Journal of Electrotechnology, Electrical Engineering and Management (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/jeeem.2022.050106
ISSN 2560-6697 Vol. 5 Num. 1

Research and Analysis of Influence of Suspended Air Bubbles on Transformer Oil Insulation Performance

Xitao Qiu[1], Tiansheng Sun[2], Jiang Wu[2]

[1] *School of Mechanical and Power Engineering, Yingkou Institute of Technology, Yingkou, Liaoning, 115000, China*

[2] *School of Electrical Engineering, Yingkou Institute of Technology, Yingkou, Liaoning, 115000, China*

Keywords: power transformer, transformer oil suspended bubbles, multiphysics coupling motion characteristics

Abstract: As the key equipment of the power system, the power transformer undertakes the important responsibilities of power transmission and voltage change, and is an indispensable part of the power system. However, the insulating oil in the transformer oil is often polluted for various reasons, which leads to the decline of the insulation performance of the transformer, causing accidents, and finally paralyzing the power system and causing huge economic losses. Aiming at the suspended bubbles in transformer oil, this paper infers the source and mechanism of bubble generation through the analysis of bubble composition, and sorts out the influence and harm of bubble movement characteristics under multi-physics coupling on transformer operation. The purpose is to summarize the research status and scientific research achievements of the past ten years, and analyze the research plan, so as to achieve an in-depth analysis of the development status of the subject and put forward a reasonable prospect for the development prospect.

1. Introduction

1.1 Research background of bubbles in insulating oil

Power transformers are one of the main equipment in power plants and substations, as shown in Figure 1. The transformer can not only increase the voltage and send the electric energy to the power-consuming area, but also reduce the voltage to the voltage used at all levels to meet the demand for electricity. The internal structure of the transformer is complex. If there is a single fault in the interior, the entire transformer may fail. Insulation is a condition for the normal operation of the transformer. The fault caused by improper insulation can cause a large-scale paralysis of the power system and cause huge losses. Therefore, in order to make the power grid operate stably and safely, the insulation performance inside the transformer must be improved.

At present, large transformers mainly rely on oil-paper composite insulation, and oil-paper insulation performance mainly depends on the quality of transformer oil [1]. However, in actual situations, due to the contact between transformer oil and air during production, transportation, and even use, it will oxidize into impurities such as acid, resin, and sediment, and insulating oil will inevitably generate a certain amount of different types of impurity bubbles. particles, and these will greatly reduce the overall insulation performance inside the transformer [1].

When bubbles are generated in the insulating oil, the relative dielectric constant of the bubbles is much lower than the dielectric constant of the insulating oil itself, which causes a certain degree of difference in the electric field strength inside the transformer. The electric field inside the bubbles is much higher than that in the transformer oil. However, the withstand electric field strength of the bubble is very low, which leads to the discharge phenomenon inside the bubble [2]. The insulating oil sample in the project is shown in Figure 2.

Figure 1 Transformer entity structure diagram

Figure 2 Schematic diagram of insulating oil

1.2 Research significance of bubbles in insulating oil

In the power system, the phenomenon of electrical equipment discharge due to insulation problems is called partial discharge (PD). This kind of fault is more obvious and will intensify as the equipment continues to operate, thereby causing large-scale power failures. Therefore, once the PD phenomenon occurs, it needs to be dealt with in time to avoid more serious accidents [2]. At the same time, the insulating oil can also dissipate heat and cool in the transformer. If there is an arc in the transformer, it will play a role in extinguishing the arc. If there are bubbles in the insulating oil, it will cause an arc inside the transformer, which will be damaged. In summary, the research on bubbles in insulating oil is closely related to the design of transformers, and is an indispensable part of power grid construction.

1.3 Hazards of bubbles in insulating oil

It can be seen from the PD phenomenon in 1.2 that although the partial discharge caused by the bubbles in the transformer has a short time and low energy, it is still very harmful. Its long-term existence will cause great damage to the insulating material. The insulating material [3] is directly bombarded by the discharge particles, causing damage to the local insulation. Second, the chemical action of the heat, ozone, nitrogen oxides and other reactive gases generated by the discharge causes the local insulation to be corroded and aged, and the conductance increases, which eventually leads to Thermal breakdown [3].

Secondly, it was found from gas chromatography analysis that the bubbles were composed of many organic component gases and flammable gases such as hydrogen, which also resulted in a low gas purity due to fluid movement. Under high temperature conditions, the probability of transformer explosion is increased.

2. Research on the causes of bubbles in insulating oil

2.1 Analysis of the causes of bubbles

At present, it is generally believed that there are four ways to generate bubbles in insulating oil:

(1) In the insulating medium and the structure of the electrode material itself, during the process of filling the insulating oil, a part of the gas will be adsorbed on the surface of the electrode in the form of tiny bubbles due to the non-wetting of the electrode, and gradually precipitate and coalesce in the working environment of the transformer. , and finally exists in the transformer in the form of gas.

(2) The bubbles in the insulating oil are divided into two types: static and flowing due to the difference in the composition and formation of the internal gas. Scholars Xiao Chang, Xiao Fafu, etc. pointed out in the article "Research on the characteristics and influencing factors of bubble discharge in insulating oil in flowing state" that bubbles in flowing and static states should be studied separately and their influencing factors should be summarized. Finally, after a lot of experiments, it was pointed out that when the temperature is between 60 degrees and 70 degrees, the bubbles are at a stable peak value; Meijer and other scholars pointed out that the bubbles in a relatively static state are really harmful to the transformer by building a bubble discharge model. During the use of the transformer, electrons and liquid molecules collide to generate gas through dissociation [2].

(3) The movement of bubbles inside the insulating oil is not only related to the operating conditions of the transformer, but also has a great relationship with the characteristics of the insulating oil itself. Scholar Liu Zhiyuan pointed out that the flow rate and temperature of insulating oil have influence on the movement of bubbles. This is related to the fact that the internal environment of the transformer is coupled by multiple physical fields. On the one hand, the transformer contains three physical fields of flow, heat and electricity; on the other hand, the bubbles are in the environment of solid-liquid two-phase flow. This complex coupling background undoubtedly increases the difficulty for further in-depth research [1].

The above four ways of generating gas are established under the condition that the transformer itself is an ideal model that is completely isolated from the outside world; in the actual production and work links, the damage of the transformer also needs to be considered. According to the article "Generation Characteristics of Bubble in Oil-Paper Insulation and Its Influence on Breakdown Performance" published by scholars Wang Fochi, Cheng Xiangrui, etc., the oil-paper insulation of the old transformer has more water content than the new transformer, and the moisture content It will increase at a rate of 0.1%-0.2% (mass fraction) per year, and its experimental data are shown in Table 1. It can be seen that the principle of bubble generation in the transformer is similar to the catalytic model. On the one hand, with the use of the transformer, the air tightness becomes worse, and the outside gas is more likely to enter the device; on the other hand, the aging of materials such as oil paper in the device causes it to adsorb. More moisture is precipitated during the transformer work, and thus exists in the form of air bubbles [4].

Table 1 Effects of different contents of air bubbles on PD phenomenon in insulating oil

Parameter calculation	Group A	Group B	Group C
N	28	133	216
Q_{min}	167	754	1283

2.2 Analysis of chemical composition in bubbles

For the research on the chemical composition of the gas in the bubble, scholar Jing Guirong pointed out in the article "From the Characteristic Gas of Transformer Oil Gas Chromatography to Fault Judgment" that since the insulating oil itself is organic, the gas composition can be detected by gas chromatography. And content, and through the results to summarize and verify the causes of gas formation. After testing, it was found that the main characteristic gases contained carbon monoxide, methane, ethylene, ethane, acetylene, carbon dioxide, hydrogen, etc. [5]. The specific components are shown in Table 2. The total hydrocarbon content includes the sum of methane, ethane, ethylene and acetylene. According to the analysis of chemical composition, it can be seen that because the insulating oil is a mixture, it is composed of various hydrocarbon molecules with different structures. The reason why the above gases are generated is that the carbon-hydrogen bonds are broken under the conditions of high temperature and discharge, and the synthetic hydrocarbon gases mainly composed of carbon-carbon single bonds, carbon-carbon double bonds, and carbon-carbon triple bonds are formed [6].

Through the analysis of the gas composition, not only the way of gas generation is deduced, but also the link of the gas problem in the power system is more accurately judged, which provides an effective means for the overhaul and maintenance of the circuit.

Table 2 Gas composition and content in insulating oil

gas composition	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	total hydrocarbons
Content ppm	150	60	40	70	5	150

3. Research on air bubbles in insulating oil

3.1 Analysis of the force of air bubbles in insulating oil

At present, some scholars have carried out related research on the generation of bubbles in insulating oil in the field of engineering thermophysics. The bubble generation methods are mainly divided into bubbling method and direct heating method. The bubbling method is to install an air needle or open an air hole at the bottom of the experimental device for bubbling [7]. Direct heating to generate bubbles is to generate vapor bubbles by heating the tube wall of the experimental equipment, which involves the heat and mass transfer behavior of the interface, and the intervention of the electric field makes the behavior of vapor bubbles more complicated. Therefore, most studies on bubble behavior under electric field use the bubbling method [8]. The force of the bubble under the action of the electric field is analyzed, the velocity field distribution inside and outside the bubble under the action of the electric field is calculated, and the behavior and dynamic characteristics of the bubble are summarized. It is concluded that the bubbles are deformed under the action of the electric field force. With the increase of the electric field strength, the deformation of the bubbles intensifies, and the aspect ratio of the bubbles becomes larger. The action of the external electric field is also beneficial to aggravate the movement of the fluid inside the bubble [9].

3.2 The influence of the environment inside the transformer on air bubbles

During the working process of the transformer, the environment where the insulating oil is located includes electric field, thermal field and fluid field. In the electric field, since the insulating oil plays the role of arc extinguishing, during the arc extinguishing process, discharge will generate gas. From a microscopic point of view, the electrons and liquid molecules collide and dissociate to produce gas; in the thermal field, due to the mutual conversion between electricity and magnetism during the working process of the transformer, a large amount of heat is emitted, and this part of the energy is insulated. The oil is absorbed, so that the internal environment of the transformer is in a high temperature environment. Part of the insulating oil is heated to form bubbles at high temperature. The experimental data are shown in Table 3. Eventually bubbles form due to fluid movement aggregation. From a microscopic point of view, the electrical current has a heating effect on the transformer oil, which leads to the production of gas. Part of it is caused by the thermal decomposition of the insulating oil itself; on the other hand, a small amount of insulating oil and the moisture in the insulating oil will vaporize to form gas during the heating process.

In the fluid field, it is quite difficult to float on the oil surface by its own buoyancy due to the small bubbles in the oil. It can be seen that the air bubbles in the oil are in a suspended state inside the transformer box. When the insulating oil flows, the air bubbles always remain suspended and move in the oil channel inside the transformer box [10].

3.3 Introduction to Multiphysics Coupling in Transformers

Table 3 Effects of different temperatures on PD phenomenon in insulating oil

Parameter calculation	Group A	Group B	Group C
N	102	25	17
Q_{min}	613	209	58

From 3.2, it is known that inside the transformer, the insulating oil is in a multi-physics field coupling situation, and the insulating oil will generate gas with different generation mechanisms under the coupling action of the power plant, the thermal field and the fluid field, and then cause the gas through the movement in the fluid field. Aggregate and finally present in the form of bubbles.

4. Conclusion and Outlook

4.1 Summary of Inference Generation

(1) The gas existing in the insulating medium and on the electrode itself is precipitated to generate bubbles.

(2) In the process of applying the voltage, the action of the electric field generates bubbles.

(3) The moisture in the transformer oil forms bubbles with the change of temperature.

(4) The transformer itself causes external moisture to enter the transformer due to the damage of airtightness or moisture.

By summarizing the way of bubble generation, we can improve the existing transformer manufacturing process and the filling method of insulating oil. Thus, the failure caused by the PD phenomenon is fundamentally avoided.

4.2 Summary of research status of bubble motion

(1) In the internal environment of the transformer, the dielectric constant of the bubbles is much lower than the dielectric constant of the insulating oil itself. Since the electric field inside the bubble

is much larger than the air breakdown voltage, a discharge phenomenon will occur inside the bubble, which is collectively referred to as the PD phenomenon [11].

(2) Under the working environment of the transformer, the electronic current has a heating effect on the transformer, so that the micro-water is heated to form bubbles, and moves in the electric field and the thermal environment, thereby coalescing into small bubble bridges.

(3) During the working process of the transformer, the action of voltage causes shock waves to appear in the transformer oil, and the shock waves cause cavitation and gas generation [4].

At present, the movement of bubbles in insulating oil is still concentrated between the flow field and the electric field, and the literature on the intervention of the thermal field is still in a relatively small position. This is related to the efficacy and properties of the insulating oil itself. After a large number of experiments, it has been shown that the content of the gas generated by the decomposition of the insulating oil due to the high temperature environment is still in a relatively low proportion in all gases.

4.3 Job Outlook

This paper takes the bubbles in insulating oil as the background, takes the relevant literature in the past ten years as the theoretical basis, and combines the research status at home and abroad to study the gas composition, generation method and working environment in the bubbles from multiple dimensions. The research ideas of bubbles in insulating oil from generation to movement in transformer are sorted out. However, there is still an urgent need for improvement in many aspects such as experimental observations and solutions in this field, and many related issues still need to be further explored. The later work can be roughly carried out in the following two directions.

(1) The concept of thermal field coupling is introduced to a greater extent, and the process of bubble generation to discharge under working conditions of the transformer is more comprehensively simulated.

(2) From a microscopic point of view, the deformation, aggregation, fusion, fragmentation and other phenomena between bubbles in different production methods in insulating oil are explained in more detail, so as to conduct more in-depth research on the theory of bubble discharge.

References

[1] Liu Zhiyuan. Research on the characteristics and influencing factors of bubble discharge in insulating oil under flowing state [D]. Chongqing University, 2016.

[2] Xiao Chang, Xiao Fafu, Xu Ziqi. Research on the characteristics and influencing factors of bubble discharge in insulating oil under flowing state [J]. Communication Power Technology, 2018, 35(06): 3-4.

[3] Wang Junjie, Zheng Minxin, Liu Genliang, Wei Yunbing. Research progress on partial discharge on-line detection of transformers [J]. Journal of Zhengzhou Institute of Light Industry (Natural Science Edition), 2010, 25(05): 21-24.

[4] Wang Fochi, Cheng Xiangrui, Zhao Tao, Liu Yunpeng. Generation characteristics of air bubbles in oil-paper insulation and its influence on breakdown performance [J]. High Voltage Electrical Appliances, 2020, 56(01): 61-67.

[5] Jing Guirong. From the characteristic gas of transformer oil and gas chromatography to fault judgment [J]. Inner Mongolia Science and Technology and Economy, 2019(21):107-108+143.

[6] He Zixiang, Zhu Fan, Zhu Yongli. Simulation of accurate diagnosis of power system transformer fault signals [J]. Computer Simulation, 2018,35(10):136-139+149.

[7] Ma Shouxiao. Research on the characteristics of partial discharge caused by suspended air bubbles in power transformer oil [D]. Chongqing University, 2010.

[8] Dong Wei, Li Ruiyang, Yu Hongling. "Research on the behavior of bubbles under the action of electric field." Energy Research and Information. 02 (2004): 110-115.

[9] Zhou Jiabin. Research on the characteristics and feature extraction of partial discharge caused by suspended particles in oil [D]. Chongqing University, 2012.

[10] Qi Guanfang, Hu Wenxu, Yu Wanhai, Yang Xiaoqiang, Han Jun. Removal Mechanism of Hydraulic Oil Bubble[J].

Journal of PLA University of Science and Technology(Natural Science Edition),2002(05):59-62.
[11] Shen Jian, Jiang Yimin, and Fu Chenzhao. "Analysis of the accident causes of oil-immersed inverted current transformers." Transformer 56.05(2019):66-71.