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# Equipment Operation and Maintenance Management of Shanghai Power Distribution Network After Power System Reform

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**Abstract**

At present, China is in the process of reforming the electric power system. The reform of the power system has a significant impact on the investment and construction of power distribution network. Therefore it is indispensable to focus on fine management of the operation and maintenance of equipment.

In this paper, the current situation of distribution network in China including Shanghai has been presented. Then, based on the influence of policy documents of power system reform, not only its impact on the operation and maintenance of the power grid enterprise and the distribution network equipment but also measures to enhance the economic benefit of distribution network has been discussed. Furthermore, by analyzing each equipment and the probability and severity of its defects according to the defect data in production management system (PMS), the methods of the whole life cycle cost (LCC) and the potential failure mode and effects analysis (FMEA) have been applied to analyze the operation and maintenance of the distribution network from the two aspects of the economy and reliability. Finally, focus on acceptance as well as operation and maintenance management measures in the current distribution network has been put forward.



*Keywords:* distribution network equipment; power system reform; LCC; FMEA

## 1. Introduction

Beginning in March 2015, China has introduced new policies and documents reforming its electricity generation, retail, usage, and many other sectors. Considering the set of policies, it is expected that this round of power system

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reforms will have a profound impact on China's electricity markets and industries, such as on the investment and construction of power distribution network in the State Grid Corporation of China. When the operating costs of the distribution network are further clarified, the driving force for company self-development is to adopt a risk management approach to balance the economy and reliability of the distribution network investment and operation. Therefore in order to reduce the actual running cost, the grid will make efforts in three aspects: (1) to invest in the transmission and distribution projects with higher returns, such as energy-saving transformers and UHV; (2) to reduce the actual operation and maintenance costs; (3) to launch energy-saving transformation, the grid involved in energy-saving services market. In this paper, it is expected that through the management of the distribution network equipment operation and maintenance research, reducing the actual operation and maintenance costs is proposed.

For power grid company of Europe and the United States in equipment management, the introduction of the original financial areas of the "asset management" concept has been given. At present its focus is mainly on three aspects. (1) equipment investment management; (2) performance management and risk management; (3) residual life management and stakeholder management. On the one hand, the management of the remaining life requires access to the state of aging equipment, on the other hand, it needs to coordinate with the grid planning timetable. In addition to traditional capacity and redundancy, grid planning concerns a set of problems such as environment and safety regulations (e.g. asbestos, use of sulfur hexafluoride), equipment informatization and intelligence, and public demand on land and power plant appearance and so on.

This paper referring to the further research on leading policy documents of power system reform and its supporting documents as well as analysis of the current situation of the operation and maintenance of distribution network equipment in China (especially in Shanghai), researches on the operation and maintenance of distribution network equipment in Shanghai. First of all, the operation and maintenance mode as well as safety and reliability of Shanghai distribution network is studied by analyzing the defect model, probability and severity of the distribution network equipment. Secondly, FMEA analysis technique is used to analyze the risk assessment of main equipment defects in Shanghai distribution network. Then, the economic evaluation and the qualitative indexes of assets operation and maintenance of Shanghai distribution network are made through the economic analysis and operation and maintenance decomposition of the main equipment. Finally, with the above technical analysis results, on the basis of current acceptance standard and procedure of international and Shanghai distribution network, key parts of the acceptance as well as management and control in main distribution network equipment of Shanghai is proposed.

## 2. Operation and maintenance modes and safety risk analysis of Shanghai distribution network

### *2.1. Distribution network equipment and its defects*

Distribution network refers to the network which distributes electricity in the power grid. It can be further clarified that the network in the power system put the secondary low-voltage step-down transformer direct or step-down power to the user. It mainly includes: overhead or cable distribution lines, power distribution equipment, distribution, the column transformer, power distribution box.

According to "Distribution Network Operating Rules", the distribution network equipment defect level is divided into general, serious and critical defects of three categories.

### *2.2. PMS data analysis*

PMS (Production management system),as one of applications of the national Power Grid Corp SGl86 engineering utilizes computer technology, modern advanced graphics, automation, communication technology and other technical means to carry out online and offline intelligent management, making the grid reliable, high-quality, economic and efficient. The system covers the fields of power transmission, distribution, transmission lines, cables, relay protection, telecontrol and communication, and serves the production and operation departments of Shanghai Electric Power Company and its subordinate units.

In this paper, based on the defect data provided by PMS, various types of equipment are analyzed, and the collected data are sorted according to the time and space boundary. After data classified according to the type of equipment, the statistical analysis of the total and classification is made. In this paper, FMEA method is used to carry out risk assessment to find out the risky parts of acceptance, operation and maintenance.

This paper analyzed on the various types of equipment defect data provided by PMS based on the collected data according to the time and space boundary setting were classified according to the type of equipment, then the overall statistical analysis and classification of it, And use the FMEA method in this article to find acceptance, risk assessment, risk part the operation and maintenance.

- PMS data analysis in line

Line equipment mainly includes: tower, cable, column transformer, wire and so on

The PMS defect data used in this paper are all data from January 2010 to November 2016. According to the total defect distribution, in all the defects, accounting for the largest is tower (67%), followed by the cable (17%). By defect time distribution, we can see the number of defects occurred in 2014 owns the largest, followed by 2013. According to the spatial distribution of defects, it can be seen that the Pudong Power Supply Company is responsible for the largest proportion (48%), followed by the City North (9%). According to the classification of the severity of equipment defects, it can be seen that the general defects accounted for the most (84%), followed by serious defects (11%), at least for critical defects (5%). By statistical analysis of the time-dependent distribution of defects, it can be seen that the number of critical defects exceeded in 2016, and the number of critical defects in the remaining years was small. According to statistics, the defects of Pudong Power Supply Company are the most defective and most of them are general defects, while the City North Power Supply Company has the situation that the number of critical defects is larger than that of serious defects.

- PMS data analysis in power plant

Power plant equipment mainly includes: low-voltage switchgear, distribution transformers, low-voltage switchgear, load switches, circuit breakers, capacitors and so on.

The PMS defect data used in this paper are all data from January 2010 to November 2016. According to the total defect distribution, the largest proportion of all defects is the low-voltage switch (23%), followed by distribution transformers (19%). By defect time distribution, the largest number of defects occurred in 2014, followed by 2015. According to the spatial distribution of defects, the City North Power Supply Company is responsible for the largest proportion (23%), followed by the maintenance company (12%). According to the classification of the severity of equipment defects, it can be seen that the general defects accounted for the most (55%), followed by serious defects (32%), at least for critical defects (13%). The statistical properties of the defects are statistically analyzed by the time distribution. It can be seen that the number of serious defects exceeds the general defects only in 2015, and in 2010, 2012 and 2013, the number of serious defects and critical defects is very close. According to the classification of the defects, statistics show that the power supply companies in the City North Power Supply Company are the most defective and most of them are general defects, and the number of serious defects in urban power supply companies is bigger than the general defects. The number of critical defects is greater than the number of serious defects in the City North, Qingpu, Chongming power supply company

- Specific equipment analysis

In order to analyze the cause of defects of the specific equipment with large number of defects, the classification statistics and analysis are made. The total number of defects in the tower is the highest, and the total number of specimens is 19,149.

(1) the causes of defects

As shown in fig1, defects accounting for the largest proportion are failing to switch on (25%), followed by SF6 pressure anomalies (16%).

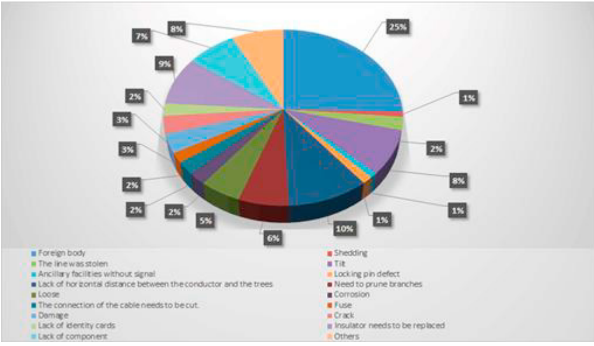


Fig. 1. Distribution of defect causes

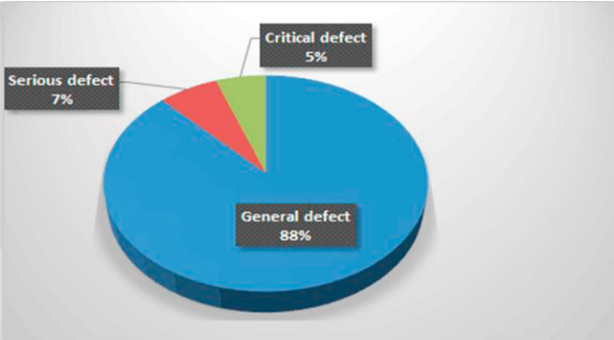


Fig. 2. Distribution of Defect Severity

(2) the severity of defects analysis

As shown in fig2, the most serious defects accounted for most defects (88%), followed by severe defects (7%) and critical defects (5%). Compared with the general, the proportion of the general defect is high, the reason is that there are many foreign bodies or inclination in the tower, and the distance between the branch and the tower tower is not enough.

## 3. FMEA used in Shanghai distribution network main system and the equipment risk appraisal

FMEA(Failure Mode and Effects Analysis) is used to analyze all possible failure modes and effects according to the characteristics and functions of the substation equipment. On the basis of this, each failure mode is evaluated, then the Risk Priority Number (RPN) is determined and the risk level of the failure is given.

### *3.1. FMEA analysis process*

There are three evaluation indexes, involved in the whole process of FMEA-based fault risk analysis which are failure severity (S), probability of failure (P) and detectability (D). According to the FMEA risk analysis method, firstly, the function analysis of all parts of the equipment is carried out to define all possible failure modes. Then, the values of the three evaluation indexes and the weight coefficients of each evaluation index are determined, that is, analyzing the possible consequences of each failure mode and giving the severity of the failure (S), determining the potential cause of each failure mode and giving the probability of failure (P), giving the detectability of each failure mode (D) according to the current maintenance and maintenance strategy of the equipment. Finally, the risk priority number(RPN) of the failure mode is obtained by using the quantitative values of S, P and D to determine the possible failure mode of the equipment and provide the basis for formulating reasonable operation and maintenance strategy, so as to improve the reliability and economy of equipment.

In the FMEA risk assessment, the product of failure severity (S), probability of failure (P), and detectability (D) are taken as the risk priority number (RPN) of the fault as shown in the following formula, higher RPN indicates means greater risk of failure mode. $RPN = S \times P \times D$

According to the risk priority number (RPN), the failure modes are sorted according to the rules to determine the risk levels and make corresponding evaluations. Then, the measures are formulated according to the evaluation results. In this paper, the "95% confidence level" rule is used to determine the RPN threshold. The 95% confidence interval for RPN is 15 to 24 on average, when RPN=15~24, the risk is moderate, non-critical, and which measures is recommended to take to reduce. The risk can be reduced by means of SOP. When RPN>24, the risk is higher, the key risk, which measures must be taken to reduce, making the risk to moderate risk below. When RPN<15, the risk is lower and acceptable. When the risk assessment RPN=15~24, the severity of a single risk index should be judged, if the S/P/D⩾ 3, control measures must be taken.

*3.2. Results and Analysis*

Defects "fuse problem", "exchange insulator", "overheating, temperature anomalies" in the line equipment own RPN more than 24 which is a high risk. In power station equipment, the RPN of "oil leakage, oil level abnormality" and "overheat and temperature abnormality" has exceeded 24, which also means a high risk.

In addition, there are many defects belonging to medium risk which own RPN between 15-24.Therefore determining the severity of a single risk indicator is needed. If the S/P/D ⩾ 3, control measures must be taken. In the line equipment, the "broken strand" defect of the wire is serious, but the frequency is not high as well as the degree of difficulty found, so S/P/D exceeds 3,and control measures need to be taken. In the power station equipment, "auxiliary equipment damage", "failure to adjust gear", "indicator abnormalities", "failure to switch on", "energy storage motor abnormalities", "fuse blown", "current reading abnormal", "overheating, and temperature anomalies" these defects are critical defects with low-frequency occurrence and easily found, so the S/P/D is much more than 3, and control measures must be taken to prevent the risk too large.

In a word, combined with defect content of RPN more than 24, acceptance and control recommendations can be made on the distribution network in Shanghai:

- In the process of acceptance sampling, it is suggested that the fuses and insulators in the line part and the oil sealing device in the power station part be taken as the key sampling objects to improve the overall quality of these devices and reduce the risk of failure.
- Equipment overheating or temperature anomalies as high-risk defects existing in the line and power plant, can be specifically further explored into the causes, so as to prevent or accelerate the repair process.
- Defects with S / P / D exceeding 3, such as wire breakage, energy storage motor abnormality, have low frequency but mostly are serious defects or critical defects. Therefore, it is recommended as the focus of the inspection and maintenance to reduce the probability of failure. For other low-risk equipment or defect causes, the inspection period can be reduced.

## 4. The economic analysis of investment and operation of Shanghai distribution network

*4.1. FMEA analysis process*

Life Cycle Cost (LCC) analysis generally refers to the total cost of an equipment or project over its entire life cycle, including not only the initial one-time cost of the equipment or project, but also the entire life cycle.

The LCC includes investment cost, operating cost, maintenance and repair cost, fault cost, and disposal cost. According to the analysis of various factors in the LCC model, a formula suitable for the calculation of the distribution network can be deduced. The formula can be written as:

$$LCC = C_I(n) + C_M(n) + C_D(n) + C_{IL}(n) \quad (1)$$

$C_I(n)$, The investment cost in year n mainly includes the purchase of equipment;$C_M(n)$, The maintenance cost in year n, mainly includes periodic maintenance and repair costs;$C_D(n)$, decommissioning cost in year n, mainly includes the cost of disposal at the time of replacement of the equipment and the residual value at the time of disposal;$C_{IL}(n)$, power loss cost in year n, refers to the equipment or line failure, maintenance, outages caused by power failure making the user or power sector losses.

*4.2. Application Analysis of Transformer LCC Model*

Two distribution transformers A and B with a load factor of 0.6 and a discount rate of 10%, and EENS (including direct economic loss and indirect economic loss) equal to 7.5 yuan / kWh are presented. Table 4-1 shows the other economic indicators for selecting two transformers.

Table 1. Transformer A, B economic indicators

| | Investment cost | Service life | Annual operation and |
|---|---|---|---|

| | (million/set) | | maintenance costs (million) |
|---|---|---|---|
| Transformer A | 13 | 17 | 0.65 |
| Transformer B | 15 | 22 | 0.75 |
| | Residual value | Failure rate(times / year) | Repair time(h/times) |
| Transformer A | 5% | 0.05 | 20 |
| Transformer B | 5% | 0.02 | 20 |

The LCC analysis shows that the equivalent investment cost of transformer A is 15269.75 yuan, which is larger than the investment cost of transformer B equal to 16525.21 yuan. But after LCC analysis, the value of transformer A is 30633.24 yuan, which is higher than that of transformer B 28091.47 yuan. From the cost of the ratio of view, the transformer A cost of investment accounted for about 51% of the cost of LCC, while the transformer B accounted for 60.24%, which shows that when the transformer A operating costs increase, the reliability reduced, investment costs of the weight will be getting lower and lower. This is also an indirect indication that decision-making analysis of the program based on the cost of the investment is obviously not applicable.

Since the cost and reliability of LCC vary with the market environment and so on, it is necessary to analyze the influence of multiple sensitive factors before determining a certain scheme. When the operation and maintenance costs, power loss, salvage value are not included, or investment costs, power outages are in the original parameters of 80% to 120% change, the sensitivity of the factors can be obtained. After analysis, it can be seen that for the transformer A, B, the investment costs have a larger impact on LCC annual cost, power outages do little. And no matter how the above factors change, transformer B annual cost is larger than the cost of transformer A, so it can be concluded that transformer B is better than transformer A. The feasibility of the LCC analysis method is verified by the example of the transformer. Therefore the method can be extended to the other equipment of the distribution network or even the whole system for the analysis and optimization of the equipment and the optimization management of the system.

## 5. Conclusion and Prospect

In this paper, the current situation of distribution network in China including Shanghai has been presented initially. Then, based on the influence of leading policy documents of power system reform and its supporting documents, not only its impact on the operation and maintenance of the power grid enterprise and the distribution network equipment but also measures to enhance the economic benefit of distribution network has been discussed. Furthermore, by analyzing each equipment and the probability and severity of its defects according to the defect data in production management system (PMS), the methods of the whole life cycle cost (LCC) and the potential failure mode and effects analysis (FMEA) have been applied to analyze the operation and maintenance of the distribution network from the two aspects of the economy and reliability. Finally, focus on acceptance as well as operation and maintenance management measures in the current distribution network has been put forward.

## References

[1] Ye Ze. The Effect, Problems and Countermeasures of Transmission and Distribution Tariff Reform in China[J]. Price Theory and Practice, 2016 (2): 35-42.
[2] Zhang Lizi. The Mechanism Construction and Method Exploration in Transmission and Distribution Tariff Reform in China[J].Price Theory and Practice, 2016 (2): 29-31.
[3] Tang W H, Spurgeon K, Wu Q H, et al. An evidential reasoning approach to transformer condition assessments[J]. IEEE Transactions on Power Delivery, 2004, 19(4): 1696-1703.
[4] Wang Haoming, Wang Zhe, Li Wei, Qi Xiaohua, Man Yuyan. Reliability evaluation method for distribution network based on self generated FMEA table [J]. Power Construction, 2014,12:106-110.
[5] Xue Yulan. Method for establishing maintenance cost based on life cycle cost concept [J]. East China electric power, 2008, 36 (10): 1243-1245.
[6] Zhang Lizi. Reform of Transmission and Distribution Tariff Stresses on Mechanism Construction and Method Exploration[N].Economic Daily, 2016-03-31 (009).