Analysis of Abnormal Detection Data of Dissolved Gases in 500kV Transformer Oil

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Abstract: Transformers may experience various faults during operation. In order to analyze the cause of the fault or even predict it, electrical and chemical methods need to be used for monitoring to ensure the safe and stable operation of the transformer. This article analyzes the phenomenon of acetylene and excessive gas content detected in the insulation oil of a 500kV transformer in a certain power plant. It is preliminarily judged that acetylene is generated by intermittent arcing inside the transformer. The excessive gas content is caused by poor sealing and leakage, incomplete degassing and exhaust before the transformer is put into operation, and residual gas gradually entering the transformer oil after the transformer is put into operation. Based on the analyzed cause of the fault, preventive measures such as strengthening daily inspections, investigating potential hazards, and conducting mass spectrometry detection are proposed.

1. Introduction

Electric power transformers are the most critical equipment in electrical systems, responsible for the important tasks of voltage transformation and power transmission. If a transformer fails, it can easily cause large-scale power outages, resulting in countless economic, social, and personal losses [1]. Currently, most of the faults that occur during transformer operation are thermal and discharge faults. Dissolved Gas Analysis (DGA) is one of the dissolved gas testing techniques for the insulation status of oil-immersed power equipment, and its basic principle is based on the dissolved gas content and composition of low molecular hydrocarbon gas in the insulation oil, which can effectively detect and diagnose the potential faults within the equipment [2-3]. It is widely used in power transformer, reactor and other equipment. Therefore, the detection of dissolved gas in transformer oil can monitor latent faults or early faults within the transformer without affecting the operation of the transformer. Combined with other electrical tests, lesions existing in the transformer can be found more effectively and accurately[4-5].In this article, we will analyze the mechanism and influencing factors of acetylene(C_2H_2) production in the oil of a 500kV main transformer that showed excessive acetylene levels and gas content after being put into operation, and propose corresponding preventive measures.

2. Abnormal data of oil detection of a 500kV transformer

A SSP-H-780000/500 three-phase forced oil circulation water-cooled no-load voltage regulating combined boosting transformer produced by Shenyang Transformer Group Co., Ltd. has been in good operation since its commissioning in April 2008. In January 2015, acetylene was first detected in the transformer oil, with values of around 0.1 μL/L for all three phases. As of March 2018, the test results had not exceeded 0.2 μL/L. However, a gradual upward trend began in April 2018, reaching 0.38 μL/L in June 2018 and 0.46 μL/L in July 2018. On February 13, 2019, the three-phase detection results were all around 0.5 μL/L. Since July 2018, the test results have remained between 0.4 and 0.56 μL/L without further significant increases. During the same period, the growth of other characteristic gases in the oil chromatography methane(CH_4), ethane(C_2H_6), ethylene(C_2H_4), hydrogen(H_2), carbon dioxide(CO), and carbon monoxide(CO_2) was relatively gradual, with no significant increases. According to industry standard DL/T 722-2014[6], the transformer exceeded the standard attention value for gas content (not exceeding 3%) in November 2009, and underwent an oil filtration in April 2010 to bring the gas content back to pre-operation standards (not exceeding 1%). After the transformer was put back into operation in April 2010, the gas content exceeded 3% again by May 2018, and has since increased to 4.6%, fluctuating mainly in the range of 3.9% to 4.7%. The chromatographic test data is shown in Table 1, and other oil data is shown in Table 2.

In addition, the electrical commissioning reports of the transformer for the years 2018-2020 were reviewed. The test results for items such as the DC resistance of the windings, winding insulation resistance and absorption ratio, insulation resistance of the core and clamps, main insulation and capacitive bushings, insulation resistance to ground at the end screen of the main insulation and capacitive bushings, dielectric dissipation factor and capacitance of the main insulation and capacitive bushings,

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dielectric dissipation factor and capacitance of the windings together with the bushings, and winding leakage current all met the requirements.

Table 1. Transformer Oil Chromatographic Testing Data

Test Date	Phase	CH_4 (μL/L)	C_2H_6 (μL/L)	C_2H_4 (μL/L)	C_2H_2 (μL/L)	H_2 (μL/L)	CO (μL/L)	CO_2 (μL/L)	Total Hydrocarbon (μL/L)
January 17, 2015	A-Phase	12.99	2.44	0.92	0.12	88.29	500.59	3008.14	16.46
	B-Phase	10.76	1.99	0.78	0.09	75.47	420.82	2538.29	13.62
	C-Phase	11.72	2.34	0.85	0.11	70.88	418.11	2797.06	15.03
August 15, 2016	A-Phase	17.34	4.28	1.66	0.11	77.17	598.34	4175.52	23.38
	B-Phase	17.02	3.75	1.24	0.12	81.32	612.40	4040.32	22.12
	C-Phase	16.72	3.67	1.25	0.10	86.28	635.91	3873.27	21.74
December 11, 2017	A-Phase	19.82	4.18	1.30	0.18	67.06	663.09	4040.62	25.58
	B-Phase	19.38	4.09	1.34	0.18	62.88	634.23	4016.14	25.01
	C-Phase	19.32	4.15	1.34	0.17	60.01	623.56	4121.43	25.00
June 16, 2018	A-Phase	20.18	4.39	1.56	0.39	46.97	654.82	4002.57	26.52
	B-Phase	21.06	4.38	1.58	0.38	50.86	680.05	3984.16	27.41
	C-Phase	19.74	4.46	1.28	0.38	46.29	650.14	4004.86	25.85
June 18, 2019	A-Phase	24.02	5.08	2.34	0.58	36.35	791.47	4767.64	32.02
	B-Phase	23.07	4.84	2.22	0.56	35.35	749.84	4568.58	30.69
	C-Phase	23.49	4.90	2.26	0.55	36.41	775.18	4615.63	31.20
November 16, 2020	A-Phase	25.17	4.90	2.71	0.50	27.49	909.21	4761.16	33.28
	B-Phase	27.11	5.40	2.97	0.54	29.20	979.12	5222.56	36.02
	C-Phase	26.09	5.19	2.87	0.53	26.76	932.00	5006.82	34.68

Table 2. B-Phase Insulator Oil Testing Data

Test Date	Moisture Content (mg/L)	Acid Value（mgKOH/g）	Dielectric Dissipation Factor(DDF,90℃)	Breakdown Voltage (kV)	Volume Resistivity (90℃,Ω·m)	Gas Content in Oil (volume fraction,%)
November 8, 2008	2.9	0.001	0.00086	56.0	1.16×10^{12}	2.35
November 15, 2009	2.4	0.003	0.00027	64.8	3.31×10^{12}	4.65
April 22, 2010	2.6	0.003	0.00044	70.2	9.34×10^{12}	0.38

January 11, 2011	2.6	0.012	0.00047	72.3	1.29×10^{12}	1.50
March 25, 2017	2.82	0.008	0.00030	85.1	9.32×10^{11}	2.25
March 21, 2018	4.45	0.022	0.00026	95.0	8.93×10^{11}	2.69
April 25, 2019	3.75	0.010	0.00018	94.8	1.37×10^{12}	3.87
November 15, 2020	5.55	0.004	0.00048	92.4	2.71×10^{12}	5.33

After discovering the above phenomena, technicians took measures to strengthen technical supervision and avoid potential risks within the transformer from worsening. These measures included increasing the frequency of oil chromatography monitoring from once a month to twice a month, using an online monitoring device for the main transformer to monitor its operating status in real-time.

3. Theoretical analysis of the gas generation

The chemical composition of transformer oil is petroleum hydrocarbons, while the chemical composition of insulating paper is cellulose (a carbohydrate). They have different types of chemical bonds in their molecular structures and different bond energies. Bond energy reflects the strength of the bond between atoms in a chemical bond, that is, the amount of energy required to break or form one mole of gaseous molecules under standard conditions. Therefore the higher the bond energy, the more stable the molecule [7].

According to the above theory, the energy released by different types of faults is different. In the case of low-temperature overheat faults, the energy generated internally is small and generally produces alkane gases such as methane and ethane. As the temperature continues to rise, alkene gases such as ethylene will be produced. When severe overheating occurs (above 800℃), acetylene gases gradually increase. Therefore, it can be inferred that the energy required for the production of hydrocarbon substances is proportional to their degree of unsaturation. That is, with the increase of temperature, the sequence of hydrocarbon substances produced should be: alkanes - alkenes - alkynes.

Based on the analysis of past transformer oil testing data, the main reasons for the increase in gas content in the transformer are as follows: Firstly, internal faults in the transformer cause the decomposition of transformer oil and the generation of gas. For example, if the internal fault of the transformer involves solid insulation, it will generate a large amount of CO and CO_2. Secondly, gas infiltrates into the transformer oil from the negative pressure zone caused by the forced oil circulation cooling system, such as the infiltration of each section of the pipeline docking into the transformer. Thirdly, newly installed or overhauled transformers have inadequate degassing or exhaust, and residual gases gradually enter the transformer oil after the transformer is put into operation.

4. Cause Analysis of Abnormal Detection Data

From the above data, it can be seen that apart from acetylene, there is no significant sudden increase in total hydrocarbons (methane, ethane, ethylene), hydrogen, carbon monoxide, and carbon dioxide. Using the three-ratio method to analyze the data[6], it was found that the fault types indicated by the sampling and testing results of the transformer from January 2015 to the present are low-temperature overheating (Code 0,0,0) and arcing discharge (Code 1,0,0). Since December 2017, the indicated fault type has been arcing discharge. Arcing discharge may occur in coil turn-to-turn, layer-to-layer discharge, inter-phase flashover; flashover in oil gap between tap lead and switch, or arc drawn by switch operation; discharge between lead and box or other grounding bodies. From the data in Table 1, it can be seen that the transformer has been in a relatively stable growth phase before June 2018, and there was a significant sudden increase from June to August 2018, while the other characteristic gases did not show a sudden increase during the same period. Therefore, the arcing discharge during this period is estimated to be intermittent.

The ratio of carbon dioxide to carbon monoxide in the transformer is generally distributed between 5.3 and 6.9, and the growth trend is relatively flat, with no significant sudden increase. The possibility of local or extensive deep aging of solid insulation materials is unlikely.

Based on data analysis, currently the content of the three-phase characteristic gases in the transformer has not exceeded the caution value specified by the standard, and the DGA three-ratio method is only one of the reference criteria[6]. Calculation of the gas production rate from the first occurrence of acetylene to the present shows that the gas production rate of the transformer has not exceeded the caution value specified by the standard. The detailed data for the gas production rate of B-phase is shown in Table 3.

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Table 3. B-Phase Gas Production Rate Data

Test Time	CH_4 (mL/d)	C_2H_6 (mL/d)	C_2H_4 (mL/d)	C_2H_2 (mL/d)	H_2 (mL/d)	CO (mL/d)	CO_2 (mL/d)	Total Hydrocarbon (mL/d)
Jan 2015 ~ Jun 2018 (Before the Abnormal Increase of C_2H_4)	0.20	0.05	0.01	0.00	0.42	3.01	27.71	0.26
Jun 2018 ~ Jun 2020 (After the abnormal Increase of C_2H_4)	0.27	0.04	0.04	0.02	-3.09	14.70	43.87	0.39
Jan 2015 ~ Jun 2020 (Average Value)	0.23	0.05	0.02	0.01	-0.88	7.33	33.68	0.31

Based on the analysis of the transformer's oil chromatography and moisture test data, it is currently known that the test data for moisture content, breakdown voltage, and others have not exceeded the standard or shown significant degradation or mutation. The growth trends of various characteristic gases are also relatively slow, and the total hydrocarbon and hydrogen gas generation rates are normal and meet the standard requirements. Therefore, the possibility of an increase in gas content due to equipment failure is relatively small.

The gas content data for each component in the transformer gas content test in the past year have been examined, and it has been found that the main gases affecting the gas content are oxygen, nitrogen, carbon monoxide, and carbon dioxide, and these four gases account for more than 99.8% of the total. Furthermore, their content has not experienced a significant increase. The O_2/N_2 ratio has been above 0.05 in all cases over the past year, indicating possible leak points in the transformer. The proportion of each characteristic gas is shown in Figure 1, and the trend of the O_2/N_2 ratio is shown in Figure 2.

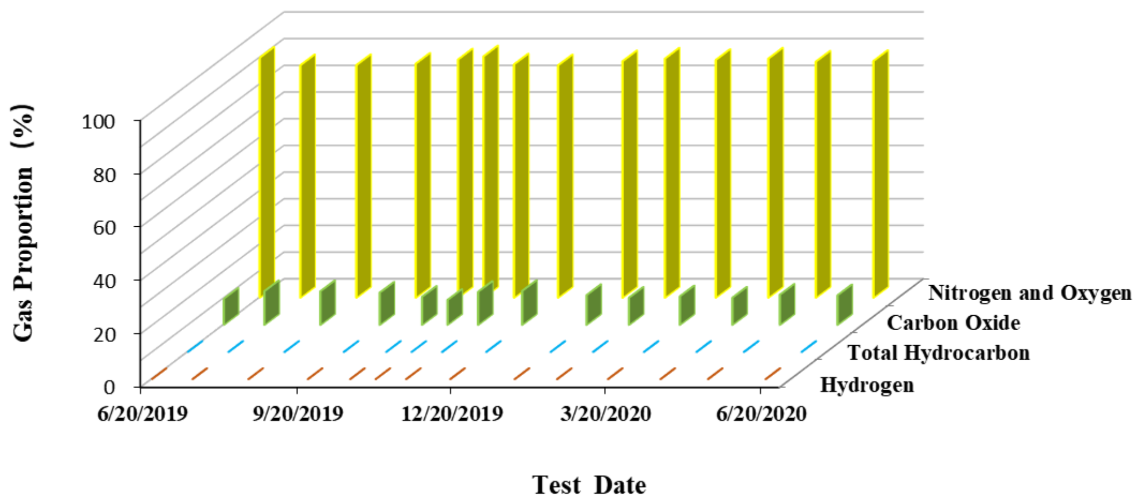

Figure 1. The proportion of each characteristic gas

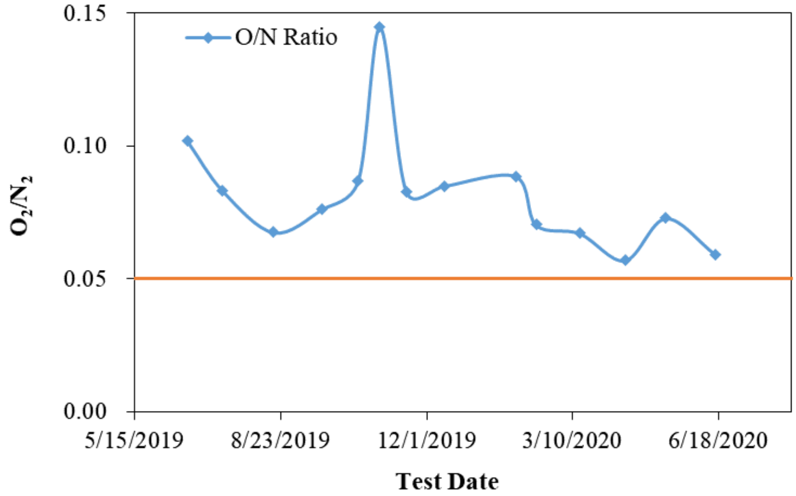

Figure 2. O_2/N_2 ratio trend chart

5. Conclusion and Suggestion

Based on the current testing data, it is inferred that acetylene is produced by intermittent arcing inside the transformer. The excessive gas content is due to poor sealing or inadequate degassing and exhaust before operation, and residual gas gradually enters the transformer oil after operation. To ensure the safe operation of the equipment, the following suggestions are proposed:

(1) If the production of characteristic gases continues to increase and reaches levels such as 1.0μL/L, or if the production rate exceeds 0.5μL/L and the production rate exceeds 0.2 mL/d, immediately stop the transformer and carry out troubleshooting.

(2) The monitoring of the dissolved gas components in the insulating oil should be strengthened, and the absolute gas production rate of each component should continue to be monitored. If there is no significant increase in the absolute gas production rate, the equipment can still continue to operate. At the same time, the normal operation of the online chromatographic monitoring device should be monitored, and the growth trend of the gas content of each component should be continuously monitored.

(3) Regarding the current appearance of acetylene, it is necessary to check whether there are hot spots and discharge locations in the equipment, strengthen infrared temperature measurement and daily inspections, and ensure that the equipment can operate safely and stably. When conditions permit, internal inspection of the oil should be carried out to find defect locations.

(4) Regarding the current excessive gas content in the transformer, check for possible leaks in the equipment, especially butterfly valves, gate valves, and capsules.

(5) To further analyze the insulation condition inside the transformer, it is recommended to carry out media spectrum detection on the transformer and determine whether the transformer is damp by detecting the water content of the transformer oil and paper insulation.

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