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Reliability Evaluation Algorithm for Distribution Network with DG

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Reliability Evaluation Algorithm for Distribution Network with DG

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Abstract. The paper proposed reliability evaluation algorithm for distribution network considering the act of weather and DG, the algorithm develops weather model for average failure rate to shows the influence of normal weather and adverse weather on distribution network reliability. Then, the optimal island partition method is proposed to determine the power supply scope after power failure. The improved minimal path method is employs to calculate the reliability index of distribution network with DG. The test covers four cases including without DG and weather, only DG, only weather, and both DG and weather are calculated and compared from the aspects of load points, feeders and system reliability indices. The results about SAIFI, SAIDI, CAIDI and ASAI show that the proposed algorithm can take the influence of distributed power supply and weather into account. The impact of distributed generation and adverse weather on distribution network reliability is studied. Considering both DG and weather, the reliability of distribution network can reflect the actual condition more accurately, which proves the validity of the method and the model.

1. Introduction

The distribution network is large and complex, and its reliability is easily affected by external conditions. On the one hand, the operation of the distribution line in an outdoor environment is susceptible to climate change. Based on experience, it is found that the possibility of component failure in severe weather will increase greatly. Although the probability of bad weather is small, it will lead to a sharp increase in power system component outage rate, and the economic loss and social impact are difficult to estimate [1]-[2]. With the deterioration of the global climate, the impact of severe weather such as freezing, storm (rain) and snow on the safe operation of distribution networks is also increasing [3]-[5]. On the other hand, distributed generation has the characteristics of high reliability, high efficiency, high quality, environmental compatibility and flexibility [11-13]. In recent years, a large number of distributed power sources (DGs) have been connected to the distribution network. The distribution network has been transformed from a radiant network with a single power supply to a network that is interconnected with power and users [6]-[7]. The models and methods of sexual analysis calculations have changed in nature. Therefore, the impact of weather and distributed power sources must be taken into account in order to fully and accurately calculate the reliability of the actual distribution network.

In the literature [8], Monte Carlo method was used to simulate the influence of weather factors on the reliability of distribution network. Cheng Lin applied fuzzy reasoning to study the outage rate modeling and grid adequacy evaluation of severe conditions [9]. The literature [9] analyzes the

reliability of power supply in different modes of operation before and after DG grid connection. In [10], the interval algorithm is used to calculate the reliability index of distribution network after distributed power access. However, research on the reliability of distribution networks with distributed power sources that account for climate impact is rare. In this paper, the calculation model of the reliability of the distribution network after DG access is considered, and the minimum loop method for calculating the traditional reliability is improved, which makes it suitable for the power supply of DG access distribution network under the influence of weather. Sexual analysis and calculation, for the reliability of the distribution network under the four different schemes: DG access without considering the weather impact, considering only the DG impact, considering only the weather impact, and considering the DG and weather effects, and adopting time-varying the unit power loss function model is used to calculate the economic loss caused by power outages under the four schemes. The system comprehensively analyzes the influence of weather and DG on the reliability of the distribution network, and has an exploration significance for the actual operation reliability calculation of the distribution network.

2. Establishment of Climate Model

According to the IEEE346 standard [11], the weather is divided into three categories: Normal Weather, Adverse, and Major Storm Memory. Due to the extremely small chance of severe weather events, they can be combined into both normal and poor conditions. If it fails during normal weather λ, the failure rate is λ' in bad weather, N is expected to last in normal weather, and S is expected to last in S. Then the average failure rate of the component λ_{av} can be expressed as

$$\lambda_{av} = \left(\frac{N}{N+S}\right)\lambda + \left(\frac{N}{N+S}\right)\lambda' \tag{1}$$

Since the average failure rate λ_{av} can only be counted in practice, if we know the proportion of faults occurring in bad weather F, we can get it from Formula (1).

$$\lambda = \lambda_{av}\frac{N+S}{S}(1-F) \tag{2}$$

$$\lambda' = \lambda_{av}\frac{N+S}{N}F \tag{3}$$

3. Classification of Optimal Isolated Islands

In this paper, the maximum economic benefit of the load point in the islands is used as the objective function to divide the islands dynamically, that is, the maximum sum of equivalent effective loads. The feeder point of DG is regarded as the center of the circle, and the searching radius is the capacity of DG. The power circle of DG is found by searching along the topological direction of the network. Starting from the load point of the DG feeder, all the branches connected with the load point are visited first, and then the lower branches are visited. Under the condition of DG connectivity between islands and regions, the power circle graph is traversed until the objective function reaches its maximum value. The islands obtained are the optimal islands satisfying the objective function. The mathematical model is as follows

$$\max L_E = \max \sum_{t \in D} \lambda(i)L_a(i) \tag{4}$$

$$\begin{cases} \sum_{t \in D} L_a(i) \leq P_{DG} \\ \text{Region D connectivity} \\ j \in D \end{cases} \tag{5}$$

In the formula, $L_a(i)$ is the load of load point i; P_{DG} is the rated capacity of DG; D is the area composed of all load points $L_a(i)$; j is the feed line number of DG; $\lambda(i)$ is the load importance factor, and the load importance factors of class I, class II and class III are 0.5, 0.3 and 0.2, respectively.

4. Distribution Network Considering Climate and DG

After DG is connected to the distribution network, when the equipment in the distribution network fails, islands are formed in the range of DG capacity by operating sectional switches. DG continuously supplies power to the load in the islands, which improves the reliability of power supply in the islands. For the load point outside the island, DG cannot supply power to it, so DG only affects the reliability index of the load point inside the island, and the reliability index of the load point outside the island is not affected by DG.

According to the second-order failure of DG and main feeder considering the impact of climate, the equivalent failure rate λ_{pi} and the equivalent outage time r_{pi} formula are as follows.

$$A_{S,k} = \frac{N}{N+S}\left[\lambda_D\lambda_{S,k}\left(r_D + r_{S,k}\right) + \frac{S}{N}\left(\lambda_D'\lambda_{S,k}r_D + \lambda_D\lambda_{S,k}'r_D\right)\right] \tag{6}$$

$$B_{S,k} = \frac{S}{N+S}\left[2\lambda_D'\lambda_{S,k}'S + \lambda_D\lambda_{S,k}'r_D + \lambda_D'\lambda_{S,k}r_D\right] \tag{7}$$

$$\lambda_{pi} = \sum_{S,k=1}^{N_D}\left(A_{S,k} + B_{S,k}\right) \tag{8}$$

$$r_{pi} = \sum_{S,k=1}^{N_D}\left[\frac{A_{S,k}}{A_{S,k}+B_{S,k}}\cdot\frac{r_Dr_{S,k}}{r_D+r_{S,k}} + \frac{B_{S,k}}{A_{S,k}+B_{S,k}}\left(\frac{r_Dr_{S,k}}{r_D+r_{S,k}}+S\right)\right] \tag{9}$$

In the formula: $A_{S,k}$, $B_{S,k}$, respectively, are the failure rate of k-section main feeder in island under normal and bad weather; $\lambda_{S,k}$, $r_{S,k}$ are the failure rate and average outage duration of k-section main feeder respectively; λ_D and r_D are the failure rate and average outage duration of DG respectively; N_D is the number of main feeder segments in front of DG and $L_a(i)$ at load point.

5. Simulation results and analysis
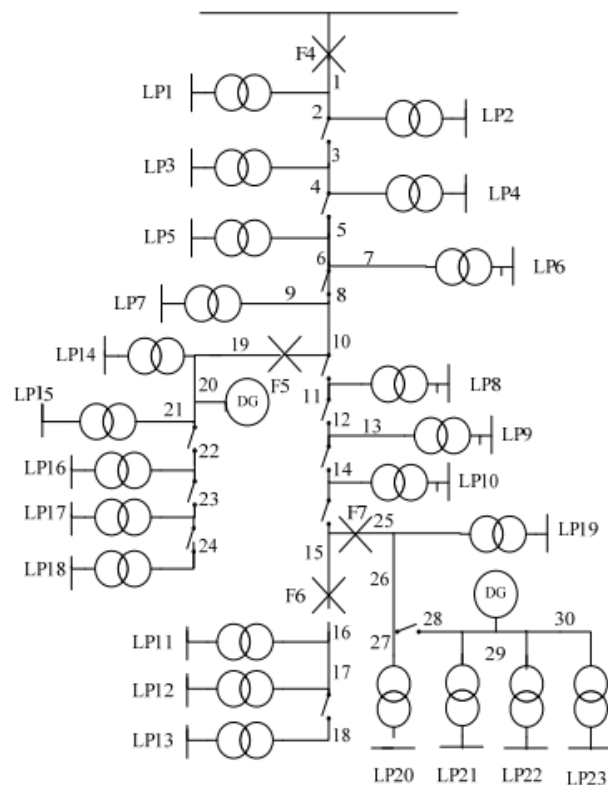
5.1. Simulation

In this paper, the main feeder F4 and its three branch feeders F5, F6 and F7 in RBTSBus633kV are selected as the research system. The system wiring is shown in figure 1. The system consists of 30 lines, 23 load points, 23 fuses, 23 transformers, 21 isolation switches and 4 circuit breakers. The fuses are installed at the head end of each load branch. It is assumed that the fault rate of the circuit breaker and the fuse is 0. Because the failure rate is very small, the reliability calculation results have little effect and can be ignored. The isolation switch operation time is 0.15h. Table 1 lists the failure rate and average repair time of each component. Table 2 shows the system load data, N=200h, S=1.6h.

Table 1. Component reliability index

Element	Failure rate	Average repair time/h
Feeder	0.03 times /(km· year)	3
Distribution transformer	0.018 times/unit	25
DG	4 times /year	25

Table 2. Load data

Number of load points	Load Point Number	Number of Load Point Users	Load value /MW
1	2	126	0.2046
1	5	132	0.2387
2	1,6	147	0.2163
2	15,20	1	0.2441
2	4,18	1	0.3166
2	7,23	1	0.2498
3	9,21	1	0.3131
3	3,13,17	1	0.3092
4	10,12,16,22	76	0.1864
4	8,11,14,19	79	0.2249

Figure 1. Connection diagram of RBTSBus6 distribution network with DG

As shown in figure. 1, a DG having a capacity of 0.5 MV is installed at the 20-branch line of F6, and a DG having a capacity of 1.0 MV is installed at the 29-branch line of F7 at the 20-branch line of F7. The two optimal islands divided by the island division scheme shown in 2 are LP14-LP15 and LP19-LP23, respectively.

In order to comprehensively analyze and compare the influence of DG and weather on the reliability of distribution network, this paper calculates and compares the reliability indexes of RBTS-Bus distribution system of four different schemes. The schemes are as follows:

Plan 1: No DG access, regardless of weather

Plan 2: DG access, regardless of weather

Plan 3: No DG access, taking into account the weather

Plan 4: DG access, taking into account the weather.

5.2. Result analysis

Figure 2 shows the expected energy not supplied (*EENS*) under four scenarios respectively. Compared with scheme 1, the reliability of load point in DG islands decreases greatly and remains unchanged outside the islands. It shows that the addition of DG can only improve the reliability of each load point in the islands, thus demonstrating the rationality of DG access to the distribution network.

Compared with the first scheme, the EENS of each load of the system increases significantly, which indicates that climate has a greater impact on reliability, and the reliability of each load point of the system decreases significantly after considering the impact of climate.

Comparing scheme 4 with scheme 1, the EENS of each load point increases, and the EENS of scheme 4 is the same outside DG island and in scheme 3, and between scheme 2 and scheme 3 in DG island. It shows that the reliability of each load point is reduced when considering both climate and DG influence, and the reliability of load point in the island is between considering only DG and climate only. Scheme 4 can more fully reflect the reliability of distribution network in actual operation.
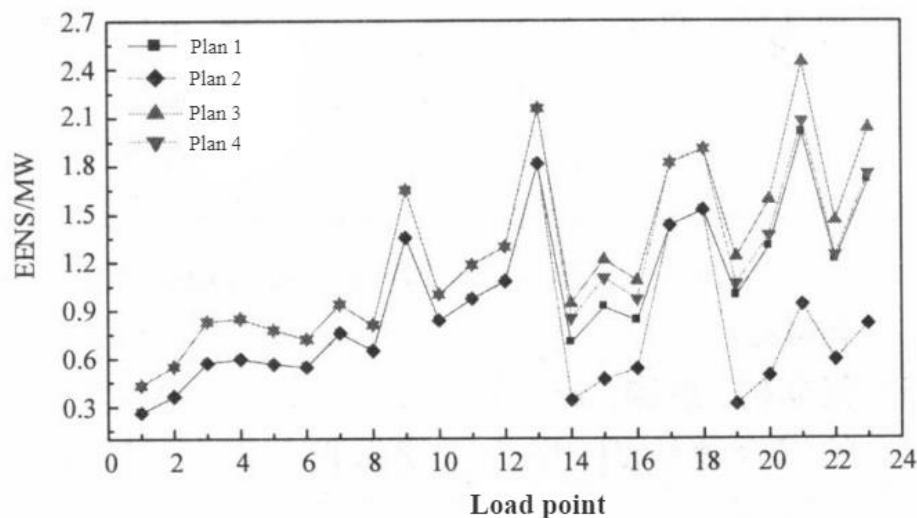

Figure 2. Expected energy not served

Tables 3, Tables 4, Tables 5 and Tables 6 are the reliability indices of feeder and system under four different schemes: SAIFI, SAIDI, CAIDI and ASAI.

The comparative analysis table 3 and table 4 shows that DG and climate have similar effects on the reliability of feeder and system. From table 5 and table 6, it can be seen that the reliability of feeder F6, F7 and system has been improved obviously after DG is connected to feeder F6 and F7. Compared with the changes of indicators of feeder F6 and F7, F7 is larger than F6, and the larger the capacity of DG is, the better the reliability of feeder and system where DG is located.

Table 3. SAIFI indices

SAIFI	Plan 1	Plan 2	Plan 3	Plan 4
F4	1.3219	1.3854	1.3272	1.3257
F5	1.7421	1.7277	1.7702	1.7585
F6	2.0281	2.0555	2.038	2.0437
F7	1.995	2.0308	1.9496	2.0336
System	1.5607	1.5846	1.5703	1.5751

Table 4. SAIDI indices

SAIDI	Plan 1	Plan 2	Plan 3	Plan 4
F4	3.0007	2.9646	4.0155	5.5036

F5	6.6131	6.5472	7.941	7.9192
F6	4.9392	2.8953	6.496	5.8846
F7	7.0645	2.8816	8.6046	7.357
System	4.2615	3.3863	5.4557	5.1828

Table 5. CAIDI indices

CAIDI	Plan 1	Plan 2	Plan 3	Plan 4
F4	2.2702	2.3233	3.0951	3.0767
F5	3.8513	3.8952	4.6476	4.6802
F6	2.5382	1.4442	3.3216	3.0064
F7	3.6449	1.5007	4.4869	3.7849
System	2.775	2.1943	3.6004	3.4317

Table 6. ASAI indices

ASAI	Plan 1	Plan 2	Plan 3	Plan 4
F4	0.9997	0.9995	0.9995	0.9991
F5	0.9993	0.9996	0.9992	0.9996
F6	0.9994	0.9998	0.9991	0.9994
F7	0.9992	0.9992	0.9995	0.9993
System	0.9995	0.9997	0.9993	0.9992

6. Conclusion

This paper studies the influence of DG and weather on the reliability of distribution network, and establishes the corresponding calculation model. By calculating the reliability of four different schemes, the following conclusions are drawn:

(1) Under severe weather conditions, the failure rate of system components is very high, and the reliability of distribution network decreases after considering weather effects; after DG access, the reliability of components outside islands is not affected, the reliability of components inside islands is enhanced, and the reliability of distribution network is enhanced.

(2) The economic losses caused by blackouts increase significantly after considering the impact of climate, and DG access can reduce the economic losses caused by blackouts.

(3) When considering both DG and weather, the reliability of distribution network is affected by both. The reliability index value is between DG and weather, which is more in line with the reliability of actual operation of distribution network.

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