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Closed Loop Management of Assets Life Cycle of Power Network Based on System Reliability

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Abstract

In order to know more accurately closed-loop management of the whole life of power grid assets under the reliability of power equipment safety assessment system, a power equipment safety assessment system was designed by means of multi-factor analysis. The all life cycle closed-loop management of power equipment was realized by studying the reliability of the system. XX area was selected as the experimental unit for the reliability of the power equipment safety assessment system established. The system was operated for 12 months, and after that, the effect of the whole life closed-loop management of regional power grid assets was evaluated. The results showed that the reliability of the power equipment safety assessment system established was very significant. It reduced the number of annual power outages and the frequency of safety failures in the region, improved the operating efficiency of the power unit, reduced the maintenance costs caused by potential power hazards, and ensured the stability of power consumption in the region, thus avoiding losses to enterprises and residents. In addition, after 12 months of system operation, the satisfaction rate of power system employees and residents to the system was very high. The system not only cultivated staff's awareness of equipment safety maintenance, but also improved work efficiency and reduced the number of manpower safety checks, and improved the closed-loop security and economic management level of power grid assets life cycle. To sum up, based on the reliability of power equipment safety assessment system, the closed-loop security and economic management of power network assets have been greatly improved, which greatly improves the security problems of power equipment, reduces the cost, and improves the operating efficiency of power enterprises. In a word, the research can be used as a reference for the follow-up study of all life cycle closed-loop management of power grid assets.

Keywords: *Power grid; Equipment; Safety; Benefit; System*

1. Introduction

The purpose of life-cycle asset management is to reduce the life-cycle expenditure of power assets and improve the operating efficiency of equipment and income [1]. It also aims at reducing the expenditure of equipment maintenance as much as possible under the premise of meeting the safety and reliability of power equipment. This kind of management method is more common in some high-cost manufacturing industries [2]. At present, this method is mainly used in industries with relatively concentrated funds in China [3], and is widely used in power companies. This situation occurs mainly because the distribution range of assets and equipment in power enterprises is very large, the management process is very long, the service life of equipment is relatively long, the number of equipment is very large, the frequency of changes is relatively high, the physical value and changes often cannot meet the requirements and other characteristics [4]. This adds great difficulty to the management, repair and maintenance of electric power enterprises [5]. In recent years, with the rapid expansion of power grid enterprises, the equipment assets of power enterprises are also increasing, and the pressure of effective asset management is doubling. Therefore, it has become a very urgent problem in the power industry how to break through the inefficient management mode in the past, find out how to improve efficiency, reduce maintenance and management costs, and realize the operation life of equipment under the premise of meeting the high efficiency and safety of power equipment [6].

As an advanced management concept and decision-making method, all life cycle management of assets is based on a systematic point of view [7]. Through the integrated management of the whole process of planning, scientific research and design, construction, operation and maintenance until retirement, under the conditions of safe and reliable operation of assets and meeting the needs of use [8], the overall cost of the all life cycle of assets can be the lowest [9]. The all life cycle management of assets is the key work of the State Grid Corporation. After years of continuous exploration and verification, it has reached the preliminary implementation stage [10]. It is an overall and systematic management innovation project of State Grid Corporation to carry out life cycle management of assets [11].

In summary, the power equipment safety assessment system is designed, and the whole life cycle closed-loop management of power grid assets based on its reliability is discussed. The results show that the power equipment safety assessment system established has high reliability, reduces the frequency of blackouts and safety accidents, improves operational efficiency, reduces maintenance costs, and ensures stable power consumption. After one year of use, the satisfaction rate of employees and residents of the power system is very high. The innovation of this paper lies in the research of power equipment safety assessment system and power equipment life-cycle closed-loop management together, and the detailed analysis and study of its operation effect. The research results of this paper provide some guidance for future research, so it is a valuable research topic.

2. Method

2.1 Life-cycle management

Life-cycle management of fixed assets is the application of system engineering theory in fixed assets management [12]. Starting from the long-term economic benefits of fixed assets, it comprehensively considers the whole process of planning, purchasing, construction, operation and maintenance of assets, technical renovation and abandonment, and pursues the minimum full-cycle cost of fixed assets on the premise of meeting safety, efficiency and efficiency. Life cycle cost (LCC) management, Efficiency Management and Safety Management constitute the all life cycle management of fixed assets. The core of LCM is to establish appropriate technical and operational standards, plan construction costs and operation and maintenance costs as a whole, and to realize and make and decision-making of the whole life cycle cost of assets, so as to achieve asset cost optimization [13].

2.2 Control model of all life cycle management of power grid assets

The goal of all life cycle cost management of fixed assets in power grid enterprises is to minimize the all life cycle cost of equipment on the basis of ensuring reliability. Its core content is to analyze and calculate LCC of equipment assets and make decisions based on quantitative value [14]. According to the operation law of the equipment life cycle, the key points of the whole process management are the standard operation state and key control points of the equipment. According to the LCC theory and the related expenditure of the equipment assets, the corresponding key points of the LCC process management and the corresponding LCC model are constructed, namely:

$$LCC + CI + CO + CM + CF + CD \quad (1)$$

CI is the cost of input, including purchase cost, construction cost, and transportation, manpower and debugging costs during installation. CO is the cost of operation, CM is the cost of maintenance, that is, the cost of periodically replacing spare parts and other parts in accordance with the maintenance requirements during the life cycle, and the material cost, labor cost, and transportation cost needed for rush repair, maintenance, test and inspection. CF is the cost of failure, also known as cost of penalty; CD is the cost of disposal, that is, the cost of dismantling and transportation after the decommissioning of equipment assets minus the cost recoverable after the abandonment of substation equipment. The safety assessment system of power equipment is shown in Figure 1.

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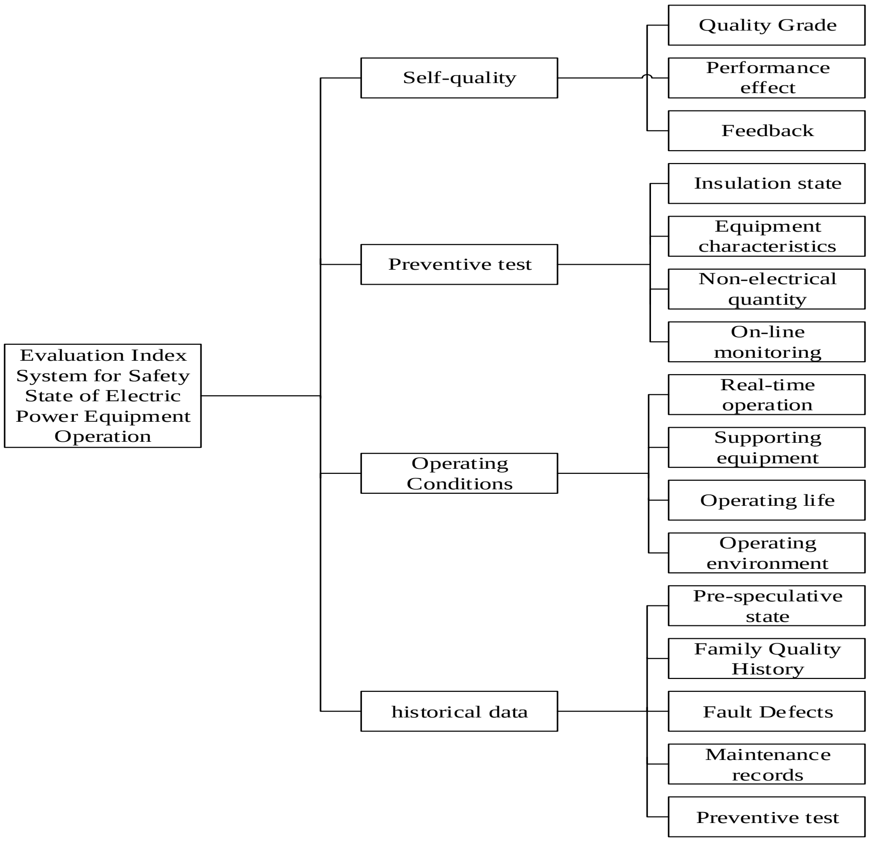

Figure. 1 Index system of safety state of electric power equipment operation

2.3 Reliability analysis of electric power equipment

Reliability refers to the ability of a component, equipment or system to perform specified functions within a predetermined time and under specified conditions. Reliability index refers to the quantity that can reflect the level of reliability from different aspects by using numerical value, which can start from both positive and negative perspectives. Reliability is used as a characteristic index of reliability to express the probability of reliable operation of components. In reliability theory, the following quantities are generally used to describe the level probability of reliability, such as reliability and availability. Frequency contains the average number of failures per unit time. Average duration includes the average time of the first failure and the average duration of the failure. Expectation value includes the expected number of days of power system failure in a year. In terms of reliability, components can be divided into two categories: repairable components and non-repairable components. Most components in power system are repairable components. The basic reliability indexes of repairable components are: failure rate, repair rate, reliability, unreliability, availability (validity), unavailability (inefficiency), average trouble-free working time, and average maintenance time.

2.4 Assessment system of all life cycle safety for electric power equipment

Each index factor of state assessment of power equipment operation safety is both deterministic and uncertain, such as quality grade, non-electric quantity, operation life, operation environment, fault defect, and maintenance record, which can be quantified and determined, and belong to deterministic factors; while other factors such as performance effect, feedback opinion and insulation status, equipment characteristics, on-line monitoring, real-time operation, matching equipment operation, pre-commissioning status and family quality history are deterministic factors and described in natural language and fuzzy concepts, which belong to fuzzy factors. The evaluator only gives a fuzzy evaluation, so the fuzzy comprehensive evaluation is a better method for 16 indicators of power equipment operation safety state evaluation. This paper adopts the fuzzy comprehensive evaluation, and its basic steps are shown in Figure 2.

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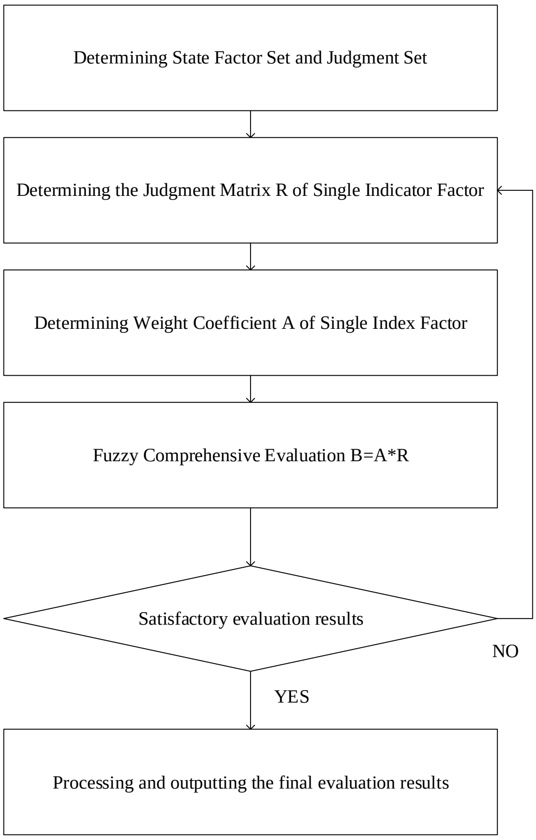

Figure. 2 Comprehensive assessment procedure of operation safety state of electric power equipment

Determination of the set of state factors: According to the index system, it is easy to determine the set of state factors for evaluation, that is, each index is an evaluation factor. There are 16 evaluation factors in the set of state factors, expressed by $U=\{U_1, U_2\ldots, U_j\ldots, U_{16}\}$.

Determination of judgement set: In general, people will choose different numbers to classify and grade the situation of things or states. In power system, people divide the situation of voltage into level 1, level 2, level 3, level 4, level 5, and level 6 according to the different critical states, totally 6 levels. A perfect alarm system of police safety protection is very important for the safety maintenance and protection of electric power equipment. It has great practical value to evaluate the actual operation of electric power equipment. Therefore, the safety level of actual work of electric power equipment is divided into 6 grades according to the degree of urgency. The order is as follows: 6, 5, 4, 3, 2, 1, in which the security situation that each level represents is shown below.

Level 6: This level indicates that the operation status of power equipment has reached a very dangerous level. The internal operation efficiency is low, exceeding the set working life seriously, the failure rate is very high, the overhaul cost is relatively high, and it is already at the very dangerous operation edge, and accidents will occur at any time.

Level 5: This level indicates that the operation of the equipment has reached the limit set by the equipment itself, the internal operation has been very difficult, the number of failures is relatively high, the cost of maintenance is relatively high, some key data cannot meet the requirements of production and operation, and the probability ratio of collapse after operation is high.

Level 4: This level indicates that the operation status of power equipment is within the time limit set by the equipment itself. The equipment has quality problems that some data cannot meet the production requirements. The equipment of this manufacturer often fails. The failure rate is not too high and the overhaul cost is acceptable.

Level 3: This level indicates that the operation status of power equipment is within the time limit set by the equipment itself. Most of the equipment data meet the production requirements, the internal operation status of the equipment is relatively normal, the equipment often fails, there are many complaints, the stability of the equipment is relatively poor, and it is very easy to break down or has risks.

Level 2: This level indicates that the operation status of power equipment is within the time limit set by the equipment itself. All kinds of operation parameters are good, the equipment quality of the equipment itself and the same manufacturer is good, the operation status of equipment and supporting equipment are ideal, the number of equipment failures is relatively small, and the overall situation is in a good state.

Level 1: This level indicates that the operation status of power equipment is within the time limit set by the equipment itself, and all the operation indexes are relatively good. There are almost no faults and overhauls, the quality is guaranteed, and the overall condition is very good.

Determination of weights: Weight mainly refers to the role and proportion of each single factor in the process of judging and evaluating a result, which plays a key role in judging the quality of the result and is a core link. At present, there are many ways of weight analysis based on multi-factors, and the results are rich and varied. But at present, almost all the approaches to determine the weight have shortcomings. To

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determine the core of the weight needs to consider the reality and select a comprehensive and specific evaluation method according to the actual situation. The weight of index factor j of the ith expert is determined by group decision-making analytic hierarchy process.

$$I_i = \sum_{u=1}^{l} w_u \times X_u^i \qquad (2)$$

By normalizing the importance I of the ith expert's opinion, the subjective weight T of the expert is obtained, which is used to represent the influence of subjective factors such as the level of knowledge, knowledge structure, and practical experience of the expert, namely:

$$T_i = \frac{I_i}{\sum_{i=1}^{m} I_i} \qquad (3)$$

Assuming that there are n factors in the index, m experts make evaluation decisions and form m × n order evaluation weight matrix as follows:

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \dots & \dots & \dots & \dots \\ c_{m1} & c_{m2} & \dots & c_{mn} \end{bmatrix} \qquad (4)$$

C_{ij} is the reciprocal of the safety grade judged by the ith expert on the factor of index j, $0 \le C_{ij} \le 1$, $1/C_{ij} \le 6$.

$$\lambda_i = \frac{\sum_{i=1}^{m} c_{ij}}{m} \qquad (5)$$

The error analysis of the evaluation weight of the first expert is carried out, and the relative proportion of the total weight error c_i is calculated as follows:

$$c_i = \left[\frac{\sum_{j=1}^{n} \left(c_{ij} - \lambda_j\right)^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} \left(c_{ij} - \lambda_j\right)^2} \right]^{\frac{1}{2}}$$

(6)

$$U_i^j = \frac{\frac{1}{c_i}}{\sum_{i=1}^{m} \frac{1}{c_i}} \qquad (7)$$

The influence of subjective weight T_i^j on each index factor is consistent, that is to say, there are comprehensive subjective weight T_i^j and objective weight U_i^j to calculate the weight A_i^j.

$$A_i^j = kT_i^j + (1 - k)U_i^j$$

(8)

k denotes the importance of subjective and objective weights, $0 \le k \le 1$.

According to the proportion of experts to the total number of expert groups that the index factor U_j (j=1,2... 16) rated as V_h (h = 1,2... (6), the judgment matrix R of state factors is formed:

$$R = \begin{bmatrix} R_{11} & R_{12} & \dots & R_{1h} \\ R_{21} & R_{22} & \dots & R_{2h} \\ \dots & \dots & \dots & \dots \\ R_{j1} & R_{j2} & \dots & R_{jh} \end{bmatrix}$$

(9)

If R is a matrix of 16 × 16 order, then the result vector is evaluated:

$$B = \frac{\sum_{j=1}^{16} \sum_{i=1}^{m} A_i^j R}{m} \qquad (10)$$

2.5 Safety maintenance management system of all life cycle for power grid assets

The integrated closed loop organization model of all life cycle asset management for power grid enterprises is shown in Figure 3. By taking reliability as an important reference index for the safety maintenance of power equipment, economy and security are the key reference parameters. On this basic level, the possible fault types, locations and ways of power equipment are analyzed and studied, and then the most suitable equipment and system maintenance mode is found.

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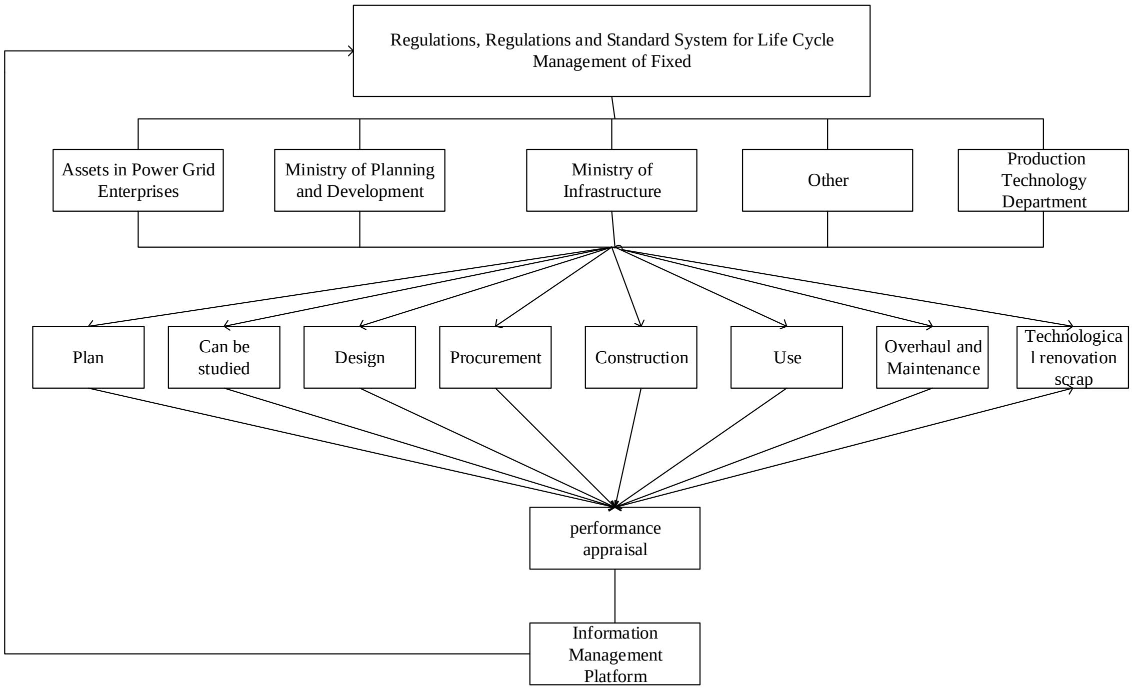

Figure. 3 Integrated closed loop organization model of all life cycle asset management for power grid enterprises

The main process steps of equipment safety maintenance are as follows:

Step 1: collect the equipment information needed to be maintained, including instructions, flow charts, operation rules, fault description reports, and similar fault analysis reports;

Step 2: conduct basic analysis, including collecting the historical data of equipment maintenance in the past, and constructing the analysis of fault equipment to realize its comprehensive analysis.

Step 3: study the flow chart of equipment, which mainly includes function flow chart, equipment past data, equipment function analysis, equipment description and numbering;

Step 4: equipment maintenance database. Through the establishment of reliability-based research model, the key degree of utilization of power equipment is analyzed. In addition, through the establishment of equipment safety analysis model, the safety of power equipment is judged and studied;

Step 5: select appropriate and efficient maintenance methods and formulate a safe and economic maintenance plan; evaluate the completed equipment evaluation and maintenance results; transmit the maintenance data of each equipment failure and the maintenance methods, plans, data etc. to the database.

3. Results and discussion

3.1 Analysis and research on satisfaction rate of power grid assets and equipment operation

Based on the reliability of the security assessment system, the analysis and research on the satisfaction rate of power network assets and equipment is shown in Figure 4. It

is seen that after the power enterprise operates the power security assessment system, the life-cycle benefit, cost rate and safety of power equipment have been improved significantly. The employees of power system and the ordinary users of power system are concerned about the safety of power system assets and equipment. The vast majority of people are very satisfied with the system, which occupies at least 58% of the survey population of their respective groups. Only less than 12% of the residents have their own views on the role of the system. It can be seen that the reliability of the safety evaluation system based on electric power equipment has brought a very positive effect on the safe and sustainable use of electricity for the vast majority of people, and has played a very good effect.

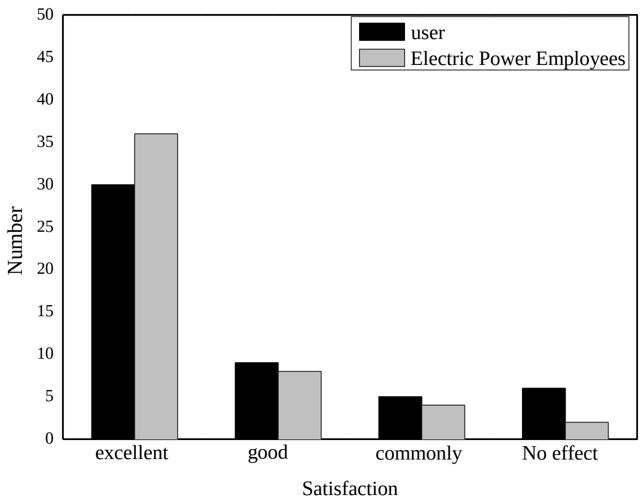

Figure. 4 Analysis and research on satisfaction rate of power network assets and equipment based on reliability of safety assessment system

3.2 Analysis of the number of blackouts of safety assessment system reliability

The analysis of outage frequency based on the reliability of safety assessment system is shown in Figure 5. It is found that the outage frequency based on the reliability of power equipment safety assessment system is less in four quarters, whether in urban or suburban areas or in rural areas. From this, it is known that the safety evaluation system of power equipment established has an efficient and comprehensive

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effect on reducing the frequency of blackouts, increasing the benefits of power enterprises, and reducing maintenance costs. Therefore, the reliability of the safety evaluation system based on power equipment established is very high, which improves the economic benefits of closed-loop management of power network assets.

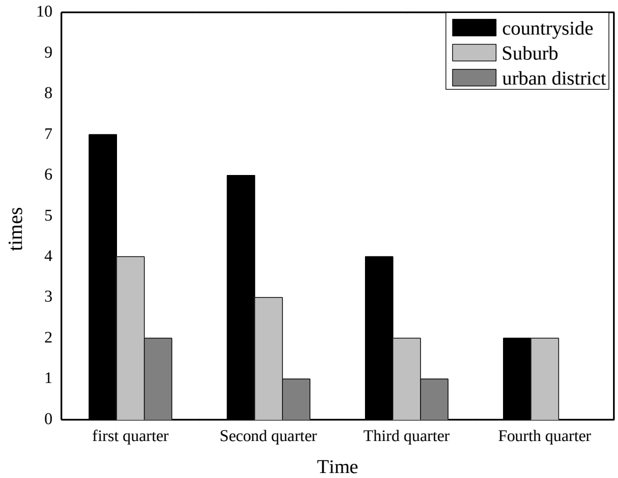

Figure. 5 Analysis of the number of blackouts based on reliability of safety assessment system

3.3 Analysis of operating benefits of electric power enterprises with reliability of safety assessment system

Based on the reliability of the safety assessment system, the enterprise life-cycle operation benefit analysis is shown in Figure 6. It is seen that the operation benefit of the electric power enterprise is greatly improved before and after the use of the new equipment safety assessment system. Compared with the four quarters of last year, the benefit has been greatly increased. The reliability of the safety assessment system for electric power equipment has greatly improved the life-cycle operating efficiency of enterprises.

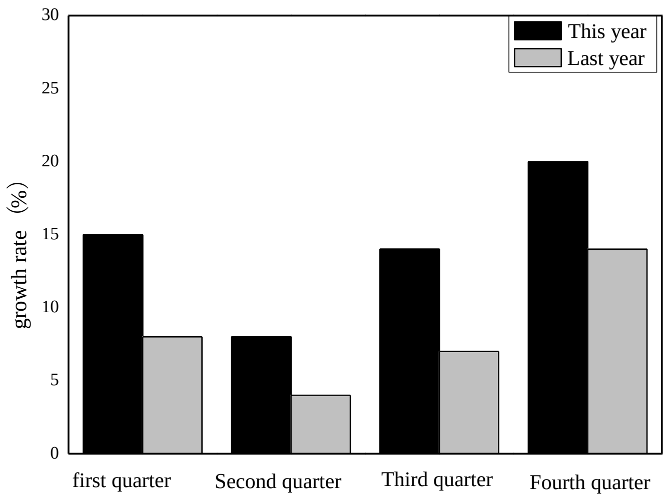

Figure. 6 Analysis of life-cycle business benefit of enterprises based on reliability of safety assessment system

3.4 Analysis of failure rate of power grid assets safety

The analysis of failure rate of power system asset safety based on system reliability is shown in Figure 7. It is seen that the normal operation efficiency of power equipment has been greatly improved after using the new power equipment safety assessment system. Whether for power generation equipment, transmission equipment or storage equipment, with the operation of the safety assessment system, the accident rate has decreased significantly. It is very important for the residents and enterprises to use electricity continuously and safely. In addition, it also reduces the cost of maintenance essentially. This is the fundamental solution to the problem. This shows that the closed-loop management of reliability grid assets based on security assessment system established not only increases the point interest and benefits, but also reduces CM.

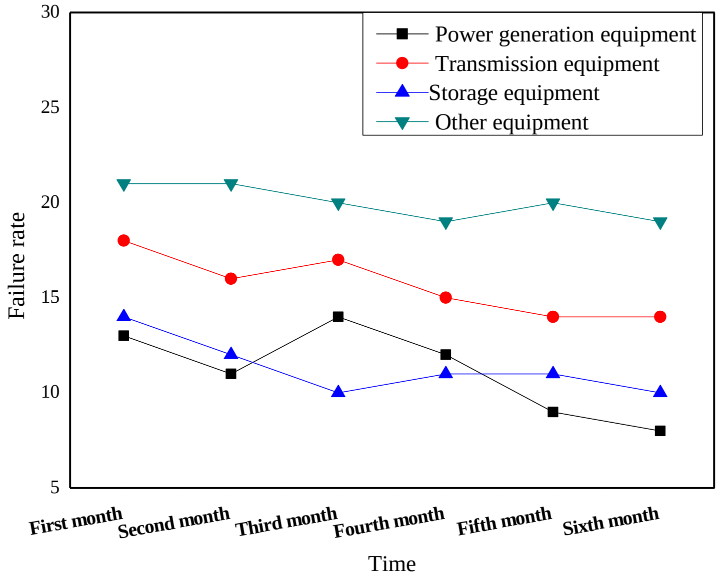

Figure. 7 Analysis of accident rate of power network assets based on reliability of safety assessment system

4. Conclusion

This paper designs the safety evaluation system of power equipment and studies the whole life closed-loop management of power network assets based on its reliability. The results show that the reliability of the safety evaluation system of power equipment established is very high, which not only reduces the number of annual power outages and the frequency of safety failures in the region, but also improves the operating efficiency of the electric power unit and reduces the maintenance cost caused by potential power hazards, thus ensuring the stable power consumption in the area. In addition, the satisfaction rate of the employees and residents of the electric power system for the system is remarkable. The system established not only cultivates the staff's awareness of the safety maintenance of the equipment, but also improves the work efficiency and reduce the number of manpower safety checks, and improve the power grid assets life-cycle closed-loop security and economic level management. The research of this paper is also limited to some extent. For instance, due to time and resource constraints, data search is not complete enough, and it is only a trial run in a region, the number of experimental samples is not large enough, the running time is not long enough, and the results obtained are slightly less convincing. Thus, follow-up research can be deeper, so as to reduce the interference to the research. Nevertheless, this study has important reference value for later researches.

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