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Reliability assessment of distribution network considering differentiated end-users demand for reliability

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Abstract. In view of the importance of the distribution network in the power system and the current problem of the fragmentation of the reliability assessment of distribution network considering differentiated end-users demand for reliability index of the distribution network, this paper proposes a comprehensive assessment method for the reliability of the distribution network. Based on the distribution network data obtained from the perception layer of the Internet of Things, the main assessment indices for the reliability of the distribution network based on the power supply capacity and the number of users, and the reference assessment indices for the reliability of the distribution network based on the reliability price are calculated respectively. Then according to the index scoring standards, the reliability assessment result of the distribution network is obtained. A case study is used in this paper to verify the effectiveness of the proposed comprehensive assessment method.

1. Introduction

The reliability assessment index of the distribution system can directly reflect the reliability of the distribution network, which is the basis for evaluating the reliability of the distribution system. When energy storage and renewable energy sources are connected, the original reliability index of the distribution network may not be fully applicable [1]. A new reliability assessment method based on optimization model is proposed, which fully considers the detailed layout and actions of circuit breakers and switches in the distribution network [2]. In terms of feeder selection, the article evaluates the reliability index of the distribution network as part of the model, and handles the most suitable feeder selection by connecting the energy storage unit to the bus [3].

The reliability index system is the basis for studying the reliability of power supply in distribution networks. Many countries in the world have established their own systems. IEEE has established the power supply reliability index system of distribution network from the aspects of frequency, time and number of power outages, which is the most authoritative and recognized reliability index system in the world [4]. Compared with the power supply reliability work of other developed countries [5-6], the power supply reliability index system in China still has the following two deficiencies [7].

(1) Due to the limitations of technical means and historical factors in the development of power grids in China, most of the current statistics and research on power supply reliability indicators focus on medium and high voltage distribution networks. Many scholars have carried out research on the power

supply reliability statistical analysis methods of low-voltage systems. Monitoring realizes the power supply reliability assessment of low-voltage distribution network [8].

(2) In foreign power markets, electric energy is a commodity that can be priced according to quantity and quality. Both power supply and use parties can formulate personalized power supply contracts according to their own needs [9]. In this market environment, the power supply reliability, power quality and user experience that the user really obtains are the focus of both parties' attention [10].

It can be seen that in the future power market environment, power supply companies need to understand the reliability of power supply from the perspective of users and establish a power supply reliability evaluation system for distribution networks that meets the power supply quality requirements of modern power loads.

2. Reliability assessment indexes of distribution network

2.1. Assessment indices based on the number of users

(1) System Average Interruption Frequency Index (SAIFI), unit is times/household. SAIFI-1 represents the average of users of the power supply system during the statistical period, which is defined as follows:

$$SAIFI\text{-}1=\frac{\sum N_i}{N_T} \tag{1}$$

where i represents a power outage event, N_i represents the number of power outage users in each power outage event in the specified time period, and N_T represents the total number of users in the area.

(2) Momentary Average Interruption Frequency Index(MAIFI), unit is times/household. MAIFI represents the average number of short-term power outages of users of the power supply system:

$$MAIFI=\frac{\sum IM_i N_{mi}}{N_T} \tag{2}$$

where IM_i represents the number of short-term power outages, and N_{mi} represents the number of outage users for each short-term power outage during the statistical period.

(3) System Average Interruption Duration Index (SAIDI), unit is hour/household.

$$SAIDI=\frac{\sum r_i N_i}{N_T} \tag{3}$$

where r_i is the time of each power outage event.

(4) Average Service Availability Index (ASAI), unit is %. ASAI is defined as follows:

$$ASAI=\frac{N_T\times(\text{Hours in a year})-\sum r_i N_i}{N_T\times(\text{Hours in a year})} \tag{4}$$

where the hours in a year in the formula is 8760 hours in a normal year and 8784 hours in a leap year.

(5) Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events ($CEMSI_n$), unit is %. $CEMSI_n$ is defined as follows:

$$CEMSMI_n=\frac{CNT_{(k>n)}}{N_T} \tag{5}$$

where $CNT_{(k>n)}$ represents the number of users with more than n power outages during the statistical period.

(6) Customers Experiencing Long Total Interruption Durations (CELID-t), unit is %.

$$CELID\text{-}t=\frac{CN_{(k>n)}}{N_T} \tag{6}$$

where $CN_{(k>n)}$ represents the number of users whose cumulative power outage time is greater than n hours during the statistical period.

2.2. Asessment indices based on the power supply capacity

(1) Average System Interruption Frequency Index (ASIFI), unit is times. ASIFI is defined as follows:

$$ASIFI = \frac{\sum L_i}{L_T} \tag{7}$$

where L_i represents the capacity of each power outage, and L_T represents the total power supply capacity of the system.

(2) Average System Interruption Duration Index (ASIDI), unit is hour.

$$ASIDI = \frac{\sum r_i L_i}{L_T} \tag{8}$$

(3) Average Energy Not Supplied Due to Interruption (AENS), unit is kWh/household.

$$AENS = \frac{\sum W_i}{N_T} \tag{9}$$

where W represents the lack of power supply per power outage.

2.3. Assessment indices based on the reliability price

(1) Customers Average Reliability Price Increment (CARPI), unit is ¥/kWh.

$$CARPI = \frac{\sum \Delta P_j}{N_T} \tag{10}$$

where ΔP_j represents the increase in the reliability price of the j-th power supply user during the statistical period, and N_T represents the total number of users in the area.

(2) System Average Interruption Duration Reduced by Reliability Price (SAIDRRP), unit is hour/household.

$$SAIDRRP = \mu_{SAID} \frac{\sum \Delta P_j \cdot SAID}{P_0 N_T} \tag{11}$$

where $SAID$ represents the average power outage time of the system, P_0 is the basic electricity price, and μ_{SAID} represents the proportional coefficient corresponding to the average power outage time.

(3) System Average Interruption Frequency Reduced by Reliability Price (SAIFRRP), unit is times/household.

$$SAIFRRP = \mu_{SAIF} \frac{\sum \Delta P_j \cdot SAIF}{P_0 N_T} \tag{12}$$

where $SAIF$ represents the average power failure frequency of the system, and μ_{SAIF} represents the proportional coefficient corresponding to the average power failure frequency of the system.

(4) Average Energy Not Supplied Reduced by Reliability Price (AENSRRP), unit is times/household.

$$AENSRRP = \mu_{AENS} \frac{\sum \Delta P_j}{P_0 N_T} AENS \tag{13}$$

where $AENS$ represents the average power outage and lack of power supply for users, and μ_{AENS} represents the proportional coefficient corresponding to the power outage and lack of power supply.

3. Comprehensive assessment method of distribution network reliability

3.1. Comprehensive assessment index system of distribution network reliability

The comprehensive assessment index system of distribution network reliability includes 13 types of distribution network reliability assessment indexes. Among them, there are 6 indexes based on the number of users, and 3 based on power supply capacity, and 4 indexes based on the reliability price.

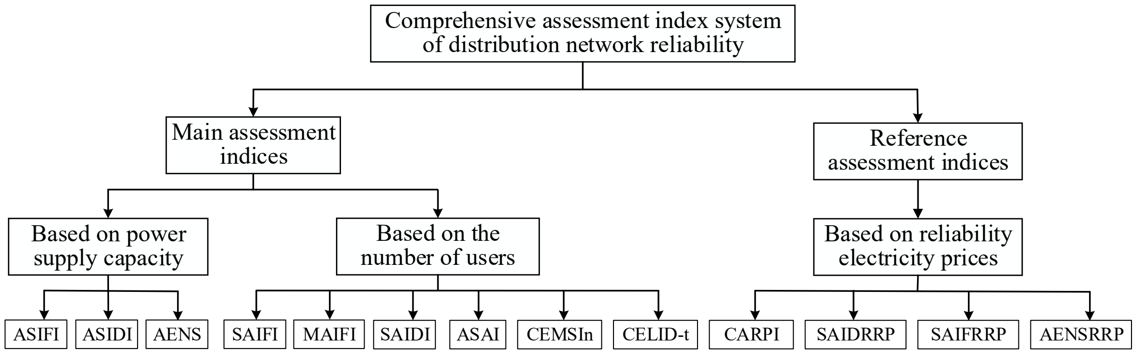

Figure 1. Comprehensive assessment index system of distribution network reliability.

3.2. Determination of index scoring standards

This paper is based on the three types of membership functions of positive index, negative index and intermediate value index, combined with the guidance of many electric power experts to determine the index scoring standards, which are shown in Table 1.

Table 1. Scoring standards for main assessment indexes of distribution network reliability.

Index	Score values corresponding to different indexes					
	100	90 points	80 points	60 points	40 points	20 points
SAIFI(times/household)	0	0.3	0.65	1.2	2	3.5
MAIFI(times/household)	0	0.1	0.25	0.4	0.7	1.2
SAIDI(hour/household)	0	0.35	0.8	1.8	2.5	4
ASAI(%)	99.999	99.99	99.98	99.965	99.95	99.925
CEMSI-3(%)	0	1	5	10	15	20
CELID-2h(%)	0	3	9	15	21	27
ASIFI(times/household)	0	0.35	0.7	1.4	2.2	3.8
ASIDI(hour/household)	0	0.38	0.9	2	2.8	4.5
AENS*(‱)	0	0.3	0.8	1.8	2.5	4

4. Case study

4.1. Initial data of distribution network

In this paper, data from three different regional distribution networks A, B, and C are used for example analysis. The basic parameters of distribution networks A, B, and C are shown in Table 2.

Table 2. Basic parameters of distribution network A, B, C.

Network	Number of users	Total system capacity	Daily power supply	Planning level
A	834	15.27MVA	274.86MWh	A+
B	968	8.74MVA	136.34MWh	A
C	1099	5.89MVA	93.53MWh	B

This paper selects three distribution network outage data in the same year in Table 3.

Table 3. Partial outage data of distribution network A, B, C.

Network	Total power outages	Total power outage duration	Total number of users with outages	Total outage capacity
A	2	61min	71	1.17MVA
B	4	154min	267	2.20MVA
C	6	422min	765	3.96MVA

4.2. Index calculation results

The data is substituted into the index calculation formula to calculate the main reliability assessment indexes of distribution network based on the power supply capacity and the number of users. The results are shown in Table 4.

Table 4. Calculation results of main reliability assessment indexes of distribution network.

Index	Network A	Network B	Network C
SAIFI(times/household)	0.08513	0.27583	0.69608
MAIFI(times/household)	0.05875	0.09298	0.19017
SAIDI(hour/household)	0.02844	0.22204	0.90861
ASAI(%)	99.99968	99.99747	99.98963
CEMSI-3(%)	0	2.9959	6.1874
CELID-2h(%)	0	3.2025	13.0118
ASIFI(times/household)	0.07662	0.25176	0.67175
ASIDI(hour/household)	0.02724	0.20267	0.88403
AENS*(‱)	0.374	1.189	2.845
SAIFI(times/household)	0.03109	0.23136	1.00916

It can be seen that the reliability indicators of distribution network A are better than those of distribution networks B and C, and distribution network B has higher power supply reliability than distribution network C.

4.3. Scoring results

According to Table 1, the three main indicators of distribution network reliability assessment were scored, and the results are as follows:

Table 5. Scoring results of main reliability assessment indexes of distribution network.

Index	Network A	Network B	Network C
SAIFI(times/household)	97.17	90.81	78.32
MAIFI(times/household)	94.13	90.70	83.99
SAIDI(hour/household)	99.19	93.66	77.83
ASAI(%)	100	91.70	80.37
CEMSI-3(%)	100	85.01	72.50
CELID-2h(%)	100	89.33	66.63
ASIFI(times/household)	97.81	92.80	80.81
ASIDI(hour/household)	99.28	94.67	80.31
AENS*(‱)	98.96	92.29	77.91
CARPI(¥/kWh)	0.04616	0.013202	0
SAIFRRP(times/household)	0.002595 (3.045%)	0.002466 (0.899%)	0
SAIDRRP(hour/household)	0.0007678 (2.700%)	0.001869 (0.841%)	0
AENSRRP(kWh/ household)	0.01108 (2.961%)	0.01064 (0.889%)	0

Figure 2 shows the radar chart of the scoring results of the three distribution network reliability indicators. It can be seen that all indicators of distribution network A are greater than 90 points, and the overall reliability is the best. Among them, MAIFI is relatively low, indicating that A is reducing the number of short-term power failures in terms of further improvement. All indicators of distribution network B score above 85 points, which has good reliability, but the score is relatively low on CEMSI-3, and the system should be focused on the weak link with a large number of internal outages. Most indicators of the distribution network C are above 75 points, showing that efforts should be made to reduce the occurrence of power outages and improve the overall reliability of the system.

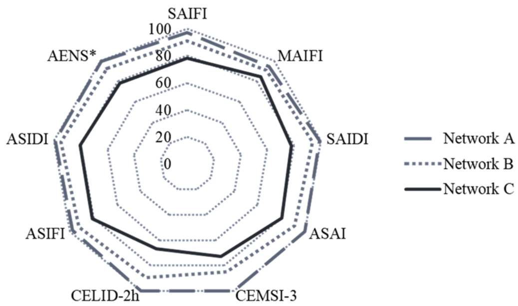

Figure 2. Radar chart of reliability index score of distribution network A, B, C.

5. Conclusion

This article proposes a comprehensive assessment method for the reliability of the distribution network, and the following conclusions are obtained:

(1) According to the theory of value engineering, the influence of the increment of reliability electricity price on system reliability index is analysed, and based on this, the reliability assessment reference index based on reliability electricity price is innovatively proposed.

(2) Combining the selected main indices for reliability assessment based on the number of users and power supply capacity, a comprehensive assessment index system for the reliability of the distribution network is constructed, and index calculation and scoring methods are given.

(3) The results show that the constructed comprehensive assessment index system for the reliability of the distribution network can comprehensively and objectively reflect the reliability performance of all aspects of the distribution network.

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