2017 Electrical Insulation Conference (EIC), Baltimore, MD, USA, 11 - 14 June 2017

Influence of Moisture on the Dielectric Strength of Insulators in GIS

Jingtan Ma, Qiaogen Zhang, Can Guo, Tao Wen, Qiandong Du, Zhicheng Wu
State Key Laboratory of Electrical Insulation and Power Equipment
Xi'an Jiaotong University
Xi'an, China

Guoli Wang, Chao Gao
Electrical Power Research Institute of China Southern Power Grid
Guangzhou, China

***Abstract*—Excess moisture in GIS will condense on solid insulating materials under certain environmental conditions and cause the reduction of flashover voltage, thus threatening its normal operation. To formulate proper standard of moisture content in GIS, it's necessary to study the influence of moisture on the dielectric strength of insulators. In this paper, the influence of moisture on the flashover voltage of insulators in SF_6 is studied with consideration of ambient temperature. The results show that flashover voltage of insulators is almost unaffected by moisture at constant ambient temperature. After a sharp change of ambient temperature, moisture within a certain amount doesn't influence flashover voltage of insulators; when the moisture content becomes larger, flashover voltage begins to decrease. The larger the moisture content is, the lower flashover voltage becomes. And moisture has a bigger influence after a sharp rise of ambient temperature than after a sharp decrease. The range of temperature plays an important role in the threat caused by moisture. In addition, the experimental results show that current standard of moisture content cannot guarantee the normal operation of GIS and some advice is given for modification of the standard.**

Keywords—SF_6; moisture; ambient temperature; flashover voltage; control standard

I. INTRODUCTION

In the past few decades, SF_6 insulated electrical equipment has been widely used. Pure SF_6 gas is stable in property and has high electric strength. However, when the moisture content in SF_6 exceeds a certain value, its insulation ability will be weakened. Excess moisture will not only lead to the generation of acidic discharge products, which could corrode insulating materials, but will also condense on solid materials under certain conditions and thus cause the reduction of surface flashover voltage. Therefore, research on the influence of moisture in SF_6 is important to the normal operation of SF_6 insulated electrical equipment [1].

Few studies could be found about the influence of moisture in SF_6. According to the research of T. Nitta, if there is condensing water on the surface of insulators, its flashover voltage will decrease considerably when temperature of the insulator surface is between zero degree and its dew point temperature; however, when temperature of the insulator surface is below zero degree or above its dew point temperature, moisture scarcely changes the flashover voltage [2]. L. Zhang finds that at the temperature of -2°C~40°C, flashover voltage of insulators will drop by 5%~7% when the relative humidity is 50% [3].

Ambient temperature has great influence on the moisture content [4-6]. Fig. 1 shows the seasonal variation of moisture content in a GIS [7]. It can be seen that the moisture content changes greatly with ambient temperature, and its value can be several times larger in summer than that in winter. Moreover, operation experience shows that accidents resulting from excess moisture mainly occur after sharp changes of ambient temperature [8-9]. Consequently, it's necessary to consider the effect of ambient temperature during the research on moisture.

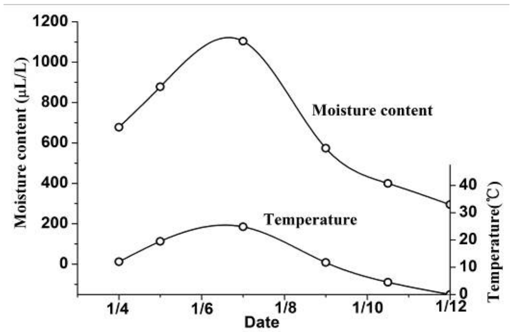


Fig. 1. Seasonal variation of moisture content in GIS.

In this paper the influence of moisture on the dielectric strength of solid insulating materials in SF_6 is studied through experiments, which could serve as reference for the amendment of moisture controlling standards.

II. EXPERIMENTAL CONDITIONS

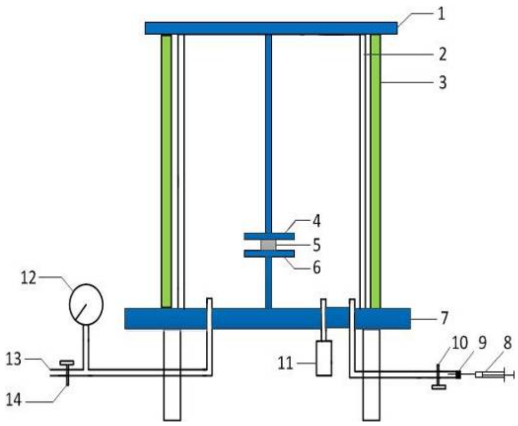
A. Experimental platform

An organic glass chamber is specially designed in order that humidity of the gas in it can be controlled, as shown in Fig. 2. Plate electrodes are used to simulate uniform electric field. Three through-holes are made at the bottom of the chamber, which connects to the gas-pressure meter, the moisture on-line monitoring system and the micro-syringe. The moisture on-line monitoring system could monitor the moisture content, the temperature and the density of SF_6 gas. The measured value of moisture content is given in the form of

Science and Technology Project of China Southern Power Grid Co. Ltd. (Contract number: CSGTRC [2015] K1552B02).

volume fraction (μL/L) and the measurement error is less than 1%. The volume of the micro-syringe is 10μL and the minimum scale is 0.5μL.

To simulate change of ambient temperature, the chamber is put into an artificial climate chamber, in which temperature could vary from -50°C ~+60°C.



1−top flange；2−organic glass cylinder；3−nylon screw；
4−high voltage electrode；5−insulator；6−ground electrode；
7−bottom flange；8−micro-syringe；9−rubber plug；10−ball valve；
11−moisture on-line monitoring system；12−gas-pressure meter；
13−air pipe；14−ball valve

Fig. 2. Structure of the experimental chamber.

B. Test models

Cylindrical models of epoxy resin, with radius 25 mm, height 10 mm are used as test samples. After each experiment the models are polished with abrasive papers of 1000# to eliminate the effect of surface roughness on flashover voltage.

C. Experimental method

The moisture content of the SF_6 gas is controlled by dropping a certain amount of liquid water into the vacuumed chamber. Due to lower boiling point of water in vacuum, the liquid water will soon evaporate into water vapor. Then inject SF_6 into the chamber and wait for 1 hour until it mixes uniformly with the water vapor, SF_6 gas with certain moisture content is obtained.

The empirical formula is obtained after repeated experiments: $H=kV$, where, H is the moisture content in SF_6 (μL/L); V is the volume of liquid water dropped into the chamber (μL); k is a constant, with its value depending on volume of the chamber, pressure, etc. In this paper k=1000 L^{-1}. Through this empirical formula, the volume of liquid water that should be dropped into the chamber could be calculated by the moisture content needed.

In each group flashover voltage is got by 5~10 times of experiments. After each flashover, the used SF_6 gas is replaced by new SF_6 gas to eliminate the effect of discharge products on flashover voltage.

III. RESULTS AND DISCUSSION

A. Influence of moisture on flashover voltage at constant ambient temperature

In the artificial climate chamber, the temperature is kept at 20°C and flashover voltage of the test model under ac voltage is measured at the pressure of 0.2MPa with different moisture content. As can be seen in Fig. 3, when the effect of moisture on discharge products of SF_6 is not considered, moisture doesn’t influence flashover voltage of insulators. That is to say, when little water in SF_6 exists in the gaseous form, it won’t affect flashover voltage of insulators.

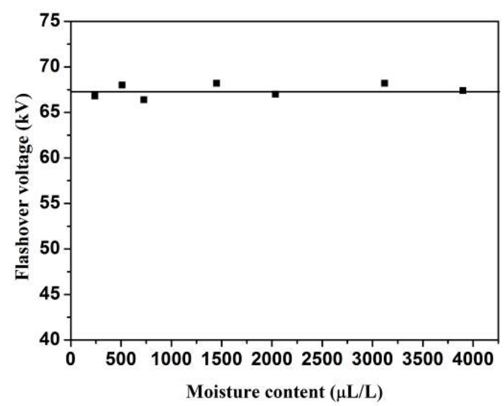


Fig. 3. Relationship between flashover voltage and moisture content at constant ambient temperature.

B. Influence of moisture on flashover voltage after sharp change of ambient temperature

Firstly the influence of moisture on flashover voltage after a sharp decrease of ambient temperature is studied. Before each experiment the temperature in the artificial climate chamber is set to 20°C, and the organic chamber, filled with SF_6 to the pressure of 0.2MPa, is put into the climate chamber. After making sure that temperature of the gas in the organic chamber reaches 20°C, the target temperature in the artificial climate chamber is set to -10°C and temperature drops rapidly. When temperature of SF_6 gets -10°C, flashover voltage of the models under ac voltage is measured. Fig. 4 shows the relationship between flashover voltage and initial moisture content. Initial moisture content refers to the moisture content in SF_6 at 20°C. The traverse line in the figure is the flashover voltage of the test model at constant temperature, when no water is thought to condense on the test model.

As can be seen from the figure, after a sharp decrease of ambient temperature, moisture within a certain amount doesn’t influence flashover voltage of the test model. The reason is that condensing water on the solid materials is too little to influence the flashover process. When moisture content becomes larger, flashover voltage begins to decrease. The larger moisture content is, the more water will condense on the solid materials, and the lower flashover voltage will become.

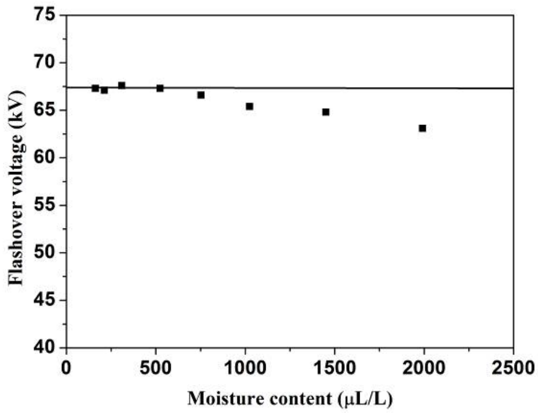


Fig. 4. Relationship between flashover voltage and initial moisture content after a sharp decrease of ambient temperature.

In the same way, the influence of moisture on flashover voltage of insulators after a sharp rise of ambient temperature is studied. Flashover voltage is measured after temperature rises from -10°C to 20°C. The relationship between flashover voltage and initial moisture content is shown in Fig. 5, and here initial moisture content also refers to the moisture content at 20°C. The results exhibit that flashover voltage of insulators decreases with increasing moisture content. After comparison of Fig. 4 and Fig. 5, it is found that moisture has a bigger influence after a sharp rise of ambient temperature than after a sharp decrease. This is because the relative humidity of SF_6 is larger during the process of temperature rise than during temperature drop [10]. Moreover, during the process of ambient temperature rise, the temperature of SF_6 gas is always higher than that of insulator, thus moisture is more likely to condense on the surface of insulator.

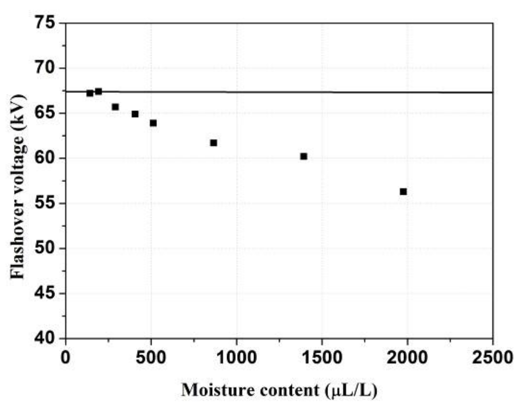


Fig. 5. Relationship between flashover voltage and initial moisture content after a sharp rise of ambient temperature.

C. *Influence of moisture on flashover voltage with different range of temperature*

The range of temperature differs among different regions, therefore in order to provide a proper controlling standard of moisture content, research on the influence of moisture with different range of temperature is necessary. Previous results show that moisture causes a bigger threat during temperature rise, so research on the range of temperature is carried during this process.

Setting -10°C as initial temperature, the climate chamber is heated to different temperatures. After each temperature rise, flashover voltage of the test models is measured. As can be seen in Fig. 6, flashover voltage decreases with larger range of temperature. When ambient temperature rises from -10°C to -5°C, flashover voltage remains constant with different moisture content. The reason is that when temperature is below 0°C, excess moisture exists in the form of ice, so it won't influence the flashover voltage of insulators [2]. At the temperature of 0°C, a part of excess moisture is in the solid form and others in the liquid form, so when ambient temperature rises from -10°C to 0°C, flashover voltage drops slightly. When ambient temperature rises from -10°C to respectively 10°C, 20°C, 30°C, 40°C, flashover voltage decreases continuously, but the decreasing amplitude gradually becomes smaller.

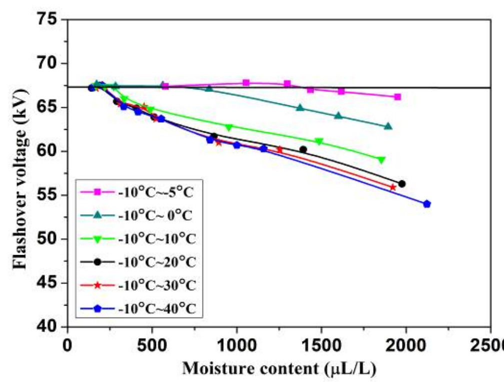


Fig. 6. Relationship between flashover voltage and initial moisture content when ambient temperature increases from -10°C to different values.

In the same manner, flashover voltage of insulators is measured after ambient temperature rises from different values to 20°C. Like the previous result, flashover voltage decreases with larger range of temperature.

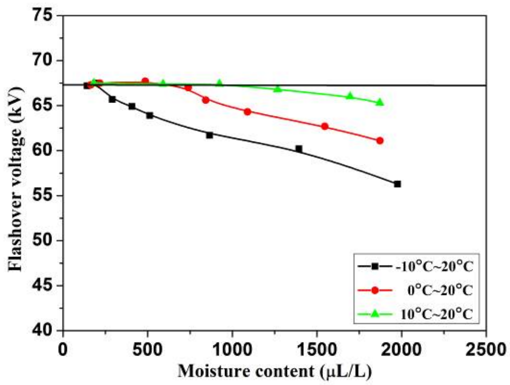


Fig. 7. Relationship between flashover voltage and initial moisture content when ambient temperature increases from different values to 20°C.

D. Discussion about moisture controlling standard in SF_6

According to the above results, a reference diagram of moisture controlling limits is drawn in Fig. 8. Three curves respectively show the controlling limits of moisture to ensure that flashover voltage of insulators doesn't change, decreases within 5% and decreases within 10%. It can be seen that 200μL/L could be a global moisture controlling limit to guarantee no reduction of flashover voltage. In fact, for regions with different climate conditions, using different controlling limits is suggested. In low-temperature regions and regions with large range of temperature, moisture content should be more strictly controlled.

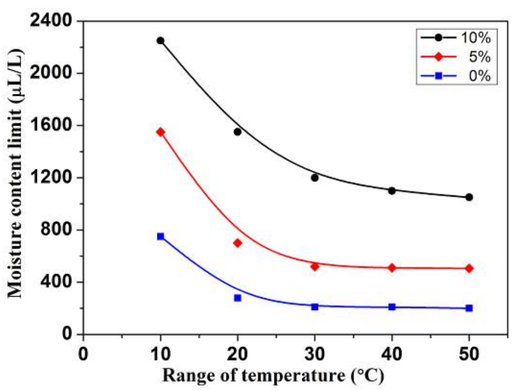


Fig. 8. Reference of moisture controlling limits with different range of temperature.

IV. CONCLUSION

This paper focuses on the influence of moisture on the dielectric strength of solid insulating materials in SF_6. The results demonstrate that at constant ambient temperature, the moisture almost doesn't have influence on flashover voltages of insulators. After a sharp change of ambient temperature, moisture within a certain amount has no influence on flashover voltage of the insulating materials; when the moisture content becomes larger, flashover voltage begins to decrease. The larger moisture content is, the lower flashover voltage becomes. And moisture has a bigger influence after a sharp rise of ambient temperature than after a sharp decrease. Flashover voltage decreases with larger range of temperature. In addition, according to the experimental results, a reference diagram of moisture controlling limits is drawn. 200μL/L is suggested as a global moisture controlling limit to guarantee no reduction of flashover voltage and it is advised that in low-temperature regions and regions with large range of temperature, moisture content should be more strictly controlled. These results could serve as reference for the amendment of moisture controlling standard in SF_6.

ACKNOWLEDGMENT

This work was financially supported by the Science and Technology Project of China Southern Power Grid Co. Ltd. (Contract number: CSGTRC [2015] K1552B02).

REFERENCES

[1] Y. Qiu, GIS device and its insulation technolog. Water Resources and Electric Power Press, 1994.

[2] T. Nitta, Y. Shibuya and Y. Fujiwara, "Factors controlling surface flashover in SF_6 gas insulated systems," IEEE Trans. Power App. Syst., vol. 97, No. 3, pp. 959-968, 1978.

[3] L. Zhang, "SF_6 humidity and insulation in electrical equipment," High Volt. App., vol. 40, No. 3, pp. 46-47, 2000.

[4] Q. Wang, J. Guo and Y. Qiu, "Influence of environmental temperature on moisture content in the SF_6 circuit breaker," High Volt. App., vol. 40, No. 3, pp. 208-209, 2004.

[5] Q. Li, Z. Wang and T. Zhang, "Discussion about the water vapor content standard & research on monitoring SF_6 gas's density and humidity," Proc. CSEE, vol. 23, No. 10, pp. 169-174, 2003.

[6] B. Li, "Further discussion on monitoring and threshold of moisture in SF_6 gas," High Volt. App., vol. 42, No. 2, pp. 109-115, 2006.

[7] IEEE Std C37.122.5-2013. IEEE guide for moisture measurement and control in SF_6 gas-insulated equipment.

[8] D. Hong, "An explosion of SF_6 potential transformer caused by moisture," Electr. Eq., vol.4, No. 3, pp. 72-74, 2003.

[9] Y. Bai, L. Guo, J. Yang, "Study of gas humidity and insulation of SF_6 electrical equipment," Shanxi Hydr., vol. 3, No.1, pp. 64-65, 2002.

[10] X. Ren, W. Ding, W. Zhou, "The moisture in SF_6 insulated CTs considering current and change of ambient temperature," IEEE Trans. Power Delivery, vol. 29, No. 3, pp. 1184-1191, 2014.