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Research on Sampling Test Effect of Large-Scale Power Transformer and its Improvement based on Game Theory

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Abstract

The large-scale power transformer is one of the key equipment for power grid, and its quality has important effects on the security, stability and economic operation of the power grid. It is a good method to strengthen the quality control for sampling test. But it is difficult to carry out for large power transformer, because of the restriction of testing condition demanding. The development of test system, test items and sampling objects determination principle are introduced. The sampling test process and results evaluation standard for larger power transformer of State Grid Corporation of China are also introduced. The sampling effects are analyzed by means of game theory. The sampling test results are analyzed in multiple dimensions, such as qualified rate, voltage grade, type, supplier coverage, and trend. The quality problems and sampling test effects are mainly analyzed. The results of no-load loss, load loss, partial discharge test and sound level measurement. The sampling qualified rate of power transformer increased from 84% in 2009 to both 100% in 2011-2013. Finally, the sampling mode innovation is studied on the basis of summarizing the experience of sampling test, and the suggestions are put forward

Keywords: *large-scale power transformer, sampling test, qualified rate, game theory, uncertainty of measurement result*

1. Introduction

Power transformer is one of the key equipment for power grid, and its quality has important effects to the security, stability and economic operation of the power grid. Because of the power transmission and transformation equipment manufacturing enterprises in China continue to increase investment, expand, the intensity of transformer market competition is more than 5 to 1 [1]. In order to obtain the market share, some enterprises take the low price competition strategy, a minority enterprise low the price artificially, compressing design margin, adopting inferior raw material during the manufacturing process, which reduce the power transformer quality and performance. It has great significance to study to strengthen the quality control method.

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Sampling test is a good method to strengthen quality control [2-4] with the reasonable sampling quantity, frequency, and the corresponding treatment measures, it can improve the supplier quality consciousness. It is difficult to carry out for large power transformer, because that has been subject to the restriction of testing condition demanding. Few people research on the organization and implementation, sampling test cost, and sampling test effects, the sampling test is difficult to carry out.

2. Sampling Test Analysis Based on Game Theory

The selection mode of the rules for the enterprise depends on the total income, including obeying rules income R_1, disobeying rules income R_0, and the probability punishment for disobeying rules F. If $R_1 > (R_0-F)$, the enterprise probably obey the rules; if $R_1 < (R_0-F)$, the enterprise may not obey the rules [5].

2.1. Hypothesis

① $N=\{1,2\}$ is a set of the two sides in the game. 1 stands for the enterprise. 2 stands for the sampling inspection unit.

② $\Theta=\{\theta_0,\theta_1\}$ is the enterprise type space, which is private information of the enterprise. The sampling inspection unit does not know the value of θ, but can get the probability of θ:

$P\{\theta=\theta_1\}=\alpha$;

$P\{\theta=\theta_0\}=1-\alpha$;

where

θ_1 the enterprise obey the rules

θ_0 the enterprise not obey the rules

③ $M=\{S_0,S_1\}$ is a set of enterprise signal space.

where

S_0 the enterprise does not put up production and sales.

S_1 the enterprise still puts up production and sales.

④ $A=\{a_0,a_1\}$ is a set of the sampling inspection unit action. a_0 stands for no sampling. a_1 stands for sampling.

2.2. Game Sequence and Solution

First step: the enterprise select the signal $m(\theta)=S\in M$ based on the private information. It means the enterprise can select to produce and sale the conformity or unconformity product.

Second step: the sampling inspection unit observes the signal S_k, k=0,1, and then form the inference about type θ :

$\pi_k=p\{\theta=\theta_1|m=S_k\}$, k=0,1。

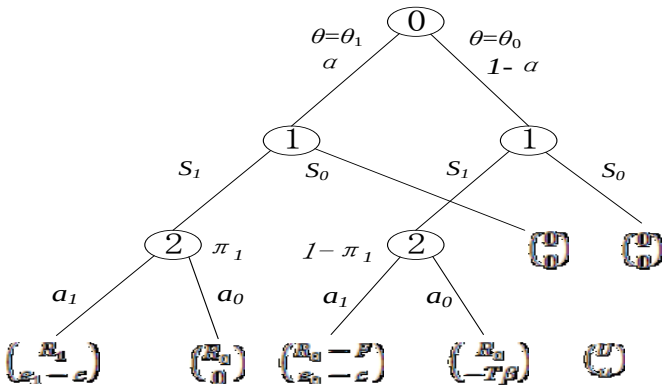
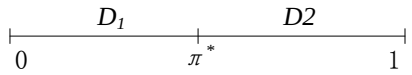


Figure 1. Game Sequence Diagram

It is solved that the sampling inspection unit inference complied with the sub-game refined Bayesian equilibrium, and the enterprise inference complied with the sub-game refined Bayesian equilibrium. The solution is shown in the follow Figure.



$$\pi^* = \frac{e_0 - c + T\beta}{e_0 - e_1 + T\beta}$$

where

c the cost of sampling inspection unit.

e_1 the reward sampling inspection unit obtained without finding the quality defects, according to the rules.

e_0 the reward sampling inspection unit obtained, when they find the quality defects.

T the punishment for the sampling inspection unit nonfeasance.

β the probability that sampling inspection unit nonfeasance can be found.

When $\pi \in D_2$, namely $\pi^* < \pi \leq 1$, it is pooling equilibrium.

When $\pi \in D_1$, namely $0 < \pi \leq \pi^*$, it is pooling equilibrium.

Only π^* close to 1, namely $e_1 = c$, and $R_0 - F < 0$, it is separating equilibrium.

2.3. Factors of R_0, R_1 and F

The value of R_0, R_1 depends on the enterprise. It can be regarded as fixed in a period [8][10]. The value of F is proportional to f_s, p_s, p_c, c_p, namely

$F = f(f_s, p_s, p_c, c_p)$,

Where

f_s the frequency of sampling inspection.

p_s the probability of finding defects by sampling inspection.

p_c the probability of enterprise's problem.

c_p the loss because of the punishment.

The values of f_s, p_s, c_p are related to the sampling inspection. The reasonable value of F can be obtained through scientific setting, which makes $R_1 > (R_0 - F)$.

3. Implementation of the Sampling Test

In order to carry out the sampling test effectively, the sampling process, determination of the sampling, sampling test and results of the evaluation are specified in detail.

3.1. Test System Development

In order to measure the technical parameters of power transformer accurately, the major parameter testing system of power transformer is developed by China electric power research institute (CEPRI), which includes the high precision measuring voltage transformer, measuring current transformer, power analyzer, sound level meter, instrument for measuring DC resistance , partial discharge test device and so on[6]. The sampling test is carried out in the suppliers' factory, and the devices should be with high accuracy, stable performance, light weight, small volume, convenient transportation and wiring quickly. All the measuring equipment was installed in the container as a set, which will ship to the test spot. Due to the constant test items, the three sets of voltage transformer and current transformer are fixed on the container chassis in cross way.

Figure 2. Instrument Transformer Distribution

3.2. Supplier Selection Principle

There are mainly six aspects for the supplier selection principle, including:
1) the suppliers who are obtained the big orders;
2) the transformers with low price;
3) the new suppliers who supply the product first time;
4) the suppliers with bad performance, whose products have more quality problems;
5) the transformer which the domestic silicon steel sheet is used;
6) the transformer used in the key project or important spot;

The project unit can also apply for sampling test, which will be determined with comprehensive consideration.

3.3. Test Item Determination

The principles for test item determination include the necessity, rationality and operability. The routine tests, take-over tests on site and reflection of the project units were considered. Finally, the sampling test items include no-load loss, load loss, sound level measurement, Long-duration induced AC voltage test (ACLD) for 220kV and above, Short-duration induced AC withstand voltage test (ACSD) for 110kV.

It not only has important influence to the economic operation of power transformer for the no-load loss and load loss, but also affects the manufacturing cost obviously. The power transformer market competition is very intense in China, which makes the supplier to lower the manufacturing cost as much as possible. It may lead the measured value of no-load loss or load loss larger than the contract value. Even then, because the numerical only can be got from the supplier routine test report, which lack checking by the third party test, it has risk.

The partial discharge has important effects to the long term safe operation of the power transformer. The unqualified rate of partial discharge under ACLD test is much higher than other test items. Because of the test environment disturbance for the take-over test on site, the test result evaluation standard is lower than the routine test. It also has risk for lacking the checking test.

The sound level of power transformer reflects the performance of the silicon steel sheet and the manufacturing technology level. With the improvement of the social environment protection consciousness, the requirement of the power transformer sound pressure level is higher and higher.

3.4. The evaluation standard of sampling test results

The results of sampling test are classified into three levels as A, B, C. Level A means that all the testing items results of the sampling transformer can reach or exceed the contract value. Level B includes three kinds of circumstances, 1) the results of no-load loss and/or load loss beyond the contract value, but within the scope of allowable deviation, other test items results meet the contract; 2) the results of sound pressure level beyond the contract value, but within the scope of allowable deviation, other test items results meet the contract; 3) the results of the no-load loss , load loss and/or sound pressure level beyond the contract value, but within the scope of allowable deviation, other test items results meet the contract. Level C also includes three kinds of circumstances, 1) the results of no-load loss or load loss beyond the scope of allowable deviation; 2) the results of sound pressure level beyond the scope of allowable deviation; 3) the results of partial discharge under ACLD or ACSD beyond the contract value. The uncertainty of measurement result (UMR) of no-load loss and/or load loss should be considered [7]. The UMR for the test system developed by CEPRI is about 2%.The corresponding treatment measures are formulated against the evaluation levels, which can play the role of guidance and constraint.

4. Result Analysis of the Sampling Test

During 2008 and 2013, 108 power transformers of 110kV to 750kV were tested by sampling test. The distribution of each voltage of the power transformer is shown in Figure 3.

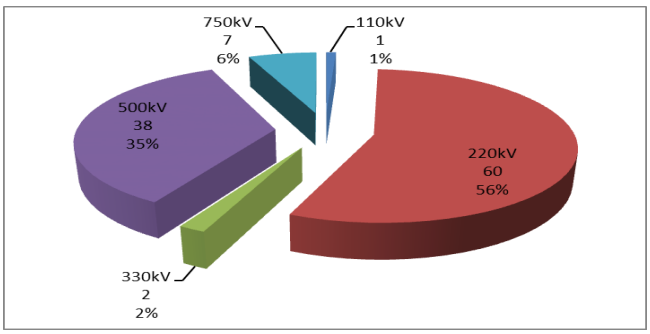


Figure 3. The Voltage Distribution of the Power Transformer

4.1. Result Level of Sampling Test

The number of Level A for the sampling test result of power transformer is 97, which takes the rate of 90%. 2 of the sampling power transformers were not classified for the testing environment. The distribution of the result level is shown in Figure 4.

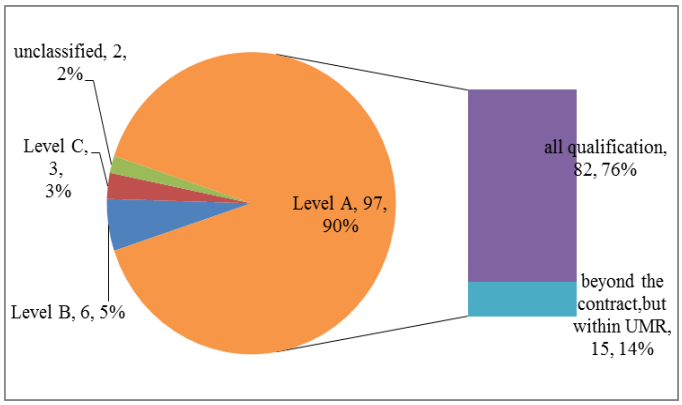


Figure 4. Distribution of Result Level

4.2. Qualified Rate of Level A

The qualified rate of Level A is up to 100% for recent three years from 84% of 2009. It is shown that the effects of sampling test are remarkable. The sampling test makes the supplier attach great importance to the quality of power transformer. Since the sampling test, three of power transformer has been classified to Level C, and two of them classified to Level B. The suppliers with Level B and C were punishment in the bidding process and the performing contract correspondingly. All the series treatments make the supplier to improve the production management, process control and testing technology and equipment. The qualified rate of Level A is shown in Figure 5.

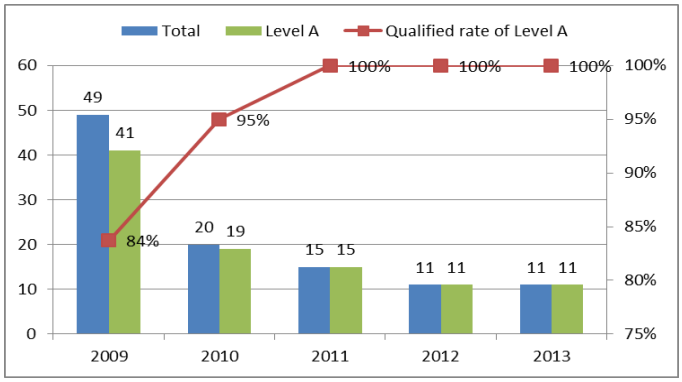


Figure 5. Qualified Rate of Level A

It is worth noting that some supplier delayed the sampling schedule casually after receiving the sampling notification, which reduces the effect of sampling test. On the other side, it also shows that the sampling test of power transformer brought certain pressure to the suppliers. It has the effect to make the supplier pay more attention to the manufacturing process control and production quality.

4.3. UMR of No-Load Loss and Load Loss

The main resources of the UMR of no-load loss and load loss for large-scale power transformer include five aspects: 1) uncertainty of the measuring current transformer and voltage transformer; 2) uncertainty of the power analyzer; 3) uncertainty of measurement of the power transformer oil temperature; 4) uncertainty of DC resistance of the winds; 5) uncertainty of calibration standard transformer and verification. Other factors of the UMR include the test voltage waveform distortion, frequency fluctuation, which can be got good control by the manufacturer in most cases [9].

The UMR of the large-scale power transformer test system is less than 2%. There are 15 large-scale power transformers, whose test results are beyond the contract but within the UMR. It is shown that the proportion to Level A is low to 9% in 2013 from 20% in 2009. The trend of the proportion is shown in Figure 6.

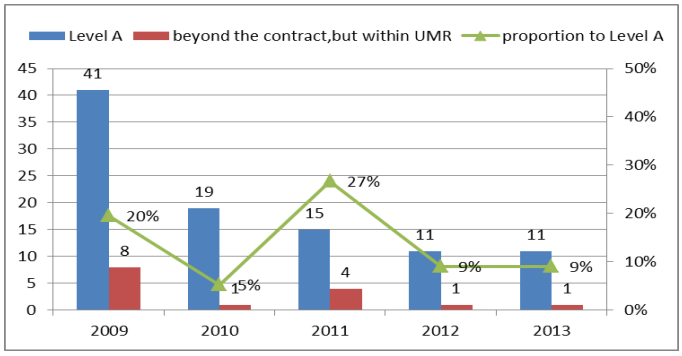


Figure 6. The Proportion to Level *A* Considered the Uncertainty

4.4. Technique Analysis of the Sampling Test Results

Three large-scale power transformers were evaluated to level C. One partial discharge under ACLD of the low voltage wind achieves 600pC, beyond the contract value 70pC, which is related to the coil insulation. One partial discharge under ACLD of the low voltage wind achieves 490pC, beyond the contract value 90pC, which is related to the body assembly; the load loss achieves 584.4kW, beyond the contract value 540kW, which is related to connection of the secondary measuring lines. One no-load loss achieves 135.5kW, beyond the contract value 127kW, which is related to the oil tank and structural component.

4.5. The Margin of Test Items

The margin of the test items M_i is defined as follow:

$M_i=(V_c-V_t)/V_t\times 100\%$

Where i=1-4

V_c means the value of the contract

V_t means the value of the test result

The margins of the no-load loss and load loss are shown in Figure 7. It is shown that the margin of no-load loss is bigger than the margin of load loss. The average and standard deviation of the no-load loss margin are 8.73% and 0.071. The average and standard deviation of the load loss margin are 3.08% and 0.034. The average and standard deviation of no-load loss margin are both bigger the load loss margin. The contract value can be improved based on the average margin of no-load loss and load loss.

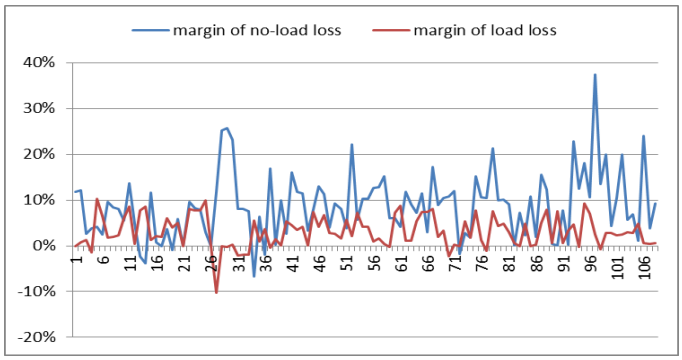


Figure 7. Margin of No-Load Loss and Load Loss

The margins of the partial discharge of HV and partial discharge of MV are shown in Figure 8. The average and standard deviation of the HV partial discharge margin are 50.39% and 0.250. The average and standard deviation of the MV partial discharge margin are 39.14% and 0.244. The average and standard deviation of the MV partial discharge margin are both smaller than the HV partial discharge margin. It is shown that the volatilities are both larger than the no-load loss or load loss.

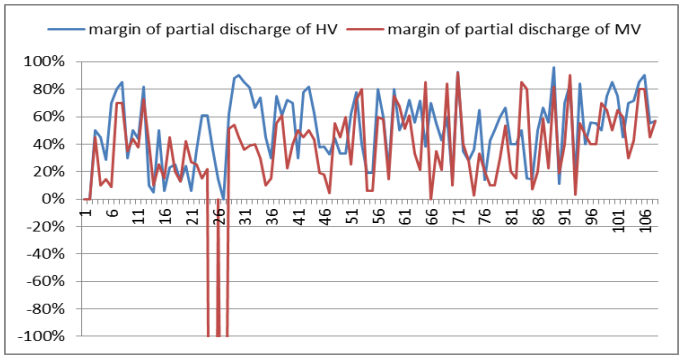


Figure 8. Margin of Partial Discharge of HV and MV

The margins of the sound level are shown in Figure 9. The average and standard deviation of the sound level margin are 7.41% and 0.047. The margin of the sound level is smaller than all the other test items, but the load loss margin.

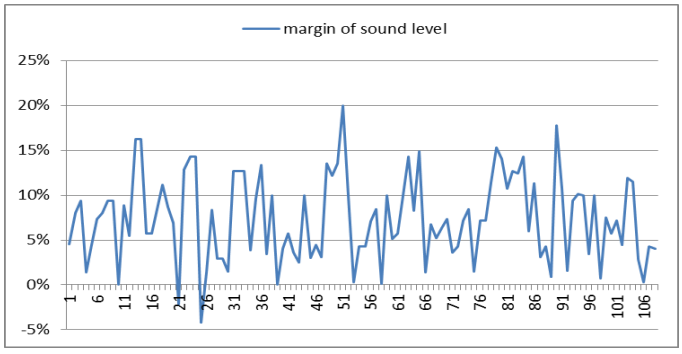


Figure 9. Margin of Sound Level

The average of the margin (AM) of the no-load loss, load loss, HV partial discharge, MV partial discharge and sound level from 2009 to 2013 is shown in Figure 10. It is shown that the AMs of HV partial discharge, MV partial discharge and no-load loss have the trend of growing up. The AMs of load loss and sound level are at the same level.

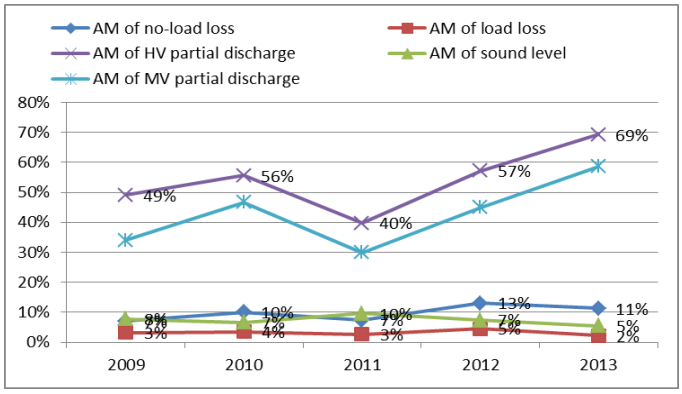


Figure 10. AM of the Four Test Items in 2009 to 2013

5. Suggestion and Improvement of the Sampling Test

The sampling test mode of the large-scale power transformer has been carried out for five years. It has played an important role to urge the supplier to quality. It has a good effect, but also faces new situations, which needs to improve the sampling test process.

5.1. To Keep Strengthening the Sampling Test.

As the materials and components of domestic rate increased greatly, some supplier expanding capacity, reconstructions of the old factory, establishment of new factories, the risks and uncertainty factors to the safe and stability operation of power transformer are rising. Some suppliers are on the lax, successfully developed the ultra-high voltage power transformer, but appearing quality problems on the general products. The sampling test should be strengthened, keep the sampling frequency, strengthen the treatments of the sampling test results, which can raise the cost of defaulting and lower the risks.

The breadth and depth of the sampling test should be expanded. The sampling test frequency should be increased. The sampling test can be taken on the different types, different period product of the same supplier, which can consolidate and improve the sampling effects. It is beneficial to master the supplier actual production ability and the power transformer performance level, which can maintain the deterrence to the suppliers and prompt to improving the quality of the power transformer.

5.2. Innovations of the Sampling Test Mode and Method.

For the nowadays sampling test mode of the power transformer, the sampling test date should be confirmed by consensus with the supplier. As the sampling test has been last for 5 years, the sampling processes and rules were mastered by the suppliers, who may prepare against the sampling products for avoiding the product quality risks. To give full play to the randomness of the sampling test, the sampling mode and method should be innovated, where the samples can be sealed by random way. Also the mode of combination of the unit's application and headquarters plan can be adopted, which can give play to the role of the project unit and the local company.

5.3. The Statistic and Analysis Should be Strengthened.

The local companies also do the sampling test. The overall product quality and technique performance of the power transformer should be mastered comprehensively, which can be used to improve effect and measures of the quality supervision, to provide decision-making reference. The technique analysis should be strengthened, and the first-hand information of the sampling test should be given full play to, including the product performance, test ability of the supplier, test environment, test personal technique level. The quality change of power transformer between the different suppliers and the different period for the same supplier should be analyzed.

The regulations and working processes should be improved. Facing the new situations of the power transformer industry and quality supervision, the experience should be summed up to improve the regulations and the working processes, which can make the sampling test more effective and standardized. The uncertainty of the measurement system should be researched deeply, which can optimize the test criteria.

6. Conclusion

For the sampling test mode, the CEPRI test based on the major parameter testing system after the suppliers' routine test, where both the testing system were compared. The major parameter testing system is verified by the practice. Mistake connection of the test lines was found during the sampling test for individual supplier, which make the load loss test result mistake. The defect was found after careful analysis, and the correctness of the sampling test was validated by the supplier.

The sampling test of the power transformer in the supplier factories is also a strict appraisal to the supplier test environment. Some suppliers test hall did not meet the requirement of the partial discharge measurement under ACLD. The interference sources were checked and analyzed by the sampling personal and experts for the test hall, and then the interferences were confirmed and/or eliminated. During the sampling test, the test environment of the supplier was improved.

The game theory analysis and results of the sampling test show that it can default risk and enhance the cost of the supplier, though the reasonable sampling frequency, sampling method and treatment against the results, which can guide the supplier to attach importance to the product quality. The organization of the sampling process is the prerequisite to the sampling effects. The experience of sampling test should be often summed up to improve the sampling test method.

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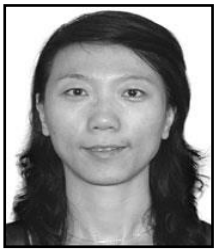

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