RELIABILITY ASSESSMENT OF LOW VOLTAGE CUSTOMERS IN POWER SUPPLY SYSTEM

Mingjun YUAN
Shandong University – China
mingjun-yuan@sgcc.com.cn

Wen ZHANG
Shandong University – China
zhangwen@sdu.edu.cn

Zhanxun YU
Shandong Electric Power Company – China
yuzhanxun@sepco.com.cn

ABSTRACT

Power distribution reliability has always been a concern of distribution utilities. This paper presents the results of a reliability assessment to the low voltage customers in a practical distribution system. The probability and statistic theory is used for the power supply reliability statistics. The main point is to set some suitable low voltage reliability monitoring points according to the measurement precision requirement. The operating data collected from the monitoring points are used to calculate the specific indices. The simulation results show that the proposed method gives acceptable reliability indices.

INTRODUCTION

Power distribution systems have been designed to deliver energy in an efficient, secure and reliable way. Power supply reliability has always an important factor to reflect the quality and safety management. It is also a significant index for the power supply service which is most concerned by distribution utilities and customers [1-6]. Consequently, power supply reliability is of great consideration in the distribution network planning. However, the statistical analysis for low voltage power supply reliability is difficult because of the vast quantity of customers, wide consumer distribution and large fundamental data required. Most of all, the infrastructure or investment is limited in China.

There are mainly two methods for the reliability statistics of low voltage customers. The first one is the automatic statistics. In this method, monitoring devices are located for each low voltage consumer, which can record the time information of power failures. This information will be transmitted to the control centre for automatic analysis. Advantage of this kind of statistics is that it can be done in an automatic, fast and accurate way with consideration of every low voltage customer. Moreover, the automatic reliability statistical system can operate synchronously with the remote reader system. However, the maintenance of equipment is difficult since it needs a large investment. This drawback determines that the automatic statistics cannot have a generalized application. The other method for the reliability statistics is in a manual mode. All of the operation data and out of power reasons are input manually. This method is used for the medium voltage customers in the beginning and applied to the low voltage statistics subsequently. It costs little but the data read-in burden is large. The result of this kind of statistics is not as accurate as the automatic one. Consequently, this method can also not be extended for a general application [7-8].

This paper presents a reliability assessment approach based on probability and statistic in distribution systems. The main point is to set some suitable low voltage reliability monitoring points according to the measurement precision requirement. The operating data collected from the monitoring points are transmitted to the monitoring centre for automatic computation and analysis of specific indices. The simulation results show that the proposed method gives acceptable reliability indices and can also be used to provide information on the reliability of low voltage customers in distribution systems.

PROBLEM FORMULATION

A monitoring and statistical analysis system for power supply reliability of low voltage customers is developed. The main point to apply the probability theory to the power supply reliability analysis for low voltage consumers is to set some suitable low voltage reliability monitoring points according to the measurement precision requirement. The operation data collected from the monitoring points are transmitted to the monitoring center for automatic computation and analysis of specific indices. Main steps, determining sample size, choosing samples and calculating reliability indices, are described as follows.

Determining sample size

The determination of sample size is an important step for probability theory. Especially for power distribution systems, there is no constant law for it since the electric loads are of different types. So the sample size will be determined under the premise that no information of population distribution can be derived. Moreover, the sample space is large enough for determining the sample size. Then sample size n is determined by satisfying the given confidence level $(1-\alpha)$ when the distribution of population X is unknown. This can also be expressed in a mathematical form

$$P\left\{\left|\bar{X}-E(X)\right|<\varepsilon\right\}\geq 1-\alpha \qquad (1)$$

where $\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$ and X_i is the sub sample.

According to the Chebychev inequality, we have

$$P\left\{\left|\overline{X} - \mu\right| \le \varepsilon\right\} \ge 1 - (\sigma^2 / n\varepsilon^2) \quad (2)$$

Therefore, for a given $(1-\alpha)$, there is

$$n \ge (\sigma^2 / \alpha\varepsilon^2) \quad (3)$$

Usually, σ^2 is unknown, but its upper bound M can be estimated, which will be used as a substitute for σ^2 . Thus, we can take

$$n \ge (M / \alpha\varepsilon^2) \quad (4)$$

Choosing samples

The samples are chosen by random sampling method. The following aspects should be satisfied when setting monitoring points. First, the overall power supply situation for the low voltage customers should be reflected truthfully. Second, there should be a uniform standard and requirement for the operation. Third, the investment should be in a minimized level in the premise that a satisfied statistical accuracy has been reached.

By full random sampling method, each sample has the same probability to be selected. This method is objective and independent, so it can be applied in practice easily.

Calculating reliability indices

One view of distribution system performance can be gotten through the use of reliability indices. To adequately measure performance, both duration and frequency of customer interruptions must be examined to provide information about average system performance. Based on the sampled data, three reliability indices are calculated and analyzed as follows.

(1) Consumer average interruption duration index

Consumer average interruption duration index (*CAIDI*) represents the average time required to restore service. Mathematically, this is given as

$$CAIDI = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (5)$$

The average interruption duration time interval is $(\overline{X} \pm L)$, and L is the length of confidence interval and $(1-\alpha)$ is the confidence degree

$$L = \frac{s}{\sqrt{n}} z_{\alpha/2} \quad (6)$$

(2) Average interruption times of customer

The average interruption times of customer (*AITC*) index gives the average times of customers experiencing sustained interruptions. The customer is counted once regardless of the number of times interrupted for this calculation. Mathematically,

$$AITC = f_n / n \quad (7)$$

where f_n is the average interruption times of the sample customers.

When n is large enough, there is

$$P\{p \in (p_1, p_2)\} \ge (1-\alpha) \quad (8)$$

where $p_1 = (-b - \sqrt{b^2 - 4ac}) / 2a$ and, $p_2 = (-b + \sqrt{b^2 - 4ac}) / 2a$, in which $a = n + z_{\alpha/2}^2$, $b = -(2n\overline{X} + z_{\alpha/2}^2)$ and $c = n\overline{X}^2$.

Therefore, the confidence interval for AITC is (p_1, p_2) with the confidence degree $(1-\alpha)$.

(3) Reliability on service in total

The reliability on service in total (*RS*) index represents the fraction of time (often in percentage) that customers have received power during the defined reporting period. Mathematically, this is given in equation(9).

$$RS = (1 - \frac{\overline{X}}{T}) \times 100\% \quad (9)$$

where T is the statistical time.

Similar to the above two indices, RS interval can be estimated by

$$RS = (1 - \frac{\overline{X} \pm L}{T}) \times 100\% \quad (10)$$

SIMULATION RESULTS

In order to present the effectiveness and feasibility of the proposed approach, it is applied to a 10-0.4kV distribution system in a China city.

Complete statistical results

The complete statistical results are showed in Table 1. There are 57959 customers in total. The number of customers interrupted and the customer interruption durations are the accumulating data of 2 months. The reliability indices are calculated based on the practical statistic data.

Table 1 Complete statistical results

Reliability indices	statistical value
Total number of customers served	57959
Number of customers interrupted	3737
Customer interruption durations(Min)	293659
CAIDI（Min）	5.0667
RS (%)	99.9941

Test results by probability and statistic

The simulation results of the practical distribution system based on the proposed approach with the sample size 2500 are shown in. The reliability indices, *RS*, *CAIDI*, *AITC* and their confidence intervals, are elaborated with 5 simulations. Fig 1 shows the errors of reliability index *CAIDI* in 5 simulations with sample size 2500. Compared the reliability indices in Table 1 and Table 2, it can be seen that the simulation results accurately reflect the actual situation of the power supply system.

The simulation results with different sample size are shown in Table 3. The reliability indices, *RS*, *RS accuracy*, *RS error*, *AITC* and *AITC error*, are elaborated. Fig 2 shows the distribution of *RS* and *RS error* with different sample size. It can be seen from Table 3 and Fig 2 that with the increasing of sample size the *RS accuracy* will increase and the *RS error* will decrease. Compared the reliability indices in Table 1 and Table 3, it is shown that errors between the simulation and statistical data are very small when the sample size are bigger than 2500.

Table 2 Reliability indices with sample size 2500

Reliability indices	2500-1	2500-2	2500-3	2500-4	2500-5
RS (%)	99.994980	99.993518	99.993135	99.995213	99.995679
confidence interval for *RS*	0.00002414	0.00002786	0.00002945	0.00002376	0.00002181
CAIDI	4.3372	5.6008	5.9316	4.136	3.7332
confidence interval for *CAIDI*	2.0514	2. 3672	2.5019	2.0184	1.8531
AITC	0.0644	0.0660	0.0676	0.0640	0.0608
confidence interval for *AITC* (p_1)	0.0529	0.0543	0.0558	0.0525	0.0496
confidence interval for *AITC* (p_2)	0.0782	0.0800	0.0817	0.0800	0.0743

Table 3 Average reliability index values with different sample size

Sample size	*RS* (%)	*RS error* (1/1000)	*AITC*	*AITC error*
500	99.995318	1.2347	0.0051	0.001347
1000	99.993777	2.5084	0.0614	0.003076
1500	99.994521	1.4676	0.0701	0.005655
2000	99.993856	0.9856	0.0610	0.003476
2500	99.994505	0.8786	0.0646	0.000083
3000	99.994072	0.6085	0.0638	0.000609
3500	99.993796	0.5567	0.0646	0.000015
4000	99.994356	0.7859	0.0624	0.002026
4500	99.994091	0.4511	0.0637	0.000743
5000	99.993855	0.3942	0.0663	0.001883
6000	99.994741	0.5826	0.0625	0.001910
7000	99.993960	0.3978	0.0651	0.000666
8000	99.994608	0.4078	0.0640	0.000451

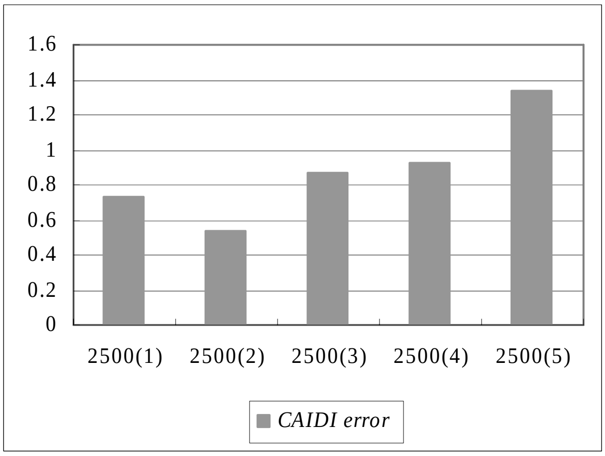

Fig 1 *CAIDI error* with sample size 2500

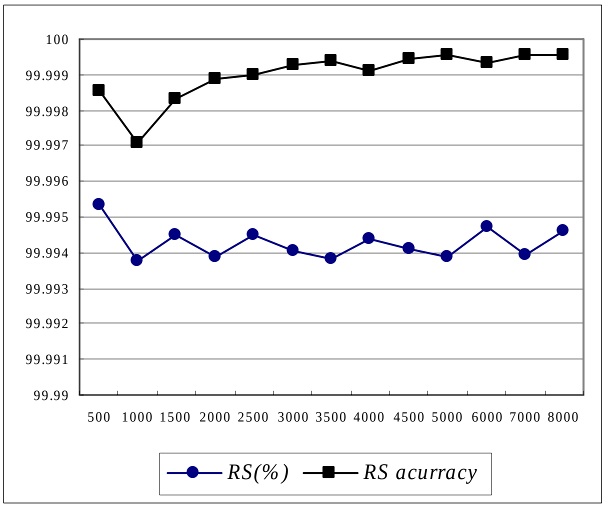

Fig 2 Average *RS* and *RS accuracy* values with different sample size

CONCLUSION

Based on the probability and statistic techniques, this paper presents a reliability assessment approach to low voltage customers in power supply systems. By setting some suitable low voltage reliability monitoring points according to the measurement precision requirement, the operating data can be collected to analyze the specific indices. Several reliability indices, such as the *CAIDI*, *AITC* and *RS*, are computed and compared. The errors between the simulation and statistical data are shown to be quite small under certain specified conditions. The reliability assessment approach proposed can be used to provide information on the reliability of low voltage customers in distribution systems.

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