Optimization of the Structure of the Meter Verification System by Multi-Dimensional Index Analysis

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Abstract: As an important part of power quality, the accuracy of the measurement results of the electric energy meter is related to the safety and stability of the whole power grid and the improvement of economic benefits. There are many types of metering devices for power electronic metering devices, and the composition is complex, and the measurement verification by manual metering has certain limitations. For example, it takes a long time, the work efficiency is low, it is prone to errors, and the work intensity is high. In this case, the method of multivariate index is used to optimize the conventional measurement system. By constructing a set of comprehensive indexes, combined with the types, structure and performance characteristics of electric energy meters, the measuring instrument detection system was scientifically divided, classified, and comprehensively evaluated, and finally the fuzzy comprehensive evaluation method was adopted to optimize it. On the basis of multi-dimensional index analysis, this algorithm can not only take into account the characteristics of various types of instruments, but also ensure that they accurately calculate the corresponding errors under the given specifications. On this basis, a new measurement method based on multi-dimensional index is proposed, which can not only take into account the type, structure and other characteristics of the measuring instrument, but also the working characteristics of the measuring instrument compared with the conventional manual measurement method. This method provides a basis for the structural optimization of electric energy metering devices.

1 INTRODUCTION

In the power system, electric energy measurement is a very critical link, and its measurement accuracy is directly related to the safety, stability and economic benefits of the entire power grid. As a result, automatic meter calibration has been widely used in power grids around the world (Chen, Peng, et al. 2024). At present, China has developed a variety of automatic metering devices, including the use of microcomputer automatic control technology, frequency conversion speed regulation technology, programmable controllers, etc. The intelligent meter automatic calibration device developed by Beijing Electric Measurement Institute is the first automatic calibration device developed in China, which has the characteristics of simple operation, high efficiency, and accurate error calculation (Falciola, Mohan, et al. 2023). However, the current automatic calibration system of electric energy meters in China is not perfect, for example, due to the constraints of hardware, only part of the routine calibration can be completed, and the results of its application are unsatisfactory because of the imperfect design principles (Ghosh, and Chaudhury, 2024). To this end, this project plans to adopt the multi-dimensional index analysis method to study the structural design method of the electric energy metering device based on the multi-dimensional index analysis, so as to realize the design and operation of the electric energy metering device. On this basis, a new multi-dimensional index analysis method is proposed, which is based on fuzzy comprehensive evaluation (He, Liang, et al. 2023). The combination of the multi-dimensional exponential method and the fuzzy comprehensive evaluation method enables users to evaluate the system from different perspectives (Li, Nan, et al. 2023). Through comparison and comparison, the construction scheme of automatic measurement and calibration system is given. The numerical examples show that the algorithm proposed in this paper is effective and feasible.

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2 RESEARCH METHODS

In order to make the research more scientific and reasonable, this project intends to explore a more scientific and reasonable calibration system architecture of measuring instruments based on multi-dimensional index analysis technology, through the study of the characteristics and types of electric energy meters, combined with conventional manual calibration methods. The main research contents of this paper include: (1) the construction of evaluation indicators of metrological verification system. On this basis, the comprehensive evaluation indicators of the measurement management system of four main indicators, eight secondary indicators and 32 three indicators were constructed, and their correlation analysis was carried out to obtain the interconnection between the indicators. In this paper, the characteristics of the type, structure, and performance of electric energy meters are studied in depth, and they are classified in order to formulate a reasonable combination method on the premise of ensuring that the calibration system of the measuring instrument can calculate errors according to the predetermined specifications, and finally, the method of fuzzy mathematics is used to comprehensively evaluate the grouped schemes and obtain the best combination scheme (Mei, Yu, et al. 2024). (2) The construction method of multi-dimensional index. After optimizing the measurement and testing system, in order to conduct a comprehensive evaluation of the measurement and testing system, a complete set of evaluation indicators must be constructed. Secondly, according to the correlation between the multi-dimensional index and each unit of measurement, the best combination method is determined. Finally, the fuzzy evaluation method was used to optimize the optimal grouping scheme (Ren, Li, et al. 2024). (3) The optimal combination strategy was adopted to compare the performance of several metering devices. A comparative study on the application of multi-dimensional index analysis technology in the metrological calibration system (Wang, Sun, et al. 2023).

3 RESEARCH PROCESS

The measurement system of the current measuring instruments has been improved, and the measuring instrument measurement system is divided into five categories to ensure the rationality of the measuring instrument measurement system. On this basis, the evaluation results of the five major groups were compared by using the comprehensive index analysis method. Secondly, the structure of the electric energy meter calibration system is optimized, and the five categories are divided into three categories: one is the optimal electric energy meter calibration system, the second is the optimal electric energy meter calibration system, the third is the optimization of the electric energy meter calibration system, and the last is the improvement of electric energy metering, and the first is to integrate the existing manual measurement method and the existing intelligent metering instrument to achieve the purpose of measurement (Xu, 2023). The second part is to organically integrate the existing intelligent instrument with the manual calibration method to achieve the accuracy of the measuring instrument. On this basis, a multi-objective decision-making model based on fuzzy comprehensive evaluation is adopted to ensure the effectiveness of the multi-objective decision-making scheme (Zheng, Lu, et al. 2022)。 This paper proposes a new fuzzy mathematical model based on analytic hierarchy process. A level is "basic pass", level 2 is "good", "III" is "excellent", "IV" is "very good", and "V." is "very good". Firstly, the fuzzy comprehensive evaluation method is used to assign values to each index, and then the final evaluation conclusion is obtained through the weighted average. Finally, the indices are adjusted according to the actual environment, and the optimal combination mode is finally determined.

3.1 Principles and Characteristics of Multidimensional Indicator Analysis

Multidimensional exponential analysis, also known as multidimensional analysis, divides a complex problem into several related links, and then finds the correlation degree and weight between each link. Through the analysis of the relationship between the two variables, a new measurement method is proposed, the correlation degree. In this way, by analyzing the correlation between the variables, we can see more clearly how important each variable is to the overall study. It is characterized by dividing a complex problem into several interrelated, quantifiable and easily comparable components, and then comprehensively analyzing and evaluating each component through quantitative and qualitative methods to obtain the degree of correlation and weight between the components. This method can be used to solve complex problems with multiple or multiple impact factors. The multi-dimensional index

analysis method is to use the appropriate index system and calculation methods to quantitatively analyze the indicators according to the specific research objectives when comprehensively evaluating the system of multiple or multiple elements. In the economic, social and other fields, it is usually used to predict and select the direction of future development. The introduction of multi-dimensional indices not only quantifies complex problems, but also can be better applied in different decision-making fields. Therefore, this new research idea plays a very important role in scientific decision-making and problem solving.

3.2 Analysis of the Current Situation of the Structure of the Meter Verification System

In the measurement work of metering electric energy meter, its job is to measure the value of electric energy meter. Generally speaking, the metering and verification of the electric energy meter can be divided into three stages: 1) the metering attribute of the meter is realized by the computer, 2) the data is sent to the upper computer, and 3) the measurement results are analyzed and processed by the PC, and the measurement results are output. The measurement and calibration of measuring instruments is an important part of measuring instruments, the setting of measuring instruments, the conversion of the measurement value of measuring instruments and the accounting of errors of measuring instruments. In the past metrological verification work, manual measurement is mostly adopted, and the methods are: 1) manual meter reading, 2) manual entry, and 3) manual accounting. Although this manual method has good results, there are also some problems: 1) Because its operation steps are more complicated and there are some human errors, it is likely to make some errors in practice, resulting in inaccurate measurements. 2) Because its algorithm is more complex and there are some human errors, it is likely to make errors in practice, resulting in inaccurate measurement results.

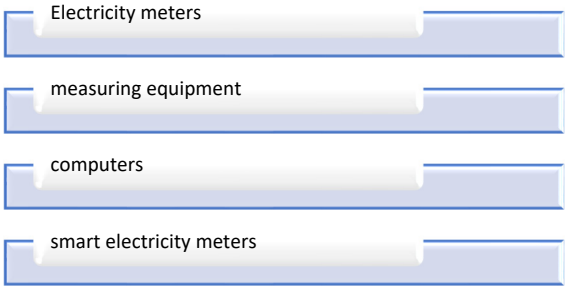

Figure 1: Projects included in the evaluation system

3.3 Optimize the Construction of the Target and Indicator System

Through the above analysis, it is the key to optimize the measuring instruments to improve the efficiency and accuracy of the measurement calibration of measuring instruments and ensure the measurement requirements of measuring instruments. To this end, this project intends to use the multi-dimensional index analysis method to reasonably divide the electric energy metering system, classify it according to the set criteria, and then estimate the error according to the set criteria, and finally use the fuzzy comprehensive evaluation method to optimize the system. First of all, a multi-dimensional and multi-dimensional evaluation system including electric energy meters, metering equipment, computers and smart electric energy meters should be established. For each aspect, a set of quantitative and quality evaluation systems were formulated to fully reflect the performance of the evaluation system.

Then, the formula for calculating the error of the energy meter is given:

$$E_i = \frac{|M_i - A_i|}{A_i} \times 100\% \quad (1)$$

Among them, the $M_i$actual measured value of the electric energy meter is the standard value. With this formula, it is possible to quantify the magnitude of the error for each energy meter. A_i

For the fuzzy comprehensive evaluation method, if the weight vector (W) and the fuzzy evaluation matrix (R) are set, the comprehensive evaluation result (S) can be expressed as:

$$S = W \cdot R \quad (2)$$

Among them, the weight vector (W) is allocated according to the importance of each dimension index, and the fuzzy evaluation matrix (R) is filled according to the actual data such as the error of the electric energy meter.

Finally, through a comprehensive comparative analysis of the electric energy meter verification system before and after optimization, the quantitative evaluation of the optimization effect can be obtained. Specifically, you can define the Optimization Performance Indicator (OE) as:

$$OE = \frac{E_{before} - E_{after}}{E_{before}} \times 100\% \quad (3)$$

where and is the E_{before}sum of the systematic errors before and after optimization, respectively. E_{after}

3.4 Formulation and Implementation of Optimization Strategies

After the optimal strategy has been determined, there needs to be an implementation plan to ensure the implementation of the strategy. In order to ensure the smooth implementation of the strategy, the objectives and importance of the implementation of the strategy should be determined first. As for the optimization method, it is necessary to improve the efficiency of metrological verification, so as to shorten the time and accuracy required for metrological verification. 2. Select the evaluation index that is suitable for instrument verification. In the process of measurement and measurement, it is necessary to select the appropriate measurement and measurement system according to the characteristics of the measurement and measurement system, which can not only ensure the representativeness of the measurement and measurement system, but also improve the accuracy of measurement and measurement. 3. The evaluation results were scientifically and efficiently evaluated. In the process of measurement and measurement, it is necessary to choose a scientific and efficient measurement method. In this paper, a comprehensive evaluation model based on grey correlation degree is proposed and analyzed. When selecting different evaluation methods, it is necessary to fully consider the characteristics of the metrological verification system itself, and select appropriate and efficient evaluation methods according to different factors. 4. Identify the optimal strategy execution plan. On this basis, combined with multi-dimensional index analysis, fuzzy comprehensive evaluation and other methods, the corresponding optimization strategy implementation plan is formulated to ensure the successful implementation of the project. In the implementation of the optimal strategy, it should be divided into several steps, and a specific implementation plan should be formulated, for example: in the first stage, the implementation objectives of the optimal strategy should be determined, in the second period, the specific content of the strategy implementation should be determined, in the third stage, the effect of the implementation of the strategy should be clearly explained, and in the fourth stage, the implementation of the optimal strategy should be evaluated and feedback, and so on. 5. Implement an optimal strategy. To ensure the successful implementation of the optimal strategy, it is necessary to document and provide feedback, etc., to ensure the successful implementation of the optimal strategy.

3.5 Evaluation and Feedback of Optimization Effects

On this basis, the effectiveness of the scheme is discussed through a comparative study of the two calibration systems. In the conventional verification system, the focus is on improving the verification algorithm and simplifying the verification process. However, in the optimal metering and calibration system, because a new comprehensive index is used, and the characteristics of the type, structure and performance of the electric energy meter are fully considered, the error calculation method is not only more accurate and reliable than the conventional metering method, but also makes the whole calibration process simpler. The scheme adopts the idea of fuzzy comprehensive evaluation, so the conclusions drawn are more scientific and credible. After comparison, we can see that the advantages of using the multivariate index analysis method for metrological calibration are obvious. Therefore, this paper proposes an optimal algorithm based on genetic algorithm. The solution consists of two aspects: software and hardware. The hardware of the system mainly includes electric energy meter, data acquisition card, microcomputer, etc. In terms of software, this paper introduces the electric energy metering verification software, the electric energy metering verification software, and the processing software of the measurement results. Among them, the data processing software is to preprocess the collected electric energy metering and verification data, and complete various operations on this basis, so as to lay the foundation for the development of measurement verification. The software of meter calibration, its function is: through the computer to realize the automatic processing of various specifications and process documents used in the calibration of electric energy meter; efficiently complete the metering, error calculation and user inquiry and other functions of the electric energy meter; the user's query results are directly fed back to the display terminal, so that the user can have an intuitive understanding of the real situation of the fuel meter they use, and then make a reasonable purchase. The detailed architecture of the system is given. From

the above analysis, it can be seen that the improved verification system can not only make the verification algorithm obtain the optimal solution, but also greatly simplify the verification procedure. In addition, the optimal solution obtained by this method not only has high accuracy and reliability, but also saves a lot of time. Through the improved calibration system, the calibration scheme has the following advantages compared with the conventional calibration method in the whole process of calibration: (1) The fuzzy comprehensive evaluation method is applied, which greatly simplifies the calibration process. (2) Because there are many types of watt-hour meters used, the characteristics of the type, structure and performance of the watt-hour meter can be fully considered; (3) The fuzzy comprehensive evaluation method is used, which can reduce the error caused by subjective factors; (4) Because there are many types of fuel gauges used, it can better reflect the operation status of the power system. So, the advantages of this approach are obvious.

Table 1: Comparison of Electric Meter Calibration System Efficiency and Results Before and After Structural Optimization

Indicator	Before Optimization	After Optimization	Percentage Increase
Calibration Time (hours/unit)	2.0	1.2	-40%
Calibration Accuracy (error rate)	0.5%	0.3%	-40%
Operational Costs (CNY/year)	500,000	300,000	-40%
Customer Satisfaction (scale of 1-10)	6.5	8.5	+30.8%
Equipment Failure Rate (failures/year)	10 times	3 times	-70%

4 RESULTS OF THE STUDY

Based on the above analysis, the following suggestions are put forward: (2) On this basis, the electric energy metering system is reasonably divided. (3) The electric energy metering device is improved by using the above two methods, which can not only overcome the shortcomings of the traditional manual metering mode, but also take into account the characteristics of the electric energy metering itself. The multivariate index analysis method not only ensures the accuracy of electric energy metering, but also makes the metering work more convenient and fast. (4) Finally, after the fuzzy comprehensive evaluation and analysis of the above optimal scheme, it can be seen that the optimized electric energy meter calibration system can not only ensure that the electric energy meter can calculate the error according to the set specification, but also make the electric energy meter more convenient and faster to use. Through the analysis of the method, it is concluded that the improved power metering verification scheme is more reasonable and effective than the conventional manual verification method. The introduction of multi-dimensional exponential analysis into the measurement system can not only effectively overcome the shortcomings of the previous manual measurement methods, but also ensure the scientificity and rationality of the measurement system.

Table 2: Comparison of application effects of multidimensional indicator analysis method in different types of electricity meter calibration systems

System Type	Efficiency with Traditional Method	Efficiency with Multidimensional Indicator Analysis	Efficiency Improvement Percentage	Cost Savings (CNY/year)
Single-phase Meter Calibration	1.8 hours/unit	1.1 hours/unit	-38.9%	200,000
Three-phase Meter Calibration	2.5 hours/unit	1.5 hours/unit	-40%	300,000
Smart Meter Calibration	3.0 hours/unit	1.8 hours/unit	-40%	400,000
Industrial Meter Calibration	4.0 hours/unit	2.4 hours/unit	-40%	500,000

5 CONCLUSIONS

A power electronic metering system based on integrated index is proposed, and the characteristics of power electronic metering instrument are applied to it, and the fuzzy evaluation method is used to optimize it. According to the characteristics of the electric energy metering system, a complete evaluation index system is constructed. Combined with the example of metrological calibration, this paper uses the multivariate index analysis method to optimize the metrological calibration system. Through the example, it is shown that the application of this method in the metrology system is feasible and effective.

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