rate is higher than normal situation for aging or weather, the result can show the advantage obviously in all aspects.

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