

Research on a New Type Coating to Improve Flame-retardant Properties of the Insulation Component in Switchgear

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Abstract. Considering the flame-retardant defects of the insulation component in switchgear, a new type coating is prepared with E-44 epoxy resin as binder and composite flame retardant (antimony trioxide(Sb_2O_3), chlorinated paraffin(CP70), aluminium hydroxide($\text{Al}(\text{OH})_3$)) as main filler. The improvement of the flame-retardant properties of the insulation component in switchgear was explored, and the electrical performance before and after coating was compared. The results show that with this new type coating, the flame-retardant properties of substrates is improved dramatically, making the flame-retardant grade reach V-0; good bonding and anti-aging performances are showed when they are applied to the insulation components of the substrates. And the electrical performance of insulation components with new coating meets the national standard.

1. Introduction

In November 2015, one of the main transformer in 220kV substation in Guangxi Power Grid Co. had unplanned outage. The totally burning of 902 switchgear and the lightly burning of potential transformer caused this unplanned outage. Flame-retardant test was conducted on the broken insulation component in switchgear, and the result showed it had none-flame-retardant grade. In the following research by Guangxi Power Grid Company Limited Electric Power Research Institute. A total of 13 switchgear were inspected for flame-retardant test, and only 23% reached the standard. The test result showed that there is a flame-retardant performance defect in the insulation parts of the switchgear. Repair the performance defects and improve the reliability of switchgear can help to ensure the production operation and personal safety. It is an effective solution to apply the flame retardant coating on the insulation component in switchgear. But most of the currently available flame retardant coating on the market only applies to wood, steel, concrete, etc., not applying to electrical equipment.

This paper proposed preparing a new flame-retardant coating with high binding strength, excellent flame retardant, water and corrosion resistance on the surface of organic compound when the electrical properties of insulation components are ensured, making process and performance preparation for the improvement on flame-retardant properties of insulation parts of high voltage switchgear the next process.

2. The research on flame-retardant coating

The safe operation of electrical equipment directly affects the stability and safety of power supply. It is found in the accident of a 220kV substation that the lack of fire resistance of macromolecular materials can lead to the expansion of fire, thus increase the risk of the accident. Therefore, making organic polymer materials flame-retardant is imminent, and the most effective method is to add flame retardant, which can convert the flammable materials into flame retardant materials, reduce the burning rate of



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The current research on organic flame-retardant coating mainly focus on the following four aspects: (1) Research on decorative flame-retardant coating for steel structure and building surface; (2) Research on the development of polymer flame-retardant monomer, such as flame retardant acrylate monomer; (3) Research on the application of new flame- retardant structure units or flame retardants in coating, such as phosphorous POSS structure polyurethane; (4) Research on the development of new flame-retardant technology, such as nano technology, microcapsule coating technology and layer self-assembly technology. However, these studies only focus on the fire-retardant properties of coating, without emphasizing their application areas. There is no targeted research on organic polymer materials of electrical equipment.

To understand the combination effect of current flame-retardant coating on the market on switchgear, we purchased two kinds of flame-retardant coating which are suitable for steel structure, and painted them on switchgear. After two kinds of flame-retardant paint are coated, the coating appears to fall off in block form (see figure 1), leading to exposing of insulation component, and therefore losing the protection of it. The result showed that the combination effect of flame-retardant paint on the market and the insulation component is poor.



Figure 1. After coated, the coating fell off.

Due to that result, this paper proposed preparing a new flame-retardant coating, which is suitable for insulation components of switchgear, meets the electrical property needs and has high binding strength, excellent flame retardant as well as water and corrosion resistance, on the surface of organic compound.

3. Preparation and coating technology of flame-retardant coating

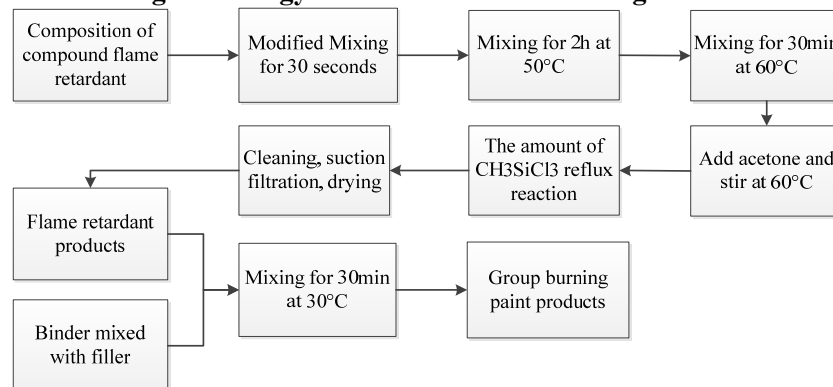


Figure 2. Preparation process of composite-flame retardant coating.

The preparation process of flame-retardant coating is shown in FIG. 2. Its production process is mainly divided into suspension preparation, flame-retardant preparation and composite flame-retardant coating preparation. The specific operation steps are as follows.

3.1. Preparation of Modified Composite Flame Retardant Suspension

Place a small amount of Sb_2O_3 powder into a mixed solution of deionized water and ethanol and stir well, and we can get Sb_2O_3 suspension. Chloroparaffin 70 (CP70) suspension can be obtained by the same method. Mix the two kinds of suspension and then add Silane coupling agent KH550. After that, keep modification temperature at 50°C and stir by magnetic force, and we can get CP70 / Sb_2O_3 modified composite flame retardant.

3.2. Preparation of composite flame retardant

Add acetone into the above flame-retardant suspension, keep the temperature at 60°C , stir by the magnetic force, add a little amount of CH_3SiCl_3 solution and let the reaction refluxed. Wash the product with a mixed solution of hydrochloric acid and ice water and filter it, and finally dry it at 50°C . And we can get modified composite flame retardant.

3.3. Preparation of a new type of flame-retardant coating

Mix the above composite flame retardant with base material and filler and stir well, then the new type of flame-retardant coating is obtained and the preparation work is finished.

4. Improvements of flame-retardant coating on the flame-retardant properties of insulation component

According to the specification required by the national standard GB/T 2408-2008, test spline which has a length of (125.0 ± 1) mm, a width of (13.0 ± 0.5) mm, and a thickness of (3.0 ± 0.5) mm, is cut from insulation component of switchgear. Make sure that the surface of the the test spline is smooth and burr-free and the corner of it is smooth (the chamfer radius is less than 1.3mm), and let it dry at room temperature after ultrasonic cleaning.

4.1. Influence of flame-retardant coating on the properties of insulation component

It is necessary to check whether the new flame-retardant coating has an effect on the flame retardant properties of the insulation component before coating.

In this paper, samples with and without flame-retardant properties (5 samples in each group) were fully coated at the same time, and then the flame-retardant test was carried out according to the national technical standard GB/T 2408-2008. The result is shown in Table 1. The results show that coating has no negative effect on the flame-retardant properties of the insulating part itself, and it can improve the flame-retardant level.

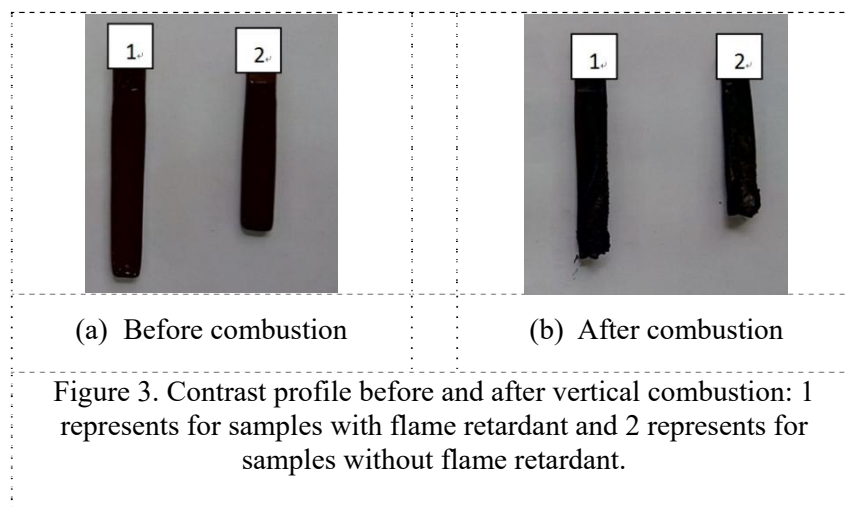


Table 1. Influence of coating on the insulation samples.

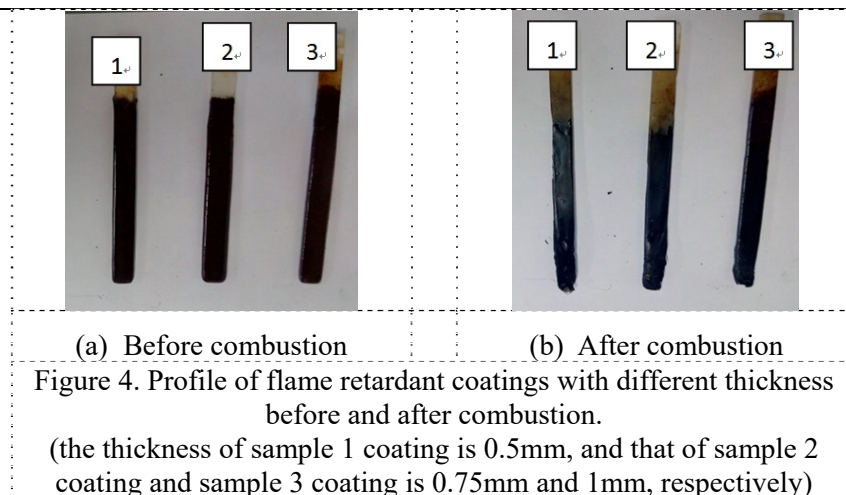
Sample number	Original flame- retardant rating	The thickness of the coating	Ultimate flame- retardant rating
1	V-0	0.75	V-0
2	Below the V - 1	0.75	V-0

4.2. The compare of different coating thickness on the flame-retardant properties of insulation component

In order to study how coating thickness influences the flame-retardant properties of insulation component, we conducted fully-coating test on coating samples with different thickness (5 samples in each group, and the flame-retardant level of the sample itself is below V-1) according to GB/T 2408-2008. The result is shown in Table 2. The result shows that the thicker the coating, the higher the flame-retardant properties, and the flame- retardant grade has reached V-0 level when the coating thickness is 0.75mm.

Table 2. The effect of different coating thickness on the flame-retardant properties of insulation parts

Sample number	The thickness of the coating	flame- retardant rating
1	0.5	V-1
2	0.75	V-0
3	10	V-0



4.3. Influence of single or full (multi) surface coating on flame retardant

In general, the best flame-retardant effects can be achieved by fully coating samples. However, due to the limitation of structure of switchgear and the coating process, the coating process at present can only be carried out on the external surface of the switchgear. Therefore, studying the effects of single and full coating on the flame-retardant properties plays an important role.

In this paper, we tested samples with different coating (5 samples in each group, and the flame retardant level of the sample itself is below V-1) according to GB/T 2408-2008, and the result is shown in Table 3. The result shows that fully coating can effectively improve the flame-retardant properties of insulation sheath. Furthermore, single-surface coating can also improve the self-extinguishing properties of the samples as the thickness of coating increase.

Table 3. The test result.

Sample number	Degree of coating	The thickness of the coating	Result (5 groups of samples, average the result of each one)	
			Self-extinguishing time	flame- retardant rating
1	Full-surface coating	0.5	20s	V-1
2		0.75	8s	V-0
3		1	6s	V-0
4	Single-surface coating	0.5	Ignition all at once	No flame-retardant rating
5		0.75	75s	No flame-retardant rating
6		1	42s	No flame-retardant rating
7		1.5	35s	No flame-retardant rating
8		2	28s	V-1
9		2.5	22s	V-1

Note: UL94 stipulates that the flame retardant grade V-1 will stop burning in 30s without dripping, and the flame-retardant grade V-0 will stop burning in 10s without dripping.

4.4. Influence of single or full (multi) surface coating on flame retardant

Aging test is simulating the aging process of the product under use, and strengthening the experiment process according to various factors involved in that process. In this paper, according to the national technical standards GB / T 16422.3-2014 "test method of light exposure in plastic laboratory ", we adopted the test parameters in Table 4 to conduct three parallel experiments, in which the sample substrate was PP board, the coating thickness was 0.75mm and the aging time was 168h. the result is shown in Figure 5. The result shows that after aging, the three groups of coating did not appear discoloration or foaming and had good anti-aging properties.

Table 4. Test result.

Temperature range	RT+10℃~70℃	Humidity range	≥95%RH
Distance between the lamp/mm	35	Lamp power/per lamp	40W
Photoperiod/h	4	Light temperature/℃	60
Condensation cycle/h	4	Condensation temperature/℃	50
Light source	UV-A	Wavelength/mm	340

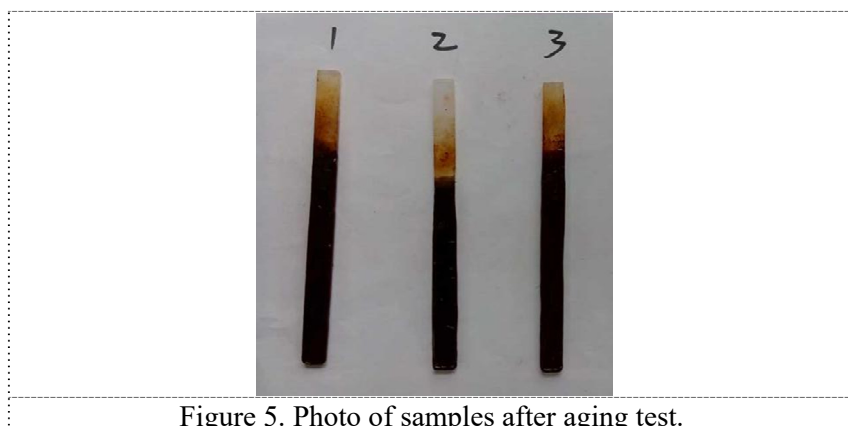


Figure 5. Photo of samples after aging test.

4.5. Coating adhesion test

According to GB/T 9286-1988, we used the grid method to test the binding force performance of the samples, and the test rating was shown in table 5. The experimental result shows that the bonding force of all three coating reaches level 0.

In order to understand the details of the bonding strength of the samples, we cut 6×6 small lattices with a spacing of 2.5 mm were from the other parts of the samples and observe their bonding force. The result was shown in Table 5. It shows that as the thickness increases, the binding force tends to decrease.

Table 5. Record of grid test.

Sample number	Thickness/mm	Phenomenon when the spacing is 5mm	Level	Phenomenon when the spacing is 2.5mm
1	0.5	The edges of the incision are perfectly smooth, and there is no peeling on the edge of the lattice.	Level0	Along the edge of the incision there is partial peeling or large peeling or whole peeling, or there is whole peeling in part of the lattices, and the area is 15%~35%.
2	0.75	The edges of the incision are perfectly smooth, and there is no peeling on the edge of the lattice.	Level0	At the intersection of the incision there are some small flakes, the actual damage within the grid area is less than 5%
3	1	The edges of the incision are perfectly smooth, and there is no peeling on the edge of the lattice.	Level0	At the intersection of the incision there are some small flakes, the actual damage within the grid area is less than 5%

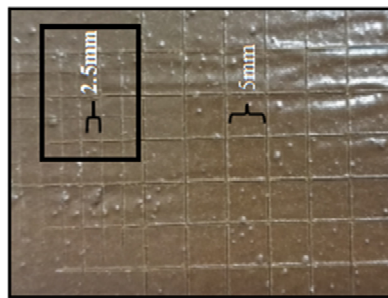


Figure 6. Topography under grid method.

5. Electrical performance evaluation of insulation component after coating

We conducted insulation performance test on Anhuisenyuan Indoor high-voltage vacuum circuit breakers which are coated by new flame-retardant coating. Figure 7(a) shows the Anhuisenyuan Indoor high-voltage vacuum circuit breakers before coating, and left, middle and right correspond to A, B and C respectively. Figure 7(b) shows the Anhuisenyuan Indoor high-voltage vacuum circuit breakers after coating.

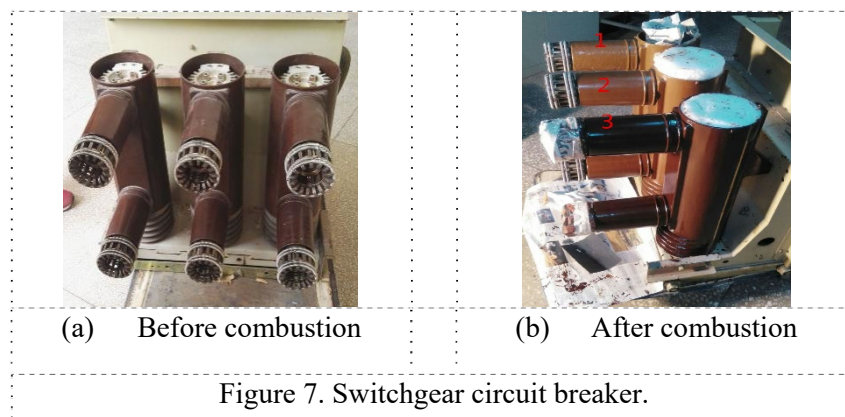


Figure 7. Switchgear circuit breaker.

5.1. Insulation resistance test

We use 2500V megger to measure, and the result is shown in Table 6, which meets the requirement.

Table 6. Insulation resistance of switchgear circuit breaker.

Test instrument	Insulation resistance tester	Instrument number	1311
Ambient temperature	16.8°C	Ambient humidity	43%
Test site	Phase	Insulation resistance before pressure (MΩ)	Insulation resistance after pressure (MΩ)
To the ground	A	13700	13700
	B	18000	15000
	C	10000	10000
Fracture	A	13000	12000
	B	10000	10000
	C	13500	13500

5.2. PD detection

We used digital partial discharge detector to test the partial discharge of Anhuisenyuan Indoor high-voltage vacuum circuit breakers, and the test voltage is 6.93 kV. The test result is shown in Table 7 and it meets the requirement.

Table 7. Partial discharge of switch cabinet circuit breaker.

Test instrument	Digital partial discharge detector	Instrument number	1103XY357
Ambient temperature	15.6°C	Ambient humidity	46%
Test site	Phase	Partial discharge	
To the ground	A	13.55	
	B	13.66	
	C	13.67	
Fracture	A	13.55	
	B	13.65	
	C	13.68	

Note: The background interference is 8.43pC, and PD standard is less than or equal to 20Pc.

5.3. Test of leakage current

We use HVDC generator to test. The test voltage is 20kV, and the pressure is 1min. The result is shown in Table 8, and it meets the requirement.

Table 8. Test result of leakage of current of switch cabinet circuit breaker.

Test instrument	HVDC generator	Instrument number	C3031620
Ambient temperature	17.3°C	Ambient humidity	41%
Test site	Phase	Current leakage before pressure (μA)	Current leakage after pressure (μA)
To the ground	A	2	2
	B	2	2
	C	1	1
Fracture	A	3	3
	B	2	3
	C	1	1

Note: The pre-test requirement of China Southern Power Grid Company Limited is that leakage current I_0 is less than 10 μA.

5.4. AC voltage test

The method to apply voltage is to make Each phase voltage to the ground of closing, Each phase voltage is Fracturing of phase-to-phase or breaking, increase the voltage to withstand test voltage 33.6kV and maintain it for 1 minute to test the insulation performance. The test result is shown in

Table 9. Aand it meets the requirement.

Test instrument		150kV Test transformer		Instrument number	
Ambient temperature		17.3°C		Ambient humidity	41%
Test site		Voltage (kV)	Frequency (Hz)	Time (min)	Result
To the ground	A	33.6	50	1	Pass
	B	33.6	50	1	Pass
	C	33.6	50	1	Pass
Fracture	A	33.6	50	1	Pass
	B	33.6	50	1	Pass
	C	33.6	50	1	Pass

6. Conclusion and prospect

(1) The new type of flame-retardant coating has a good bonding performance in the PP plate, which is level 0 (the best level), and can effectively solve the problem of poor binding strength of general coating on the surface of the switchgear.

(2) Coating insulation component of switchgear whose flame-retardant fails in the operation with flame-retardant paint can effectively improve the flame-retardant properties of the switchgear itself. When the thickness of single-sided coating is more than 2mm, switchgear sheath without flame-retardant can reach level V-1 (section 5.1 of China Southern Power Grid Company Limited technical specification requires it be no lower than level v -1).

(3) The insulation performance test results (results of Insulation resistance test, PD detection, current leakage test as well as AC voltage test) of insulation components of switchgear meet the requirement of corresponding standard, which show that the operation of equipment will not be affected. Furthermore, the curing speed of new coating meets the construction requirements of the site.

(4) The next step will be related to the type test, which can verify the influence of new flame-retardant coating on various performance parameters when the switchgear is under operation.

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