

A study on reliability of power customer in distribution network

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Abstract. The existing power supply reliability index system is oriented to power system without considering actual electricity availability in customer side. In addition, it is unable to reflect outage or customer's equipment shutdown caused by instantaneous interruption and power quality problem. This paper thus makes a systematic study on reliability of power customer. By comparing with power supply reliability, reliability of power customer is defined and extracted its evaluation requirements. An indexes system, consisting of seven customer indexes and two contrast indexes, are designed to describe reliability of power customer from continuity and availability. In order to comprehensively and quantitatively evaluate reliability of power customer in distribution networks, reliability evaluation method is proposed based on improved entropy method and the punishment weighting principle. Practical application has proved that reliability index system and evaluation method for power customer is reasonable and effective.

1. Introduction

Research of power supply reliability in China has been carried out from the perspective of power system instead of customer experience, and only taken middle and high voltage customers into account [1-3]. However, with development of power grid and electricity market, existing evaluation index system has been gradually revealed its defects. Firstly, due to faults in low voltage distribution network, untimely information transmission, complex nonlinear load and others factors, the actual power reliability in customer side is always worse than reliability data released by power company. The existing reliability enhancement work thus can't improve customer experience effectively. Secondly, traditional evaluation index system, which is oriented to power system without considering electricity availability in customer side, has been unable to meet the new demand for precise management in distribution network and development of power sale market. Thirdly, it also does not apply to active distribution network or smart grid whose operation demand a more accurate reliability index system to reflect customer condition.

In Europe and America, IEEE Standard 1366TM—2012 is widely applied in reliability assessment of distribution network, and its statistical scope includes all voltage level customers [4-6]. Reference [4] provides an index system to discuss power supply reliability from frequency, duration and reliability rate, including sustained interruption indices, load based indices and momentary indices. In [5], reliability problem is boiled down to three aspects: adequacy, security and power quality, but current reliability standards at home and abroad rarely consider influence of power quality. In China,



there have been many researches and experiments carried out to study reliability of power customer. These researches are mainly focused on finding a feasible method to expand reliability statistics scope to low voltage customer [2,3]. Besides, the relationship and conversion method between power quality and reliability were studied [7,8].

However, there is still a lack of unified definition and assessment system for reliability of power customer. To solve this problem, this paper proposed the concept, index system and a comprehensive evaluation method for distribution network reliability of power customer. Besides, several 10kV distribution network are chosen from Guangdong power grid to verify the feasibility and effectiveness of index system and evaluation method.

2. Reliability of Power Customer

2.1. Difference between Reliability of Power Customer and Power Supply Reliability

Power supply reliability aims to reflect continuous power supply ability of power system, while reliability of power customer needs to reflect actual electricity availability and customer's using experience as well as expanding reliability statistics scope to low voltage customer. Referring to standard [4], reliability of power customer in distribution network is defined as the probability that customer can continuously obtain qualified electrical energy from power grid during reporting period.

As shown in Fig.1, power supply reliability analysis takes middle voltage distribution network into account without considering the grid outside point of common coupling (i.e. PCC). The statistical scope for reliability of power customer should be extended to customer side including customers and power grid outside the PCC. The monitoring point is set in customer's electricity meter. Cooperating with power supply reliability, it can cover the whole distribution network and customers.

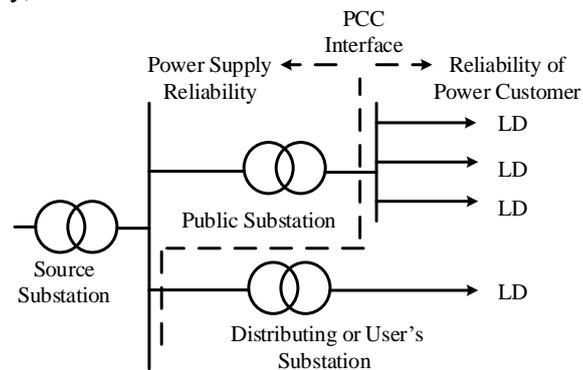


Figure 1. Statistical Scope of Power Supply Reliability and Reliability of Power Consumer.

Reliability of power customer is required to consider all situations that customer can not normally use electric power. According to its definition and statistical scope, there are three requirements for reliability evaluation of power customer.

- 1) The power continuity in customer side should be evaluated in detail.
- 2) The power availability in customer side should be evaluated, mainly including outage and equipment shutdown caused by power quality problems, in the case that no interruption happens in the power system.
- 3) The reliability difference between customer side and the PCC should be evaluated to find weak link of distribution network reliability.

2.2. Evaluation Index System

The existing power supply reliability index system is oriented to power system without considering actual electricity availability in customer side. It is unsuitable for reliability analysis of power customer. Based on three evaluation requirements and relevant standards, an evaluation index system is established in this paper, including 7 customer indexes and 2 contrast indexes. Table 1 shows evaluation index system for reliability of power customer.

Table 1. Reliability Index System.

Classification	Indexes	Notation	Unit
Customer Indexes	Reliability probability of power customer	RP	%
	Average temporary interruption duration	ATID	h
	Average sustained interruption duration	ASID	h
	Average interruption frequency	AIF	times
	Repeated interruption probability	RIP	%
	Equipment shutdown frequency	ESF	times
	Voltage eligibility rate	VER	%
Contrast Indexes	Difference in reliability probability	ΔRP	%
	Difference in interruption frequency	ΔIF	times

2.2.1. Customer indexes. Aiming to reflect real reliability level of power customers, statistical scope of customer indexes is extended to low voltage customers. Each customer separately charged by power company is taken as a statistical unit. Referring to power supply reliability indexes, five customer indexes are proposed to describe the power continuity in customer. Besides, two indexes are designed to represent power availability and power quality.

Existing standards generally use duration, frequency and reliability probability to evaluate power supply reliability which can basically reflect continuity of power supply. Three indexes widely used in traditional power supply reliability analysis is reliability on service (RS), average interruption hours of customer (AIHC), and average interruption times of customer (AITC). In this paper, similar indexes continue to be used, but their statistical unit is extended to each customer separately charged. With reliability improvement of power grid, proportion of temporary interruption is increasing. Temporary interruption ignored in power supply reliability analysis should be included into reliability analysis of power customer. So two duration indexes are set to reflect temporary interruption and sustained interruption respectively. In view that average index can't express the non-uniform distribution of reliability in distribution network, repeated interruption probability index is designed to judge whether outage densely occurred in some customers.

The outage or equipment shutdown in customer side caused by instantaneous interruption and power quality problem are increasingly common. This case has little influence on security of power system, but its harm to customers is as serious as sustained outage. Therefore, equipment shutdown frequency and voltage eligibility rate are added into customer indexes to represent power quality and availability.

Seven customer indexes are defined as follow:

1) Reliability probability (RP) of power customer is defined as the rate between duration that customer can obtain qualified power supply and total statistics duration.

2) Average temporary interruption duration(ATID) of power customer is the average temporary interruption hours of all customers during a predefined period.

According to [4], temporary interruption and sustained interruption is distinguished by outage duration. If duration is less than or equal to five minutes, it is defined as temporary interruption, otherwise it is called sustained interruption.

3) Average sustained interruption duration (ASID) of power customer is the average sustained interruption hours of all customers during a predefined period.

4) Average interruption frequency (AIF) of power customer indicates how often the average customer experiences a sustained or temporary interruption over a predefined period.

5) Repeated interruption probability (RIP) is defined as the proportion of customers whose interruption frequency is more than 3 times a year.

6) Equipment shutdown frequency (ESF) is how many times customers suffer equipment shutdown due to power quality in a year.

7) Voltage eligibility rate(VER) is defined as the rate between duration that voltage of customer satisfies standards and total statistics duration.

2.2.2. *Contrast indexes.* The contrast indexes are calculated by power supply reliability indexes and customer indexes. It is used to find difference between power supply reliability and actual reliability of power customer in a distribution network. It also reflects reliability promotion space in low voltage distribution network and service quality. It is considered that most of power quality problems influenced customers are caused by the interference from nearby, so contrast indexes didn't consider power availability. The definition of two contrast indexes is presented as follow.

1) Difference in reliability probability (ΔRP) is the probability difference between reliability of power customer and power supply reliability in a distribution network.

2) Difference in interruption frequency (ΔIF) is the frequency difference between interruption counted in customer side and interruption counted in middle voltage distribution network.

3. Reliability evaluation method

The procedure of comprehensive evaluation method designed for reliability of power customer shows as follow. 1) Through data pretreatment, the original data is converted to normalized and dimensionless index data. 2) Weights of each index are calculated by improved entropy method. 3) The final weight matrix is obtained according to the punishment weighting principle. 4) Comprehensive evaluation result is determined by the weighted sum of all indexes.

3.1. Improved entropy method

If all entropy values are all close to 1, traditional entropy method will over-enlarge gap and lead to unreasonably weight. This problem will occur in reliability evaluation when research objects are all high reliability distribution networks [9]. Therefore, this paper uses an improved entropy method, which not only overcome defect of traditional entropy method, but also maintain the ability to enlarge local difference.

According to the improved entropy weight method, weight of each index can be calculated as follows:

$$W_j = \begin{cases} (1 - \bar{H}^{35.35})W_{0j} + \bar{H}^{35.35}W_{3j}, & H_j < 1 \\ 0, & H_j = 1 \end{cases} \quad (1)$$

Where W_j is the weight of index X_j , H_j is the entropy of index X_j , and \bar{H} is average value of all entropy values that are not 1.

3.2. Calculation of comprehensive evaluation result

The evaluation for reliability of power customer is so strict that any unqualified index can reflect the low reliability level of a distribution network. The evaluation result calculated by linear weighted sum method is unsuitable to highlight characteristics of reliability. Therefore, this paper proposes a punishment weighting principle to obtain reasonable weight matrix. Assuming that indexes after pretreatment are all profit-type indexes, when index value b_{ij} (i.e. the j th index value of the i th distribution network after pretreatment) is more close to 1, distribution network S_i will perform better in index X_j . To enlarge gap and emphasize effect of unqualified index, the index of a certain distribution network will weight zero if its value is better than average value, otherwise maintain its weight.

The final weight β_{ij} of each element in the index data matrix $\{b_{ij}\}$ is chosen as follow.

$$\beta_{ij} = \begin{cases} W_j, & b_{ij} \leq \bar{b}_j \\ 0, & b_{ij} > \bar{b}_j \end{cases} \quad (2)$$

Where, \bar{b}_j represents the average value of column j in matrix $\{b_{ij}\}$. The comprehensive evaluation value of distribution network S_i is denoted as y_i .

$$y_i = \sum_{j=1}^9 \beta_{ij} |b_{ij} - \bar{b}_j| \quad (3)$$

In this comprehensive evaluation method, a lower comprehensive evaluation value indicates higher reliability of power customer.

4. Application examples and analysis

4.1. Data and evaluation results

Ten 10kV distribution networks in Guangdong power grid and their customers are investigated and analysed with the index system and evaluation method presented above. These distribution networks are recorded as S1 ~ S10. Table 2 and 3 show the original index data of 10 evaluated distribution networks and the comprehensive evaluation results using different index systems. The first three indexes in Tab.2 are power supply reliability index system (i.e. RS, AIHC, AITC), and others indexes are reliability index system of power customer (i.e. RP, ATID, ASID, AIF, RIP, ESF, VER, Δ RP, Δ IF).

Table 2. Original Data of Each Distribution Network.

	RS/%	AIHC/h	AITC/times	RP/%	ATID/h	ASID/h	AIF/times	RIP/%	ESF/times	VER/%	Δ RP/%	Δ IF/times
S ₁	99.92	6.99	1.58	99.914	0.21	7.32	1.77	2.1	0	97.84	0.061	0.19
S ₂	99.917	7.24	1.58	99.913	0.18	7.43	1.76	5.3	57	96.78	0.042	0.183
S ₃	99.879	10.63	3.81	99.877	0.09	10.66	3.82	6.8	0	97.24	0.014	0.008
S ₄	99.86	12.24	4.52	99.859	0.33	12.01	4.73	4.7	35	94.29	0.011	0.211
S ₅	99.832	14.76	5.09	99.825	0.3	15.07	5.14	20.7	10	95.78	0.07	0.05
S ₆	99.735	23.19	6.16	99.729	0.53	23.18	6.48	35.7	3	96.55	0.06	0.315
S ₇	99.642	31.35	7.81	99.621	0.28	32.88	7.89	32.4	2	96.41	0.206	0.081
S ₈	99.63	32.45	7.4	99.613	0.25	33.68	7.51	44	6	96.32	0.169	0.113
S ₉	99.523	41.77	13.12	99.517	0.25	42.07	13.3	65	8	95.93	0.063	0.184
S ₁₀	99.365	55.63	14.53	99.358	0.28	55.93	14.65	78	16	95.88	0.066	0.119

Table 3. Comprehensive Evaluation Results.

	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉	S ₁₀
Evaluation value with traditional indexes	0	0	0	0	0	0	0.112	0.140	0.425	0.645
Evaluation value with new indexes	0.009	0.064	0	0.119	0.022	0.101	0.113	0.121	0.257	0.388

4.2. Comparison analysis of index system

1) Comparing two index systems, it is found that power supply reliability index data obtained from power system can't reflect the actual reliability in customer side. Specifically, RP is generally lower than the RS, and AIF is higher than AITC. The sum of ATID and ASID is always longer than AIHC. Thus, only when index is extended to customer side will customer's reliability experience be accurately reflected.

2) Various factors affecting reliability are comprehensively considered in reliability index system of power customer, such as high repeated interruption probability and unacceptable power quality. The ESF index of S2 is greatest among ten distribution networks indicating that this region has serious power quality problems or contains lots of sensitive customers. Distribution network S7 has the greatest contrast indexes value which means that reliability of low voltage distribution network should be improve.

Obviously, reliability index system of power customer proposed in section 2 is more detailed and comprehensive than traditional power supply reliability index system. It is helpful to describe overall reliability level and defects of distribution network from continuity and availability.

4.3. Comparison analysis of evaluation results

1) In traditional power supply reliability evaluation, only three indexes are used and reliability rank of 10 distribution networks in descending order is S1,S2,S3,S4,S5,S6,S7,S8,S9,S10. As to reliability evaluation of power customer, results are calculated with nine indexes and reliability rank in descending order is S3,S1,S5,S2,S6,S7,S4,S8,S9,S10. The reliability evaluation result of power customer is more close to customer satisfaction survey results which proves the index system and evaluation method presented in this paper is more reasonable and accurate.

2) The distribution networks, classed as low reliability level in traditional power supply reliability evaluation, will get the same conclusion in reliability evaluation of power customer. However, the qualified distribution networks in traditional evaluation do not always perform well in the reliability evaluation of power customer, such as distribution network S4 and S2.

Traditional power supply reliability evaluation roughly reflect continuity of power supply, while reliability evaluation method of power customer established in this paper more accurately described reliability and customer experience from both continuity and availability. Furthermore, power company and customer can easily observe the reliability level and improvement space of distribution network through evaluation results.

5. Conclusion

With development of power sale market, power company and customer have gradually produced their own evaluation demands for power reliability. Reliability evaluation for power customer will become an inevitable demand for precise management in distribution network and pricing according to quality.

In this paper, the concept and evaluation requirements for reliability of power customer are discussed. Secondly, a reliability index system for power customer are establish, consisting of seven customer indexes and two contrast indexes. Finally, based on improved entropy method and the punishment weighting principle, reliability evaluation method suitable for power customer in distribution network are put forward.

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