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Sealing Integrity of Polymeric ZnO Surge Arresters

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Abstract

The sealing integrity is related to the safe operation of arrester, the prime failure reason of porcelain housed arresters is moisture ingress. To be a meaningful test, a polymer arrester sealing test must be a realistic acceleration of field service. We think the test should be an accelerating course of actual temperatures, the enduring property to mechanical load and temperatures should be considered together. A union test method consisting of the thermal mechanical test and thermal cycling test is proposed to test the sealing integrity of polymeric arresters, which uses dielectric loss, leakage current, 1mA DC voltage and partial discharge as the diagnostic techniques, and the test results were presented. The comparison states that the TMTCUT method is suitable for the test of sealing integrity of polymeric arresters.

1. INTRODUCTIONS

Metal oxide surge arresters have been widely used in power system to guarantee the safe operation. But the vast majority of porcelain distribution arrester failures are the results of moisture ingress. According to the statistics results of PP&L Co., the overall failure rate of surge arresters with pocerlain houses ranged between 0.2 and 1.0%, and about 25% of these failures were of the catastrophic type.[1)] The failure rate because of moisture ingress reached 85.6%.[13)] In China, the failure rate of arresters is 0.68%, and the prime reason of failure is because of moisture ingress.[14)] Although all arresters with porcelain houses are equipped with pressure relief devices, sometimes the arrester would explode. The explosion would destroy other equipment and is dangerous to peoples.

In the recent years, the polymeric ZnO surge arresters have been developed and put into operations based on their excellent characteristics. In arresters made with polymer materials, the gas volume is extremely small, especially in solid insulation polymeric arresters there are not any gas volume inside arresters in the structure due to polymeric materials are filled into the internal gas volume. It has been proposed that a polymeric arrester design should not have any significant internal air volume.[2)] Perhaps there are some air voids inside filled polymeric materials and polymer housings during the manufacturing course. As a result, the amount of water that can ingress is limited to what the internal parts can absorb in a few very small void spaces. It is considered essential that even these small volumes be maintained free of moisture.

There are three ways for moistures to enter into the interior of polymeric arrester:

(a) unperfect sealing,
(b) air bulbs or air voids inside the filled polymeric materials and silicone rubber housings,
(c) the permeating of silicone rubber housings.

Up to now, there is not any report about the moisture ingress failures of polymeric arresters in field services. But in order to keep the safe operations of polymeric arresters, it is necessary to provide an effective test standard of sealing integrity. The test standard should consists of test techniques and diagnostic techniques.

2. CONSIDERATIONS ON SEALING INTEGRITY TESTING

To be a meaningful test, a polymer arrester sealing test must be a realistic acceleration of field service conditions, be applicable to the type of design under consideration, and have performance requirements that are measurable. The field service conditions include the effect of pollution, sun radiation, moisture and mechanical stress and the temperature changes. Ordinary, the temperature change is in the range from -40°C to+60°C. For suspended-type polymeric arrester, a perpendicular tension load should be considered comprising of self weight, the effect of wind and ice and connecting conductor. For post-type and bottom-mounted, a horizontal tension force should be considered comprising the effect of wind, ice and connecting conductor in horizontal direction.

The test method of sealing integrity on polymer arrester should consider the effect of temperature and mechanical stress, which should meet the next listed items:

(a) Inspecting the sealing property of connecting parts and sealing techniques,
(b) Inspecting by modeling whether the aging in different atmosphere conditions brings a harm to the sealing integrity,
(c) Inspecting the sealing integrity of sealing structure when an mechanical stress is applied on it.
(d) Whether the permeation of silicone housing would be changed under different atomosphere conditions,

(e) The sealing integrity of polymeric arrester operating in the power system is inspected for a long time, so the test method should consider the accelerating effect of tension load and temperature.
(f) The test method should not be difficult to conduct. We think it is better that the test duration is not long.

3. PROPOSED TEST METHOD

In order to inspect the sealing integrity of polymeric arresters, a technique capable of detecting minute amounts of water ingress shall be developed. Because technology tends to advance faster than the standards writing process, up to now, all standards do not address the unique design aspects of polymer arresters and do not currently provide an effective test method of sealing integrity in literature. Traditional sealing test methods cannot be run on polymer arresters because of lack of internal air space. IEC and IEEE standards[5, 6)] do not consider the unique needs of polymer arresters, and are not sufficiently comprehensive for such products. And other test methods [3, 4, 8, 9, 11, 12)] can not meet the all demands above. The proposed test method is called as thermal mechanical and thermal cycling union testing (TMTCUT).

3.1 Thermal Mechanical Test

The thermal mechanical test is used to accelerate the effect of mechanical stress and temperature cycling to the sealing structures of polymeric arresters. If the sealing structure is damaged during the thermal mechanical test, then it is easy to be found out during the next water immersing test. Polymeric surge arrester should endure the defined mechanical stress and keep good sealing after the thermal mechanical test.

The tested samples should endure the temperature cycle 4 times from -40±5°C to 60±5°C in a temperature regulating chamber. Every cycle time is 24 hours. The maximum and the minimum temperatures should be at least continuously kept for 8 hours in every cycle. Before test, the bottom of post-type and bottom-mounted polymeric arrester is fixed in the test chamber, 100% of the maximum permitted horizontal tension load (M. P. H. T. L.) is put on the top. The sample must endure the load and the action direction of the load should be changed during the test(seen in FIG. 1 and FIG. 2). The temperature cycle is illustrated in FIG. 2. The test is finished in the temperature regulating air chamber. The tested samples are whole arresters.

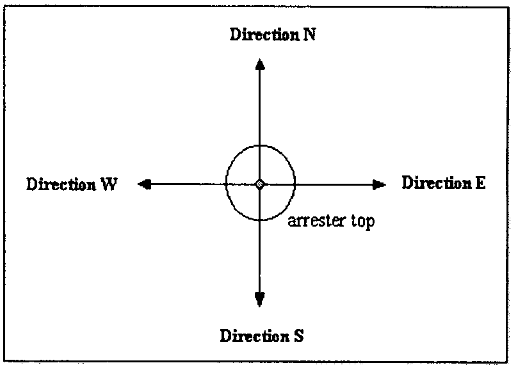

FIG. 1 The applied rated horizontal tension load on the top of post-type and bottom-mounted polymeric arrester during thermal mechanical test.

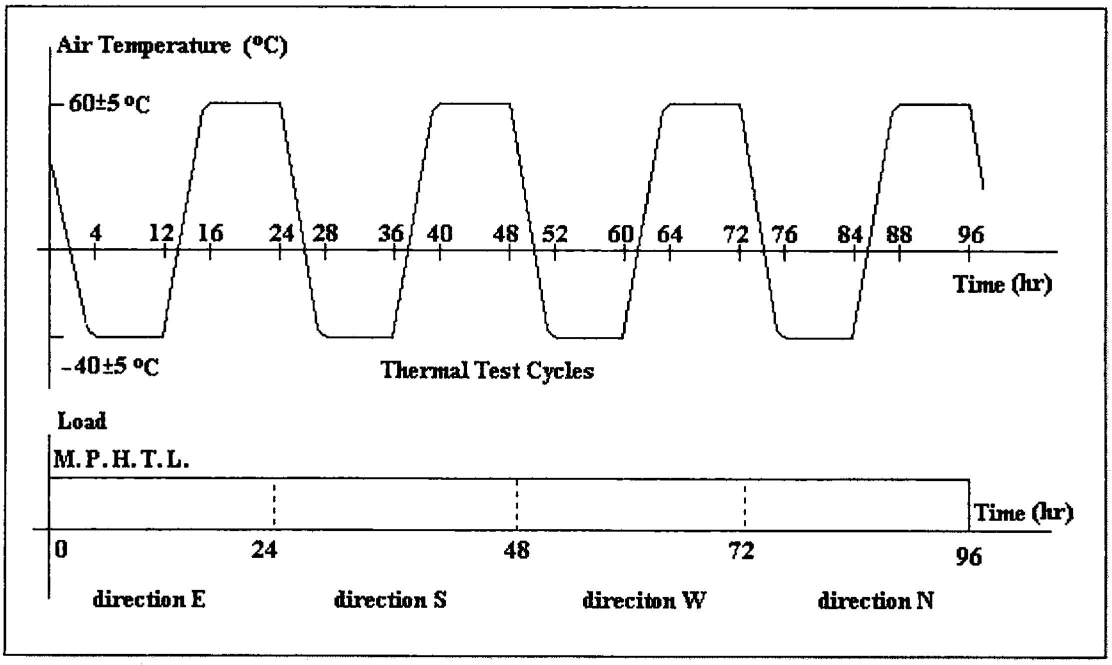

FIG. 2. The temperature cycles of thermal mechanical test.

Table 1 The maximum permitted horizontal tension loads for arresters with different rated voltages

Rated Voltage (kV)	3.8 - 19	42 - 84	100 - 200	288 - 468
Maximum Permitted Horizontal Tension Load (N)	147	294	490 - 980	980 - 1470
Maximum Permitted Vertical Tension Load (kN)			2.5 - 5.0	

For suspended-type arrester, the top should be fixed, and a vertical tension load must put on the bottom during the test course.

The rated horizontal tension loads for arresters with different rated voltages are listed in Table 1.

3.2 Thermal Cycling Test

After thermal electrical mechanical test, the samples is put into water (contained $1kg/m^3$ NaCl) for a thermal cycling test.

First the sample is put into 100°C boiling water (contained $1kg/m^3$ NaCl) for 2 hours, then immediately immerse in 0°C cool water for 2 hours, this a temperature cycle. The cycle is repeated for 40 times. Then the samples is drown out from water and put on the room with environmental temperature to dry its surface (in order to eliminate the effect of surface leakage current to test results) for 12 hours, if the surface of samples is still wet, then continue to put it in the room for 1 to 24 hours to dry out.

40 cycles is decided according to the analysis of Bennet *et al.*,[4] they selected 330 cycles in 50°C by permeability analysis of silicone rubber housings. We know that the cycle number will decrease at high temperature. The vapor pressure P_o of permeant outside sample can be modeled using Antoine's equation:[10, 11]

$$P_O = 10 \qquad T+235$$

P_o is related to temperature T. So we simply suppose that the cycle number n is in verse proportion to P_o. So the cycle number in 100°C could be calculated to be 40 cycles by using the 330 cycles in 50°C.

Because the sample is immediately put into high/low temperature water without the temperature changing course from high to low or from low to high, we test the sample in high/low temperature for 2 hours in every cycle.

The principles of water immersing test are:

(a) Check the sealing property after the thermal mechanical test;

(b) In the boiling water, the inner bulbs would expand. The sealing integrity of the sealing structure and the permeating of silicone rubber in high temperature be inspected;

(c) In cool water, the inner bulbs shrink, and the inner pressure of bulbs would be decreased, then water would ingress the interior of arrester if the sealing integrity is not perfect. The sealing integrity of the sealing structure and the permeating of silicone rubber in low temperature would be inspected.

(d) Salt water is used to increase the sensitivity of test. Actually, the moisture invading into the interior of arrester is a kind of electrolyte in which salt dissolves. Because the arrester would be polluted when it operates outdoor, the pollution would dissolve in the water on the surface of arrester;

(e) In the whole test program, the sealing integrity of sealing structure and silicone rubber materials would be strictly checked.

4. DIAGNOSTIC TECHNIQUES

In our proposed thermal mechanical and thermal cycling union testing (TMTCUT), several measurement criteria are used to determine the leaking integrity of polymeric arresters:

a. After the union testing, check the appearance, there should be not any cracks on the surface of silicone housing;
b. the difference of 1mA DC voltage between before and after test should not exceed 1%;
c. The difference of partial discharges under 1.05MCOV between before and after test should not exceed 10pC;
d. the difference of leakage currents under $0.75U_{1mA}$ DC voltage between after and before test should be less than 10μA;
e. the difference of dielectric loss under 0.5MCOV between after and before test should be less than 2.0%.

There are 4 different diagnostic techniques in the proposed method, we wish the sealing integrity be checked seriously. If any item reaches respective criterion, then the arrester will be consider as failure.

In the proposed measurement criteria, in order to increase the leakage current, the applied voltage to measurement leakage current is higher than that provided by Bennet *et al.*,[4] we think the leakage current of varistor would not confound that of solid insulation structure in our test voltage. After all, there is several microamperes through the insulation structure as analyzed by Bennet *et al.*.

For routine test of sealing integrity, we choose a thermal cycling testing which consists of one hour in 100°C boiling water and one hours in cool water with room temperature. After and before the testing, 1mA DC voltages, partial discharges under 1.05MCOV, dielectric loss under 0.5MCOV and leakage current under $0.75U_{1mA}$ DC voltage are measured, and their measurement criteria are 0.5%, 5pC, 1.0% and 4μA, respectively.

5. SEALING DESIGN TESTING RESULTS OF DISTRIBUTION POLYMERIC ARRESTERS

Two 35kV and two 110kV post-type polymeric metal oxide surge arresters were tested according TMTCUT method, measuring results were listed in Table 2, all measurement items are in the demand ranges.

Another 110kV polymeric arrester provided by a foreign company was labeled as 110kV No.3 samples, which was inspected according TMTCUT method, too. But the test results stated that 1mA DC voltage, partial discharge under 1.05MCOV, dielectric loss under 0.5MCOV and leakage current under 0.75U1mA DC voltage exceeded the respective measurement criteria. So sealing integrity is not good. The comparison states that the TMTCUT method is suitable for the test of sealing integrity of polymeric arresters.

6. CONCLUSIONS

(1) The sealing integrity is related to the safe operation of arrester, the prime failure reason of porcelain housed arresters is moisture ingress. Although, Up to now, there is not any report about the moisture ingress failures of polymeric arresters in field services, in order to keep the safe operations of polymeric arresters, it is necessary to provide an effective test standard of sealing integrity.
(2) All test methods related to the sealing integrity are discussed in this paper, including IEC and IEEE standards, thermal shock testing, boiling water immersion, rail insulator sealing test, thermal cycling test and Chinese standard draft. We think all these methods are not completely suitable for polymeric arresters.
(3) The considerations on sealing integrity test are discussed. To be a meaningful test, a polymer arrester sealing test must be a realistic acceleration of field service. We think the test should be an accelerating course of actual temperatures, the enduring property to mechanical load and temperatures should be considered together.
(4) A union test method consisting of the thermal mechanical test and thermal cycling test is proposed to test the sealing integrity of polymeric arresters.
(5) The diagnostic techniques are discussed, including dielectric loss, leakage current, 1mA DC voltage and partial discharge.
(6) The results according to the proposed method of sealing integrity were presented. The comparison states that the TMTCUT method is suitable for the test of sealing integrity of polymeric arresters.

Table 2 TMTCUT Measurements

Test Items		1mA DC Voltage (kV)	Partial Discharges Under 1.05MCOV (pC)	Dielectric Loss at 0.5MCOV (%)	Leakage Currents Under $0.75U_{1mA}$ DC Voltage (μA)
35kV No.1 samples	before	74.1	1.3	5.3	12.8
	after	73.5	1.3	5.6	13.4
	change	-0.6	0	0.3	0.6
35kV No.2 samples	before	74.1	1.3	5.1	11.3
	after	73.4	1.4	5.2	11.5
	change	-0.5	0.1	0.1	0.2
110kV No.1 samples	before	151.0	1.2	5.2	14.5
	after	150.3	1.5	5.9	16.3
	change	-0.7	0.3	0.7	1.8
110kV No.2 samples	before	150.4	1.5	5.0	15.0
	after	150.3	1.5	5.9	18.9
	change	-0.1	0	0.9	3.9
110kV No.3 samples	before	148.5	1.6	6.1	16.1
	after	143.4	28.7	54.3	27.8
	change	-5.1	27.1	48.2	11.7

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