A Comprehensive Evaluation for the Power Supply Reliability in Distribution Network based on Improved Entropy Method

Tao Zhang¹, Hao Liu¹*, Qinghui Zeng¹, Guowei Li¹, Rongbo Luo¹, Hui Li¹ and Junbo Wang¹

¹Foshan Power Supply Bureau of Guangdong Power Grid Limited Liability Company, Foshan, 528011, China

*77163134@qq.com

Abstract. Considering power quality, a user-oriented and extended index system of power supply reliability has been built, and a comprehensive evaluation of power supply reliability based on improved entropy method in distribution network has been designed in this paper. Firstly, the paper has built an extended power supply reliability index system from 3 following aspects: the supply side, user side as well as the contrast, therefore, 7 new user-side indexes can reflect the real level of the power supply reliability by its continuity and availability, and 2 contrast indexes can reflect power supply reliability of the line among users in low and medium voltage; Secondly, considering its requirements and index characteristics, a comprehensive evaluation based on improved entropy method has been established. An initial index weights can be attained by this method, then, the weight matrix can be determined by a principle called ‘overflowing-value punishment’. What’s more the comprehensive values can also be attained after weighting and summation. Finally, its effectiveness can be verified by the result of case.

1. Introduction

A system-oriented index system is used to evaluate the power supply reliability in domestic distribution network now, and only users in middle and high voltage are involved [1-2]. Even these indexes can be measured in user side in part of statistical areas, only the problem that measuring points are energized or not is taken into consideration, rather than the power quality problems that affect regular power consumption. What’s more, the actual power consumption reliability is not accurately and roundly presented, which doubles the work. With the increasing requirements of power quality in all kinds of electricity equipment, a poor power quality may lead to more and more power interruptions among users or equipment outages in industrial and agricultural manufacture. On the other hand, the reform of power market and an easing policy of the electricity price make the policy that pricing by quality the mainstream. Thus, how to make the power supply reliability in distribution network close to users’ actual power consumption experience is inevitable problems for power companies. Therefore, it’s necessary to take the effect of power quality into consideration, broaden the definition of power supply reliability, build an index system and a comprehensive evaluation to reflect users’ real consumption experience.

The existed study mainly focuses on exploring feasibility methods from reliability forecast and calculation departments extend to users [2-4], for example, probability statistics and fault simulation. Besides, the power supply reliability evaluation mainly focuses on the voltage dip and correcting the
power supply reliability calculation [5-6]. Considering user experience, it is not simply adding power quality indexes on the evaluation of power supply reliability, the difference among users’ tolerance should be taken into consideration. On this basis, we should investigate the influence of power quality on the actual user-side power supply reliability. The reliability research and evaluation considering power quality in the distribution network in China are just on initial stage. The evaluation index system is still imperfect, lacking of comprehensive evaluation to adapt the characteristics of reliability evaluation.

In order to solve the above-mentioned problems, this paper propose an improved entropy method to comprehensively evaluate the power supply reliability. Firstly, considering the existing evaluation indexes about power supply reliability and power quality from the user side, then building an extended power supply reliability index system. According to the improved entropy method and the principle of ‘overflow punishment’, designing an arithmetic of the power supply reliability in distribution network is the next task. At last, its effectiveness can be verified by making a comprehensive evaluation based on the statistics of one certain power supply station.

2. Extension of the power supply reliability indexes

2.1. Comprehensive evaluation index system
To reflect the actual experience from users in low and medium voltage to the power supply reliability comprehensively, the index system, on the one hand, should extend its statistical range to user side, on the other hand, need to enrich the content of power supply reliability and take the influence of power quality into account. This paper takes the relevant standard of power supply reliability in the system in China and other countries as a reference, and considering different statistical ranges, the primary indexes can be divided into 3 parts: supply-side indexes, user-side indexes and contrast indexes. Connecting with the actual situation of power companies and two evaluation keys of power supply reliability in distribution network, secondary indexes which reflect the power supply reliability are selected from each primary index. Considering the impact of power quality, an expended index system for power supply reliability has been built, which is shown as Tab 1.

| Primary indexes                      | Secondary indexes                                      |
|--------------------------------------|--------------------------------------------------------|
| Supply-side indexes                  | Reliability on service (RS)                            |
|                                      | Average interruption hours (AIH)                       |
|                                      | Average interruption times (AIT)                       |
|                                      | Average electricity shortage (AES)                     |
|                                      | Reliability on service of customer (RSC)               |
|                                      | Average temporary interruption duration(ATID)          |
|                                      | Average sustained interruption duration (ASID)         |
| User-side indexes                    | Difference in reliability on service ( Δ RS)           |
|                                      | Difference in interruption times ( Δ AIT)              |
| Contrast indexes                     | Difference in reliability on service ( Δ RS)           |
|                                      | Difference in interruption times ( Δ AIT)              |

From the view point of users, the expended power supply index system takes both the continuity and availability into consideration, which covers the shortage of the traditional one and reflect actual
outages in user side as well as power quality problems. At the same time, with the comparison among indexes, problems for example, the reliability in low-voltage distribution networks and the efficiency of information reply, can be found. Therefore, it provides the power companies with instruction about improving users’ power supply reliability and the electricity consumption experience, what’s more, it can be effective reference indexes priced by reliability.

2.2. Supply-side indexes
Supply-side indexes are used for reflecting power supply reliability of middle voltage users and the level of power supply reliability in distribution network, regarding middle voltage users as statistical units, which means one 10(6 or 20) kV distribution transformer can be seen as a statistical unit of public transformers, while one electric energy measuring point can be seen as a statistical unit of specialty transformers.

Power supply reliability can be widely evaluated by frequency, duration and reliability these 3 aspects at home and abroad now [7-9], what’s more, indexes to measure the load loss and electricity are also involved in North America. Therefore, the main reliability indexes defined in the national standard [8] are still used in this paper. Besides power supply reliability, interruption times and interruption frequency, grid companies now take the average power supply shortage into consideration to evaluate the influence degree and scope of outage.

2.3. User-side indexes
User-side indexes are used to reflect the real degree of power supply reliability. The statistical range should be promoted to low-voltage customers and regard an electricity customer who accept the one power supply company’s metering and charging as a statistical unit, including 380V/220V as well as higher voltage class users with independent measurement. However, those outages caused by users’ self-operating, self-maintaining and self-managing power supply equipment should be excluded.

Not only common power supply reliability indexes which extending to the user side are involved in user-side indexes, but the newly-built indexes that reflect outages from other dimensions. The reliability, duration and frequency indexes can be extended to low-voltage user side first, which means using indexes like user-side power supply reliability, the average interruption hours as well as the average interruption times to evaluate.

For reasons of the metering accuracy, reclosing and so on, only the interruptions more than 3 or 5 minutes in the power supply side in practical statistics are involved. With the improvement of the grid reliability, the proportion of short-time outages are increasing gradually. While there are large differences in receptivity among users, it is not rational to consider persistent outages only. Therefore, average interruption time indexes are set respectively for 2 kinds of accidents in this paper. According to the national standard DL/T 836-2012, the duration of interruption no longer than 3 minutes can be defined as short-time outage, and the longer interruption is defined as persistent outage. So, the former condition is involved in short-time outage statistics, the latter is involved in persistent outage statistics.

To the problem that the users’ average indexes can’t reflect the uneven distribution of low-voltage distribution network reliability and the interruptions concentrate on certain customers, repeated interruption probability index, which means the proportion of users with outages more than 3 times a year is involved in this paper.

Seven user-side indexes basically reflect the real level of users’ power supply reliability. They can also be regarded as a consideration factor of improving users’ consumption experience or an evaluation criterion which pricing by reliability and quality.

2.4. Contrast indexes
Contrast indexes can be calculated by supply-side indexes and user-side indexes, which is intended to reflect the differences between supply-side indexes reliability and user-side indexes in distribution network and show the improvement room of low-voltage line reliability in distribution network and the level of service, such as the delivery of replying information. In this paper, the power quality in
supply-side is considered basically qualified, and most of users’ power quality problems are result from interference source nearby. Therefore, contrast indexes about availability are not established.

3. Evaluation process designing
The process of power supply reliability comprehensive evaluation in distribution network which designed in this paper can be expressed as follow: 1) Pre-processing the initial data, which makes all kinds of indexes transforming into dimensionless extra-large normalized indexes data. 2) Calculating the weight of each indexes by improved entropy method. 3) Getting the final weight matrix according to the principle: indexes which are superior to average level of one certain will clear the weight, while the rest remains. 4) By weighted summation, we can get the comprehensive evaluation value.

3.1. Improved entropy method
The entropy of the index $X_j$ can be expressed as:

$$H_j = -\frac{1}{\ln m} \left( \sum_{i=1}^{m} f_{ij} \ln f_{ij} \right)$$

(1)

In the above formula, if $f_{ij}=0$, we can make $\ln f_{ij}=0$; $0 \leq H_j \leq 1$, if $H_j =1$, which means the $b_{ij}$ is equal for each $X_j$.

We can get the weight of index $X_j$ by using entropy weight method:

$$\omega_j = \begin{cases} \left(1-\frac{35.35}{H_j}ight)\omega_{ij}, & H_j < 1 \\ 0, & H_j = 1 \end{cases}$$

(2)

3.2. Comprehensive evaluation of power supply reliability
It’s relatively harsh to evaluate power supply reliability, any index unqualified can reflect the low-level reliability in distribution network. However, this feature cannot be better reflected by traditional linear weighted summation and calculation method of comprehensive evaluation. Therefore, a weighting method with the feature of value-overflooding punishment is proposed in this paper to get the comprehensive evaluation value of power supply reliability. To scatter the degree and highlight the effect of unqualified indexes. For the value of indexes less than the average, improved entropy method is used to weight. For those higher, we regard them as 0, which means the weight of each index in the matrix $\{b_{ij}\}$ can be expressed as:

$$\beta_{ij} = \begin{cases} \omega_j, & b_{ij} \leq \bar{b}_j \\ 0, & b_{ij} > \bar{b}_j \end{cases}$$

(3)

And the comprehensive evaluation value of $S_i$ can be expressed as:

$$y_i = \sum_{j=1}^{13} \beta_{ij} \left| b_{ij} - \bar{b}_j \right|$$

(4)

According to the calculation method of comprehensive evaluation value, the less number of indexes lower than the average level, the smaller the differences to the average level and the comprehensive evaluation value is, also means the better the objective's power supply reliability.

4. Case analysis

4.1. Case data and calculation results
Based on the above designed power supply reliability index system in distribution network and comprehensive evaluation method, the investigation on one certain city’s partial 10kV distribution network in Guangdong Power Grid as well as customers. 10 distribution networks are selected to be the objective of case analysis and written respectively for $S_1$ to $S_{10}$. For lack of space, the radar map in this paper about the comparison between $S_4/S_7/S_{10}$. For lack of space, the radar map in this paper about the comparison between $S_4/S_7/S_{10}$. For lack of space, the radar map in this paper about the comparison between $S_4/S_7/S_{10}$.
By comparison, there are large differences between the supply-side reliability index data and the degree of users’ true reliability, therefore, only extent indexes to user side can truly reflect the experience of the reliability. What’s more, the expanded power supply reliability index system after considering power quality can reflect incidents like high repetitive outage rate and poor power quality, which affects the power supply reliability well, at the same time, the continuity and availability are also combined. For example, the repetitive outage rate in distribution network can reach up to 65%, since on the one hand, the average interruption times can be high, on the other hand, there can be a weak area of reliability in distribution network; part of equipment with the most off-stream times in the distribution network \( S_1 \), shows that there are severe power quality problems many sensitive users in this area; the distribution network \( S_6 \) has the lowest voltage qualified rate, and the off-stream times of part of equipment are also high at the same time, which reflects the low degree of the user-side power availability, and the equipment breakdowns caused by voltage quality problems like voltage dip are also frequent. Besides the indexes about power availability has reached the average level in distribution network \( S_4 \), while it is slightly lower than the average level in power supply side and user side, especially in middle and low voltage users, the difference is the most obvious, which means the reliability of from outgoing lines in transformer area to users’ incoming lines is relatively low.

The weight determined by improved entropy method and the comparison result of comprehensive evaluation in two index systems are listed respectively in Tab 2 and Tab3.

**Table 2.** The weight of each index in two index systems

| Index Weight | RS | AIH | AIT | AES | RSC | ATID | ASID | AITC | RIP | ESF | VER | Δ RS | Δ AIT |
|--------------|----|-----|-----|-----|-----|------|------|------|-----|-----|-----|------|------|
| 0.0757       | 0.0757 | 0.0892 | 0.0855 | 0.0765 | 0.0629 | 0.0765 | 0.0897 | 0.0867 | 0.0620 | 0.0670 | 0.0532 | 0.0994 |

**Table 3.** The comprehensive evaluation results of two index systems

| Evaluation value with traditional indexes | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|------------------------------------------|----|----|----|----|----|----|----|----|----|-----|
| 0                                        | 0  | 0  | 0  | 0.1124 | 0.4248 | 0  | 0.6446 | 0.1401 | 0  | 0  |

| Evaluation value with new indexes         | 0.0095 | 0.016 | 0.0544 | 0.1159 | 0.2883 | 0.0874 | 0.429 | 0.0994 | 0.1  | 0   |

4.2. Vertical comparison results of comprehensive evaluation between the new and old index system

In traditional power supply reliability evaluation, the power supply reliability of 10 distribution networks from high to low as follow: \( S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_10 \), are evaluated by the only 3 indexes: power supply reliability rate, the average interruption hours and the average interruption times. Only comprehensive evaluation results of \( S_4, S_9, S_7 \) and \( S_2 \) are regarded relatively poor, the other indexes perform better than the average, of which the evaluation values are 0. However, according to the extended power supply reliability index system, distribution networks from high to low as follow: \( S_{10}, S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 \). Besides \( S_{10} \), all the other evaluation values are not 0, which means for the indexes lower than the average level, there is room for improvement.

In traditional power supply reliability, distribution networks with low reliability level the evaluation in the user side can also be regarded as relatively poorer performance. For example, \( S_4, S_8, S_7 \) and \( S_2 \). While those better distribution networks in traditional evaluation result, are not always perform better, for example, the power supply reliability level of distribution networks \( S_3 \) and \( S_5 \) are equal to \( S_{10} \), however, power availability problems like high partial equipment outage times and
excessive low voltage qualified rate exist respectively, making users’ true power supply reliability experiences in distribution networks $S_3$ and $S_6$ are worse than $S_{10}$. All of supply-side indexes in $S_6$ are better than the average level, however, since the users’ average short-time interruption hours and middle and low voltage users’ average interruption times are obviously poorer than the average level, the extended power supply reliability also performs poorer in evaluation.

Traditional power supply reliability evaluation can only reflect its continuity in supply side but cannot get the true power continuity and availability from user side. However, the extended evaluation index system of power supply reliability established in this paper can reflect both the power supply reliability in supply side and the true power supply reliability level as well as its room for improvement in detail from 2 aspects: users’ power continuity and availability.

4.3. Effect evaluation of the comprehensive evaluation in this paper
1) The distribution of partial index value is quite different after normalization, while most of the equipment outage times indexes are close to 1, therefore, the improved entropy method can be used to better balance the evaluation value of each index.

2) It can be proved, according to the comprehensive evaluation result, that for most of indexes, they are qualified and have a similar level, each has its advantages and disadvantages. However, for distribution networks with some certain relatively poor index, weighting method with overflowing-value punishment can be used to enlarge unqualified indexes effectively and make the difference.

3) Distribution networks with poor power supply reliability in traditional evaluation, can still come to the same conclusion in the extended comprehensive evaluation. Therefore, the evaluation index system of power supply reliability established in this paper, as well as whether this evaluation method can reflect users’ real power supply reliability level truly and accurately, can provide grid enterprises with evaluation method and improvement direction of improving power supply reliability and users’ experience.

5. Conclusion
1) Catering for the management and development demands of grid reliability, a user-oriented and extended evaluation index system of power supply reliability, considering power quality problems, has established in this paper since power quality problems haven’t taken into consideration, what’s more, it’s not accessible to users’ real electricity-consuming experience in traditional power supply reliability evaluation indexes. 13 indexes involved in this system, which can be divided into 3 aspects: supply-side index, user-side index as well as contrast index, to evaluate the real power supply reliability that users experienced comprehensively and accurately from power supply continuity and power availability these two aspects.

2) Based on the established extended power supply reliability evaluation indexes, as well as the principle of overflowing-value punishment, a comprehensive evaluation based on improved entropy method has designed to enlarge the influence of unqualified indexes and ensure the sensitivity of power supply reliability evaluation. This evaluation method can be used to instruct the distribution network to improve users’ reliability reconstruction.

Acknowledgement
Foundation item: Supported by the Technical Projects of China Southern Power Grid (No. GD KJQQ20161015)

Reference
[1] Li Rui, Xu Hao, Cai Jie, et al. Reliability evaluation of distribution system considering partitioning and fusion of hierarchical structure [J]. Power System Technology, 2015, 39(2): 494-499.

[2] Lv Chunquan, Jia Wei. Extension of power supply reliability statistics through to low voltage networks and its implementation [J]. Power System Technology, 2000, 24(3): 53-54+65.
[3] Zhang Teng, Zhang Bo. Power supply reliability evaluation for consumers in low voltage distribution network based on probability statistics[J]. Power System Technology, 2004, 28(17): 81-84.

[4] IEEE Transmission and Distribution Committee, IEEE Std 1366-2001. IEEE trial-use guide for electric power distribution reliability indices[S]. New York: IEEE standards association, 2012.

[5] Guideline for reliability assessment and reliability planning-evaluation of tools for reliability planning[R]. California: EPRI, 2006.

[6] Electric Power System Council of Japan. The Rules of ESCJ[S]. Japan: Electric Power System Council of Japan, 2008.

[7] Tao Shun, Xiao Xiangning, Liu Xiaojuan. Study on distribution reliability considering voltage sags and acceptable indices[J]. Proceedings of the CSEE, 2005, 25(21): 63-69.

[8] Yang Jingyan, Ni Wei, Xiao Xiangning, Huang Wei. Reliability evaluation of distribution network considering voltage sags[J]. Proceedings of the CSEE, 2005, 25(18): 28-33.

[9] Ouyang Sen, SHI Yili. A new improved entropy method and its application in power quality evaluation[J]. Automation of Electric Power Systems, 2013, 37(21): 156-159+164.