ISSN: 2414-1895 DOI: 10.6919/ICJE.202001_6(1).0009

Distribution Network Operation Risk Assessment Considering Various Influencing Factors

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Abstract

The frequent occurrence of large blackouts caused by distribution network failures has led to the study of the operational risks of the distribution network systems. Aiming at the increasing influence factors of operational risk in the development of the distribution network, a risk assessment model considering multiple influencing factors is proposed. In the model, the calculation of power outage cost of distribution network adopts a new method, which reflects the comprehensive impact of frequency, duration and cost, and can more scientifically calculate risk cost and make the risk assessment results of distribution network are closer to the fact. Finally, the Monte Carlo method was used to evaluate the risk of RBTS Bus-3, and compared with the evaluation results of the analytical method, so the validity of the evaluation method was verified.

Keywords

Distribution network, risk assessment, outage cost, Monte Carlo method.

1. Introduction

The issue of electrical power safety is closely related to the economy and society and has been highly concerned by people. The occurrence of grid accidents often cause enormous losses, and the consequences are more and more dangerous. Therefore, risk assessment is of considerable significance to many aspects, such as planning and operation of power systems. Research on risk assessment has become the primary task and challenge of today's power industry.

The distribution network is an essential part of the entire power system. It is directly connected to the user and has a significant impact on the quality of the user's power supply. With the increasing scale of distribution networks, there are more and more distribution network equipment whose range is broader and broader, and the risk factors are also increasing. For a long time, risk assessment has focused on power generation and transmission, and there has been less research on distribution networks. In document four, the analytic hierarchy process of fuzzy number complementary judgment matrix is used to assign weights to the risk indicators of the distribution network to construct the model of a risk assessment. In reference five, the symbolic dynamics is used to describe the structural risk of the distribution network, while proposing the operating system, and the hierarchical iterative analysis method is used to obtain the risk of the distribution network. In literature six, it introduced the risk assessment system based on utility theory which adopt statistical practices to get accident probability and establish a severity function.

The most significant difference between the distribution network and the leading system is whether it is directly connected to the user. The failure of the load point will lead to the interruption of the user's power supply and the loss of power failure at first. The risk assessment of the main network focuses on the overall load of the whole system, while the distribution network will pay more attention

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to the user's risk indicators. Therefore, some risk assessment methods of the leading network are no longer applicable to the distribution network. Throughout the research results of risk assessment existing in the distribution network, the combination of qualitative analysis and empirical analysis based on subjective factors is more common without standard evaluation system, and the factors considered in the quantitative evaluation method are also relatively simple. Therefore, the risk assessment of distribution network considering various influencing factors have particular theoretical significance and engineering value.

2. The Risk Assessment of Distribution Network

2.1 The Risk Assessment Model of Distribution Network

The structure of the distribution network is complex and vulnerable to many risk factors, such as the working-age of each component, weather, different load types, equipment pollution, available repair resources, environment animal climbing, outdated equipment, inadequate relay protection measures or misuse. This paper strive to incorporate the broader influencing factors of the distribution network into the assessment process, taking into account the impact of the following several factors on the risk indicators:(1)working age of each component ;(2) weather factors;(3)available repair resources including seasonal changes, weekdays and weekend changes, daytime and evening changes.

The risk assessment of the distribution network is not only to assess the probability of failure events, but also to assess the severity of the failure consequences. In this paper, the likelihood of a failure event is represented by the failure rate of the component, which is calculated adopting a method that comprehensively considers various influencing factors. However, the failure loss is represented by the power outage loss under the fault condition, and the calculation method for the time-delay power loss of different types of users is proposed.

The Operational Risk Calculation Formula of Distribution Network:

$$R=\sum_{i=1}^{n} f_i \times C_i \tag{1}$$

In this formula, f_i represents the frequency at which the ith failure state occurs; C_i is the failure loss in this state; n means the total number in the failure state.

2.2 Risk Indicator Model

All components use a two-state model. The failure rate and repair rate are functions as the change of time. Component failure and repair time are subject to exponential distribution.

2.2.1 Risk Indicator Model Considering Working Age of Component

The relationship between failure rate and working time is like the tub over the life of the component. The failure rates of elements at different lifetimes are：

run-in period :

$$\lambda(t)=K_0 \mathrm{e}^{-\beta t} \cdot \lambda_{\mathrm{c}} \tag{2}$$

$$\beta=\ln K_0 / t_{\mathrm{B1}} \tag{3}$$

wear-period:

$$\lambda(t)=K \mathrm{e}^{\gamma t} \cdot \lambda_{\mathrm{C}} \tag{4}$$

$$K=\mathrm{e}^{-\gamma\left(t_L-t_{\mathrm{w}2}\right)} \tag{5}$$

In this formula, t is the working age of the component; K_0 is the maximum value of the impact factors(K_0 max =10); λ cis a constant of failure rate commonly used;it is the life of the component($t_L=30$); t_{B1} is the run-in period of components, two represent the wear-period whose average is 2.

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2.2.2 Risk Indicator Model Considering Weather

This article divides the weather into three categories, normal weather, bad weather, and catastrophic weather. The main influence of weather factors on risk indicators are:

（1） Impact on failure rate

Assume that the failure rate in normal weather is the average failure rate λ, then the weather-affected failure rate is:

$$\lambda(t)=\omega(t)\times\lambda \tag{6}$$

In this formula, $\omega(t)$ is the variable weighting factor. In this article, when the weather is normal $\omega(t)=1$; when it is bad weather $\omega(t)=1.2$; when it is the catastrophic weather $\omega(t)=2$.

(2) Impact on repair time

Assume that the repair time in normal weather is r, then the weather-repair time is:

$$r(t)=\omega(t)\times r \tag{7}$$

2.2.3 Risk Indicator Model Considering Repairing Resources

Available repairing time resource has an impact on component of repairing time. Therefore, the repairing time of component is:

$$r(t)=\omega_w(t)\times\omega_{\mathrm{d}}(t)\times\omega_{\mathrm{h}}(t)\times r \tag{8}$$

In this formula, $\omega_w(t)$ is a variable weighting factor affected by the season; $\omega_{\mathrm{d}}(t)$ is the weighting factor affected by weekdays and weekends; $\omega_{\mathrm{h}}(t)$ means the factors affected by the night and daytime. In this paper, $\omega_w(t)=1.2$, $\omega_{\mathrm{d}}(t)=1.0$, $\omega_{\mathrm{h}}(t)=1.1$

2.3 Risk Indicator Model Considering Multiple Influencing Factors

Combining the effects of various influencing factors on the failure rate and repairing time, the following formula is obtained.

$$\lambda(t)=\omega_{\mathrm{weather\_}\lambda}(t)\times\omega_{\mathrm{life}}(t)\times\lambda \tag{9}$$

$$r(t)=\omega_{\mathrm{weather\_}r}(t)\times\omega_{\mathrm{source}}(t)\times r \tag{10}$$

In this formula, $\omega_{\mathrm{weather\_}\lambda}(t)$ represents the weighting factor of the weather; $\omega_{\mathrm{life}}(t)$ is the weighting factor of working age of component; $\omega_{\mathrm{source}}(t)$ means the weighting factor of available repairing time.

2.4 Loss of Power Outage in the Distribution Network

The power outage loss of users in the distribution network is mainly determined by the type of user, the level of productivity, the time, and the number of power outage. Common methods for calculating power outage losses are the electricity generation comparison method and the constructor method. However, they cannot accurately reflect the relationship between frequency, time, and loss of power outage. Therefore, this paper adopts the calculation method of time-phased power outage loss for different types of users, and only considers the direct power failure loss.

2.4.1 Calculation method of power failure loss

For the statistical data of the discrete power outage time and power outage loss of industrial users in Canada in 1991, the curve corresponding to the power outage duration and the power outage loss is obtained by the method of linear interpolation fitting. As shown in Fig.1, the approximate expression of the following polynomial can be used:

$$R(t)=0.0032t^3-0.2048t^2+4.8724t+1.38 \tag{11}$$

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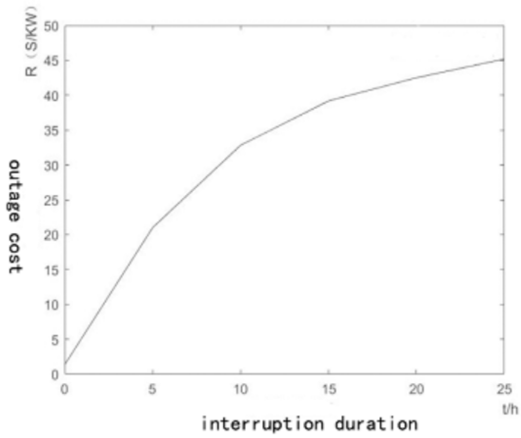

Fig. 1 Canadian industrial customers' interruption cost function in 1991

We observed that as the blackout time continues to increase, the slope of the blackout loss curve tends to be fixed. This value can approximate the average production benefit of the user's consumption of 1kWh of electricity.

$$\left.\frac{\partial f(t)}{t}\right|_{t=\infty} = P \tag{12}$$

In this formula,t is the user's power outage time, and P is the commentary benefit of such users per kWh of power production products, yuan / kWh.

Distribution network users are broadly divided into seven categories: large users, commercial users, industrial users, agricultural users, ordinary resident users, government and association users, and firm institutions. For different types of users, their power outage function curves are roughly similar.

$$\mathrm{f_2(t) = kf_1(t)} \tag{13}$$

In this formula, $\mathrm{f_1(t)}$, $\mathrm{f_2(t)}$ means the function of power loss function of different kinds of users. k is the pending coefficient of different users.

The following formula can be derived from Equation(13) and(14):

$$\left.\frac{\partial f_2(t)}{\partial t}\right|_{t\to\infty} = P_2 \approx k\left.\frac{\partial f_1(t)}{\partial t}\right|_{t\to\infty} \tag{14}$$

P is the average benefit of the product by user 2 per kWh, yuan/kWh.

The slope of the curve with approx. T=24h is equipped to the average benefit of per kWh power production after the power outage time is long enough. The average benefit P_2 of per kWh power production can be determined based on the type of user 2. After estimating the undetermined coefficient using Equation(14), the power loss function $f_2(t)$ of user two can be obtained.

2.4.2 Power Outage Loss Cost

$$\mathrm{C_F} = \sum_{i=1}^{m} R_i \times L_i \times \lambda_i \tag{15}$$

In this formula, m is the load point of the distribution network; $R_i$means the power outage loss coat corresponding to the average power outage duration of the node I per kWh load; L_i is the load capacity of the node i; λ_i is failure rate of load point i.

3. The Application of the Monte Carlo Method

At present, the main risk assessment methods for power systems are analytical methods and simulation methods. The calculation result of the analytical approach is accurate, but its calculation amount and the number of components increase exponentially. It is challenging to realize the analysis

ISSN: 2414-1895 DOI: 10.6919/ICJE.202001_6(1).0009

of the risk of a large-scale power system by analytical method. Therefore, the Monte Carlo method is a random test with a computer and finally takes statistical scores on the results of the test with a method of analysis and calculation. It does not require harsh assumptions in line with the actual situation. Because its principle comes from probabilistic calculation theory, its calculation error is inversely proportional to the square root of the number of trials. To reduce the error will undoubtedly increase the calculation time.

Application of Monte Carlo method to the distribution network is proposed as the risk assessment model, and the general idea is as follows: firstly, according to the randomness of each component, and synthesizing the sequence of each component can obtain the operating state sequence of the system. Then the operation of the system is determined in each hour. In the event of a malfunction, its duration and consequences are recorded in the system state transfer cycle, so that the many fingers of the fault are further calculated. When the operating state of 8760h is determined, the risk indicators can be obtained for the year. Performing a simulation of the system for many years, If the requirements of calculation are met, the risk indicators of the system can be considered.
The calculation process is as follows:

(1) Read the average failure rate λ and average repair time of each component and initialize it. The number of years of simulation NY=30, assuming that the first time of simulation h=0.

(2) According to different NY, the influencing factors for the failure rate of each component are calculated, which are $\omega_{life}(t)$, $\lambda(t) = \omega_{life}(t) \times \lambda$. If $NY \leq 2$, the formula of failure rate is(2). If $NY \geq 28$, the formula is(4), otherwise $\omega_{life}(t) = 1$.

(3) The influencing factors for the average repair time of each component is counted, which are $\omega_{source}(t)$, $r(t) = \omega_{source}(t) \times r$, t is the value of an integer-based on h.

(4) The probability of normal weather, bad weather, and catastrophic weather respectively is P_n, P_a, P_m. Sampling the weather condition produces a uniformly distributed random number V. If $V > P_a$, it is the usual weather(x=0); if $P_m < V \leq P_a$, it is the lousy weather(x=1); if $V \leq P_m$, it is the catastrophic weather(x=2).

(5) According to the weather condition x, the corresponding factors which are $_{\text{weather-}\lambda}(t)$ and $\omega_{\text{weather-r}}(t)$ are calculated for the failure rate $\lambda(t)$ and repair time $r(t)$.

(6) Produce a uniformly distributed random number based on each component and get the regular time and fault time by using the conversion formula. It is as follows: $TTF_i = \frac{1}{\lambda_i} \ln U_i, TTR_i = r_i \ln U_i$

(7) Find the smallest part i of TTF and consider that the element is cut off at this time, it presents: $TTF = \min\{TTF_i\}$

(8) Judge the position of malfunction. If it is on the main feeder, the load points can be determined after reconstructing the network. If it is on the branch, it will only affect the load points of the department. Count the load point time T_{up} and fault time T_{down}, $T_{up} = TTF$, $T_{down} = TTR$.

(9) According to the h, the simulation time is $h = h + TTF$.

(10) Determine if $h \times NY$ is higher than simulation time($8760 \times NY$) ., If it is, go to(11), if it is not, go to the(1).

(11) Calculate the load point and risk indicators of system separately.

In the radiating network of the distribution network, the power supply path from the powerpoint to the load point can be considered as a series connection of several components, so the risk index of the load point is the series calculation value of each component.

Load point indicator: the failure rate of load point λ ; average power outage duration at load point r; annual average power outage time of load point U.

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System indicator: failure frequency of system F_f; average failure duration D_f; failure probability of system P_f.

$$F_f = M_{\text{dn}} / \left(\sum_{k=1}^{M_{dn}} D_{\text{dk}} + \sum_{k=1}^{M_{dn}} D_{uj} \right) \tag{16}$$

$$D_{\text{f}} = \sum_{k=1}^{M_{dn}} D_{dk} / M_{dn} \tag{17}$$

$$P_{\text{f}} = \sum_{k=1}^{M_{dn}} D_{dk} / \left(\sum_{k=1}^{M_{dn}} D_{dk} + \sum_{k=1}^{M_{dn}} D_{\text{uj}} \right) \tag{18}$$

In this formula, D_{dk} is the duration of the kth outage; D_{uj} is the duration of the jth running state; M_{dn} and M_{up} are the number of system failures and running states within a specific span respectively.

4. Example

4.1 Case Analysis

This paper takes RBTS Bus-3 as an example to conduct a risk assessment analysis. If only permanent failures are considered, all components can be repaired; If the switching device is not considered to be malfunctioned, the component failure and repair time are subject to exponential distribution. Different types of users data are shown in Tab.1.

Tab. 1 Load date of RBTS Bus-3

Load points	Load point	User type	Load level at each load point		User number
			Peak value	Mean value	
9	1,4-7,20,32,36	Residents of the user	0.8367	0.4684	250
5	11,12,13,18,25	Residents of the user	0.8500	0.4758	230
4	2,15,26,30	Residents of the user	0.7550	0.4339	190
3	39,40,44	Large user	6.9167	4.3886	1
3	41-43	Large user	11.5833	7.3496	1
3	8,9,10	Industrial user	1.0167	0.8472	1
9	3,16,17,19,28,29,31,37,38	Business user	0.5222	0.2886	15
2	14,27	Office structure	0.9250	0.5680	1

4.2 Result Analysis

The schemes in Table 2 are calculated by Monte Carlo Simulation, which considers the risk indicators of the system under three factors that is working-age of component, weather, available repairing resource. Scheme 1 considers the impact of the service life of the component on the risk indicator. In this case, since the component has a much higher failure rate during the run-in and wear phases than the useful life, the failure frequency of the system is lower than that of the scheme 2 Option 3 is much larger. Option 3 considers the impact of available repair resources. Due to its effect on component repair time, the system's failure duration is greater than that of scenario 2. Scheme 4 comprehensively considers the influence of various factors above, so the system's failure frequency, failure duration, and failure probability increase, which also sufficiently proves the risk assessment model of the distribution network considering various influencing factors to be scientific and rational.

It can be seen from the data in Table 3 that the indicators obtained by the analytical method and the Monte Carlo method are consistent. It is difficult to implement the analytical method for the large-scale power system risk assessment, and the advantage of the Monte Carlo method is distinct. The comprehensive risk value calculated by the analytical method and the Monte Carlo simulation method in the example is the value of the risk probability and the risk loss, which are R1=14354.41 yuan and R2= 13553.94 yuan.

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Tab. 2 System risk indicators

Plan	F_f (times/year)	D_f (hours/year)	P_f
1	0.2989	2.7471	0.0029
2	0.2069	1.9243	0.0020
3	0.2063	2.3131	0.0024
4	0.3006	3.4066	0.0036

Tab. 3 Risk indicators at load point

Load point	analytic method				Monte Carlo simulation			
	Λ (times/year)	R (hours/time)	U (hours/year)	Cr (yuan)	Λ (times/year)	R (hours/time)	U (hours/year)	Cr (￥)
1	0.301	11.44	3.44	98.27	0.298	11.38	3.39	97.05
3	0.314	11.17	3.51	6290.87	0.302	11.04	3.33	6016.60
8	0.221	1.94	0.43	1888.23	0.208	2.03	0.42	1842.14
11	0.314	11.17	3.51	102.97	0.321	10.98	3.52	104.40
13	0.301	11.44	3.44	99.83	0.300	11.32	3.40	99.01
21	0.301	11.44	3.44	88.57	0.295	11.24	3.32	87.06
24	0.314	11.17	3.51	101.37	0.302	11.05	3.34	96.99
27	0.321	10.96	3.51	1812.70	0.315	10.98	3.46	18477.53
32	0.288	12.18	3.51	96.73	0.292	12.05	3.52	97.61
38	0.269	12.70	3.41	5711.04	0.256	12.36	3.16	5372.37
41	0.189	1.83	0.34	13377.1	1.83	1.83	0.33	12669.35
44	0.202	1.77	0.36	8315.59	1.75	1.75	0.36	8363.85

5. Conclusion

It is difficult to deal with the influence of random factors in the system by analytical method. The calculated risk index ignores the random variability of failure rate and repair rate of each component, and THE Monte Carlo Simulation method makes up for this shortcoming, so the result is credible. The theoretical analysis of the risk indicators considering a single factor and comprehensively various influencing factors is consistent with the simulation result, which proves that the risk assessment of distribution network operation considering multiple factors has specific theoretical significance and practical engineering value.

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