Sampling Statistics Research Based on Quality Evaluation of Electricity Meters from Different Manufacturers

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Abstract: It is of great significance to study and analyze the measurement performance and sampling inspection methods of smart meters, and to conduct sampling inspection according to the quality status of smart meters, so as to improve the reliability of smart meters. On the basis of qualified rate test and error test of electric energy meters, radar chart and Wilcoxon rank sum test method are adopted to carry out quality inspection comparison of electric energy meters of the same specification from different manufacturers, and sampling statistical test method is studied accordingly. The method described in this paper is suitable for quality analysis and sampling inspection of electric energy meters.

1. Introduction
As the basic metering equipment in the power consumption information collection system of smart grid, smart watt-hour meters have legal verification and rotation periods. During the rotation period, they should not only have accurate metering but also provide timely and complete data information for the collection system and provide timely and effective services for users. Moreover, the electric energy meter has many types, large quantities and wide distribution characteristics. Currently, there are 480 million electric meters operating online in the national network. For so many electric meters, if there are problems with the quality of the factory and low operating reliability, the replacement of the operating electric meters is not only time-consuming and laborious, but also easy to cause power disputes and is extremely inconvenient to overhaul.

In order to reduce the workload of dismounting and replacement of the electric energy meter and the processing of the faulty electric meter, the operating cost of the system is reduced; the number of power outages of the user is reduced, the service quality of the electric power company is improved, and the electric energy measurement is fair and just. Testing and researching the quality of electric energy meters and improving the reliability of electric energy meters are one of the current focuses. However, the applicability of reliability engineering in China's smart meter manufacturers is not high, and the basic data and prediction practice are relatively weak. The integration, integration and analysis of the reliability data of smart meters, and the quality evaluation and sampling methods of electric energy meters have become the current urgent problems to be solved [1].

2. Basic Concept of Quality Inspection for Electric Energy Meter
Watt-hour meter is one of the national key measuring instruments listed in the compulsory inspection catalogue. The reliability of electric energy meters involves many links such as electric energy meter component manufacturers, electric energy meter manufacturers, on-site operation environment, etc. Different electric energy meter manufacturers will produce the same specifications of electric energy meters with different quality problems. The reliability of electric energy meter can be improved from
two aspects: (1) manufacturers of electric energy meters should strictly control the technological process to strengthen the quality during production and manufacturing; (2) analyze the reliability data of the electric energy meter and strengthen the service cycle of the electric energy meter from various aspects. This paper mainly studies the quality evaluation of watt-hour meters of the same specification from different manufacturers, and studies the sampling method of watt-hour meters according to the quality inspection, providing the basis for the subsequent sampling inspection of watt-hour meters.

The submersible test, start-up test, withstand voltage test, walking test and metering error of electric energy meter directly or indirectly affect the metering performance of electric energy meter. Electric energy meter creep test refers to the fact that each current line of the electric energy meter has no load current, only limited current can be used to ensure the user's electricity fairness; the start-up test can check the sensitivity of electric energy meter. The unqualified items of withstand voltage test results mainly include black screen, failure of programming key, abnormal measurement error, lack of voltage on battery display, abnormal communication of electric energy meter, etc. The character walking test evaluates the metering performance of the electric energy meter based on the character walking speed of the electric energy meter. Visual inspection of the meter can be carried out from the following aspects: whether there are cracks in the shell, fuzzy marks, LCD damage, and defects such as disconnection of connection terminals.

3. The Qualified rate of Watt-hour Meters of The Same Specification from Different Manufacturers.

Two electric energy meters of the same specification from different manufacturers were selected, and a total of 8,000 electric energy meters were sampled for research, of which 4,405 electric energy meters from H manufacturer and 3,595 electric energy meters from S manufacturer. The collected test qualification rate information is compared with radar chart method to compare the quality and reliability of watt-hour meters from various manufacturers.

3.1 Qualification rate data set

This data set contains all qualified and unqualified information. Because the sum of the unqualified rate and the qualified rate is 1, we only need to care about the qualified rate, and the unqualified rate can be obtained accordingly. There is no obvious special feature in this data set for the comparative calculation of qualified rate. Therefore, the whole data set is taken as the analysis data set. The data set will be used for quality inspection and evaluation of watt-hour meters of the same model from different manufacturers. The qualified rate data set includes: pressure test, start-up test, submersible test, walking test, other tests and visual inspection.

| Table 1. Distribution of Qualified Levels of Various Manufacturers. |
|---------------------------------------------------------------|
| Project | Pressure Test | Submersible Test | Start Test | Walk Test | Other Tests | Visual Inspection |
| Manufacturer H | 1 | 0.9999 | 0.9999 | 0.9999 | 0.9995 | 0.9996 |
| Manufacturer S | 1 | 0.9996 | 0.9994 | 1 | 0.9999 | 0.9996 |
3.2 Comparison of Qualified Rate

The value in the above figure indicates the qualified rate level of the meter item. The total qualified rate is calculated with the weight of 0.25 for visual inspection and 0.15 for other items. Therefore, the total pass rate of the manufacturer H is approximately 0.9998, and the total pass rate of the manufacturer S is approximately 0.9996. We can have a more intuitive understanding of the comparison of the qualified rate levels of the two types of electric meters. From the total qualified rate, it can be seen that the qualified rate of electric meters of manufacturer H is better than that of manufacturer S.

4. Error of Watt-hour Meter of Same Specification from Different Manufacturers

Error detection will be carried out for watt-hour meters of the same specification from 2 different manufacturers. The collected error data will be compared with radar chart and Wilcoxon test method to compare the quality and reliability of watt-hour meters from various manufacturers.

4.1 Error Data Set

The absolute value of the relative error of the ammeter is required to be controlled within 2%, otherwise it is unqualified, but there are 10517.00%, 9988.78% and 9650.39% among them. We judge that these special error data are almost impossible to be generated by the ammeter. It is caused by manual data input or other errors. As this obviously abnormal data only accounts for a very small proportion, it will cause great interference to the subsequent statistical analysis. Considering that some meters do have large errors due to various quality problems or improper use, these "problem information" should not be ignored. Therefore, we are very careful in determining the boundary. We should not only ensure that the obtained model is true and reliable, but also cannot ignore those cases with large errors. After reviewing the overall situation of this batch of data, we have relaxed the data selection limit to 5% and only eliminated a very small number of obviously abnormal data that will greatly affect the analysis.

Error is an important parameter that comprehensively reflects the quality characteristics of electric energy meters. Through comparison, the quality level of electric energy meters of various manufacturers can be judged. Considering that the error conditions of watt-hour meters are different under different powers, a total of 8 detection points of $\cos \phi = 1$ and $\cos \phi = 0.5L$ are respectively selected to analyze the error between watt-hour meters of different manufacturers.

Table 2. Average value of watt-hour meters of various manufacturers at various detection points.

| Detection point          | $I_{\max}$ | $I_b$ | $0.5I_b$ | $0.1I_b$ | $I_{\max}$ | $I_b$ | $0.5I_b$ | $0.1I_b$ |
|-------------------------|-------------|-------|----------|----------|-------------|-------|----------|----------|
| Manufacturer H          | 0.1386      | 0.1408| 0.0878   | 0.2403   | 0.1108      | 0.1201| 0.1919   | 0.1138   |
| Manufacturer S          | 0.2985      | 0.2032| 0.2236   | 0.1854   | 0.2006      | 0.1006| 0.1805   | 0.1534   |
4.2 Error Comparison

4.2.1 Comparison by Radar Chart

In the above radar chart, the average value and median value reflect the magnitude of the overall error. The smaller the value, the smaller the error. The standard deviation and variance reflect the fluctuation of the error. The smaller the value, the more stable the meter is. It can be seen that the error of the ammeter of manufacturer H is relatively better than that of manufacturer S, and the error fluctuation is relatively stable for both manufacturers.

4.2.2 Comparison by Wilcoxon Test Method

(1) Basic ideas

The two groups of data are compared in size, and they are grouped together and sorted from small to large, and their numbers are recorded. If the serial numbers of one group of data are mostly backward, this group of data is generally large. If the serial number of a group of data is higher, then the group is considered smaller.

(2) Inspection background

Two samples \( H_1, H_2, \ldots, H_m \) and \( S_1, S_2, \ldots, S_n \) are obtained from two populations \( h \) and \( s \) respectively. We need to check whether the median (or mean) of the two populations are equal, i.e.:

- Alternative hypothesis \( H_1 \): the median of population \( s \) is greater than the median of population \( h \) \((M_s > M_h)\).

(3) Test derivation

After mixing the two samples, new samples \( Z_1, Z_2, \ldots, Z_n \) are obtained, where \( N = m + n \).

Then the rank \( R_i \) of \( S_i \) (i.e. the ranking of \( S_i \) in the combined sample sorted from small to large) is:

\[
R_i = \text{Rank}(S_i) = \sum_{k=1}^{N} 1(S_i \geq z_k)
\]  

Table 3. Error Sorting of Hybrid Meter Samples at Each Detection Point

| Detection point | \( \cos \theta = 1 \) | \( \cos \theta = 0.5L \) |
|-----------------|-----------------|-----------------|
|                 | \( I_{max} \)  | \( I_p \)     | \( 0.5I_p \) | \( 0.1I_p \)  | \( I_{max} \)  | \( I_p \)     | \( 0.5I_p \) | \( 0.1I_p \)  |
| Manufacturer H  | 0.1386          | 0.1408         | 0.0878       | 0.2403       | 0.1108       | 0.1201       | 0.1919       | 0.1138       |
| Rank            | 6               | 7              | 1             | 15           | 3            | 5             | 11            | 4             |
| Manufacturer S  | 0.2985          | 0.2032         | 0.2236       | 0.1854       | 0.2006       | 0.1006       | 0.1805       | 0.1534       |
| Rank            | 16              | 13             | 14            | 10           | 12           | 2             | 9             | 8             |

Remember \( W_S = R_1 + R_2 + \cdots + R_n = 84 \)

When
\[ \frac{W_S - \frac{n(N-1)}{2}}{\frac{n\pi^2(N+1)}{12}} > z_{1-\alpha} \]  \tag{2}

Among them, \( z_{1-\alpha} \) is the \( \alpha \) sub-site of standard normal distribution, \( \alpha \) is the test level, generally 0.05. The original assumption is rejected.

According to formula (2), if \( 1.680 > 1.645 \), the original assumption is rejected, i.e. the error of population S is considered larger than that of population H. Therefore, from the perspective of error, manufacturer H's ammeter is better.

5. **Sampling Inspection Methods for Electric Energy Meter**

5.1 **Basic Sampling Methods**

Determination of sample size is one of the processes to complete quality inspection. Reasonable sampling scheme can make samples accurately reflect the quality of products, and at the same time a large number of samples will increase the sampling cost and timely consumption. Therefore, reasonable sampling is of great significance to study the quality and reliability of electric energy meters. According to the two situations of watt-hour meter failure rate \( p \), a sampling sample size model of watt-hour meter can be obtained:

(1) when \( P \leq LQ \), there are

\[ n = \frac{Nt^2p(1-p)}{(N-1)d^2+t^2p(1-p)} \]  \tag{3}

(2) when \( P > LQ \), the electric energy meter shall be fully inspected and collected.

Where: \( LQ \)- limit quality level; \( P \)- estimate of meter failure rate; The \( N \)- sample population and \( t \)-reliability are the double-sided \( \alpha \) quantiles of the standard normal distribution. \( d \)-precision, expressed in absolute error limit; \( n \)-sample size.

Referring to *Reliability Requirements and Assessment Methods for Electric Energy Meters*, it is determined that the limit quality level is 6%. That is, when the unqualified rate of a batch of electric energy meters reaches 6%, the batch of electric energy meters will be rejected by the sampling scheme with high probability. The unqualified rate of intelligent watt-hour meters of the two manufacturers is between 0.1% and 0.3%, taking \( P = 0.3\% \), i.e. \( P < LQ \), adopting the sampling scheme, and the credibility is \( 1-a=0.95 \), i.e. \( t = 1.96 \); Precision requires absolute error \( d \) to be controlled at 0.004, so the total number of samples is

\[ n = \frac{Nt^2p(1-p)}{(N-1)d^2+t^2p(1-p)} = 8000 \times 1.96^2 \times 0.003 \times (1-0.003) / (8000-1) = 660 \]

Sampling ratio in each layer by equal proportion sampling method:

\[ f = \frac{n}{N} = \frac{660}{8000} \approx 8.25\% \]

Therefore, manufacturer H sampled 363 electricity meters and manufacturer S sampled 297.

5.2 **Optimization of Sampling Methods**

According to the quality inspection results of electric energy meters, Neyman allocation method is adopted to optimize the sampling scheme.

According to the qualified rate result of electric energy meter, the unqualified rate of sampling is determined \( P : P = 1 - \frac{Z_A + Z_B}{2} = 0.0003 \). According to the above formula, the unqualified rate of electric energy meter is calculated by using the sample size model, and the total number of samples to be extracted is as follows:

\[ n = \frac{Nt^2p(1-p)}{(N-1)d^2+t^2p(1-p)} = 72 \]

When sampling the number of samples required by each manufacturer, unequal proportion distribution method is adopted, and distribution is mainly based on variance:
1) Optimum allocation

Optimum allocation is to randomly allocate the sample quantity sampled by the population to the manufacturers sampled by the two electricity meters. When the variance of the estimators reaches the minimum under the given total cost, or the total cost is the minimum under the given variance of the estimators.

The linear function of sampling cost is:

\[ c = c_0 + \sum_{h=1}^{k} c_h n_h \]  \hspace{1cm} (4)

Where: \( c \)- total cost, \( c_0 \)- basic cost, \( c_h \)- cost per unit sample in each manufacturer.

The optimum allocation method is:

\[ n_h = \frac{\sum_{h=1}^{k} w_h S_h / \sqrt{c_h}}{\sum_{h=1}^{k} n_h S_h / \sqrt{c_h}} \hspace{1cm} (h=1,2,3,\ldots,k) \]  \hspace{1cm} (5)

2) Neyman allocation

Assuming that the sampling costs of the two manufacturers are equal during the sampling of electric energy meters, the optimal distribution is simplified as follows:

\[ n_h = \frac{\sum_{h=1}^{k} w_h S_h / \sqrt{c_h}}{\sum_{h=1}^{k} N_h S_h / \sqrt{c_h}} \hspace{1cm} (h=1,2,3,\ldots,k) \]  \hspace{1cm} (6)

Where: \( n \)- total number of samples, \( N_h \)- total number of each manufacturer, \( S_h \)- standard deviation obtained by each manufacturer during quality inspection, and \( n_h \)- sample number of each manufacturer. This distribution is called Neyman allocation.

When Neyman allocation is used for sampling inspection, the standard deviation of each quality inspection result of manufacturer H is 0.000198, and that of each quality inspection result of manufacturer S is 0.000526.

Therefore, manufacturer H sampled 24 electricity meters and manufacturer S sampled 51.

Neyman allocation can comprehensively consider the quality of electric energy meters, take into account the actual average damage rate, withstand voltage test, walking test and other test qualification rates and error levels to carry out different samples for different manufacturers, so that the sampling is more accurate. According to this, random whole meter sampling is carried out on electric energy meters to provide basis for sampling inspection of later batches of electric energy meters.

6. Conclusion

Through statistical analysis of measurement performance test and investigation results of smart meters, on the basis of qualification rate test and error test of watt-hour meters of the same specification from different manufacturers, the quality data of watt-hour meters are statistically analyzed by radar chart and Wilcoxon rank sum test method.

Through combing the quality data of electric energy meters, analyzing the average damage rate of electric energy meters, and considering the sampling cost and precision of electric energy meters, the distribution method of Neyman allocation is adopted to optimize the sampling method of electric energy meters of the same specification from different manufacturers, so as to improve the sampling accuracy of electric energy meters and provide basis for sampling inspection of electric energy meters of different manufacturers in batches.

References

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