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Effect of arc current on properties of composite insulators for overhead lines

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Abstract: Results of power arc tests carried out on composite insulators for 110 kV overhead lines are analyzed. The effect of arcing on the basic electrical and mechanical parameters of the tested insulators is examined. Results of pre- and post-arc electric strength tests as well as those of thermomechanical and mechanical tests carried out on insulators subjected to the power arc test are presented.

Key words: composite insulators, power arc tests, electric strength, mechanical strength, tests.

I. INTRODUCTION

Since the beginnings of electrotechnics ceramic materials, mainly porcelain, have been used to make indoor and overhead-line insulators. Such materials have several apparent advantages and most important, their long-term behaviour is known. One of the few, but very troublesome, drawbacks of ceramics is their brittleness. Ceramic insulators' weak point is the joint between the metal end fitting and the ceramic material. Differences in thermal expansion between the two materials can cause mechanical stresses which in extreme cases may destroy the insulator. This problem is solved through the use of special cements which, besides providing the mechanical joint between the end fitting and the insulator, perform the function of an expansion joint. Nevertheless, there have been cases when ceramic insulators fractured, bringing down a high-voltage conductor and thus posing a hazard to people and animals. The brittle fracture of a ceramic insulator may also occur under arcing even if the insulator is equipped with protective horns. Polymeric composite insulators (PCI) do not have the brittle-fracture disadvantage. The use of such insulators on MV and HV lines have become increasingly common in the technologically advanced countries of the world [1, 2].

Composite insulators have several other vital advantages. For the voltage of 110 kV and higher they are price competitive with ceramic insulators. Their relatively light weight facilitates mounting. The composite insulator's silicon weathershed even in heavy pollution conditions retains its hydrophobic properties, which in electric terms means high resistance – much higher than that of ceramic insulators – to a pollution flashover. As regards the technological aspect, composite insulators can be made as strings of any length. Hence it becomes possible to make one-string long-rod insulators for extra-high voltages.

One of the hazards to HV lines are overvoltages which may result in an arch discharge along the insulator. Such power arcing is accompanied by intensive heat emission and as a result of it the insulator is subjected to thermal shocks. Experiments have shown that ceramic and glass insulators usually do not withstand such a shock and are damaged. Data on the behaviour of composite insulators under arcing are sparse. The insulator's element most susceptible to damage as a result of arcing is the joint between the insulator metal fitting and the glass-epoxy core. If the fitting is heated up above a critical temperature, the core's resin matrix may burn out and the core may lose its mechanical strength. To clarify the points raised above power arc tests on composite insulators were carried out.

II. SUBJECT OF TESTS

Two types of 110 kV rated voltage composite insulators for overhead lines: domestically produced – denoted as Type 1 and foreign-made (by one firm) – denoted as Type 2 were subjected to power arc tests. For comparison, a porcelain long-rod insulator (Type P) was also subjected to the tests. Insulators with and without protective fittings were tested. The protective fittings used are shown in fig. 1.

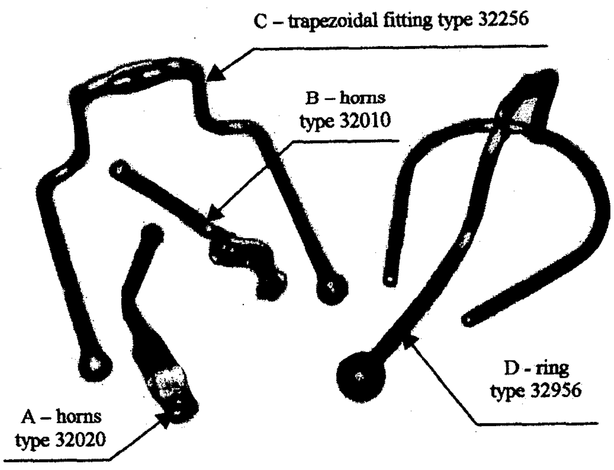

Fig. 1. Protective fitting used in arc tests.

The tests were carried out for the following insulator-protective fitting configurations:

- Type P – an insulator without protective fittings,
- Type P+(A) – an insulator equipped with arcing horns of type 32020,
- Type 1 – an insulator without protective fittings,
- Type 1 +(A) – an insulator equipped with arcing horns of type 32020,

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- Type 1+(CD) – the insulator's top end equipped with trapezoidal fitting of type 32256 and its bottom end in arcing ring of type 32956,
- Type 2+(B) – an insulator equipped with arcing horns of type 32010.

III. TESTS

Power arc resistance tests were carried out, in accordance with standard IEC 61467:1997 [3], by loading the insulator with force M_L=5 kN in a setup shown in fig. 2. The arc was started by evaporating a fusible wire, mounted as shown in fig. 2, by current I_R=25 kA.

In addition, before and after the power arc tests the following were checked:

- the electric strength under the alternating voltage of 50 Hz in dry conditions,
- the electric strength under the alternating voltage of 50 Hz and rain,
- the electric strength under the surge voltage of $1.2/50 \cdot 10^{-6}$s,
- the resistance of the particular insulator sheds.

To examine in detail the power arc's destructive effect on the insulator sheds, the singeing products were investigated by IR spectroscopy and X-ray analysis.

IV. TEST RESULTS

The porcelain long-rod insulators (Type P), both with and without protective fittings, suffered mechanical damage (rupture) during the power arc test. Whereas the two types of composite insulators retained their basic service properties despite changes, visible to the naked eye, in the surface of the weathershed.

A. Changes in surface

After the power arc tests a dark coating, easily removed by wind and rain, appeared on the silicon surface of the sheds. An X-ray analysis showed that the dark coating, being a product of the decomposition of the silicone rubber under the influence of arc temperature, was

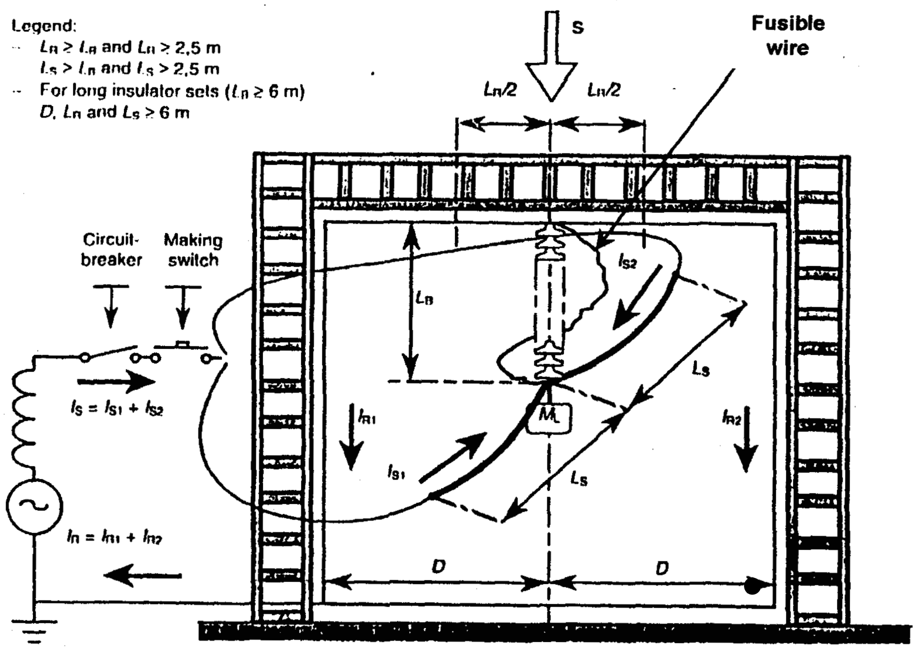

Fig. 2. Insulator on arc resistance test stand [3]

a cristobalite (a low-temperature form of SiO_2). A decrement of the silicon rubber mass was noticeable.

Pre- and post-arc measurements of resistance of single sheds along the insulators did not show a substantial difference (about 10^{14} ohm).

The fact that the surface of the insulators retained its hydrophobic properties is also significant.

The protective fittings were partially melted in places. The end fittings of the insulator without protective fittings (Type 1) were melted to a large degree at the joint between the end fitting and the insulator core. But this did not result in the rupture of the insulator or damage to its core. Nor was the core material uncovered.

B. Electric strength

Benchmark tests on new insulators and insulators after power arc tests were carried out by applying surge voltage of both polarities and the alternating current of 50 Hz in both dry and rain conditions. The test results are presented in table 1.

It follows from the results that the exposure of the surface of the insulators to arcing and the surface changes resulting from this exposure did not affect significantly the electric strength of the insulators.

C. Mechanical strength

The insulator's mechanical strength is as important as its electric strength. To determine if and to what degree the exposure of the insulators to arcing affects their mechanical strength, a thermomechanical test and tensile strength tests were carried out.

The thermomechanical test was carried out in accordance with Standard IEC 1109 [4]. The test consists in repeating four times a 24 h temperature cycle during which two temperature levels are maintained. For 8 hours the insulator is kept at the temperature of -35±5°C and during the next 8 hours the temperature is increased to -50±5°C and then maintained at this level for the next 8 hours. During the test the insulator is stressed continuously with a force of 0.5 SML (60±5 kN in the considered case). After the 96 h cycle the insulator is visually inspected and its length is measured. No change in the insulator's length by a value higher than the measuring accuracy (0.5 mm) is allowed before and after the test. The results of the thermomechanical test carried out on the composite insulators are presented in table 2.

Table 1. Electric strength test results

Insulator type	Surge flashover voltage [kV] (-)	Surge flashover voltage [kV] (+)	Dry flashover voltage of 50 Hz [kV]	Rain flashover voltage of 50 Hz [kV]
1	2	3	4	5
Type 1 – new	505	495	340	340
Type 1+(A) after arc test	510	488	340	340
Type 1+(CD) – new	606	399	295	286
Type 1+(CD) - after arc test	653	532	306	390
Type 1 - after arc test	592	503	350	408
Type 2+(B) - new	590	550	344	345
Type 2+(B) - after arc test	575	550	400	395

Table 2. Thermomechanical test results

Insulator type	Electrical exposures		Mechanical load [kN]	Test time [h]	Assessment of insulator	
	Arc time [s]	Arc current [kA]			Increment in length [mm]	Test result
Type after arc test	1.0	25	60	96	Not found	Positive (+)
Type 2+(B) after arc test	0.2 0.2 1.0	25	60	96	Not found	Negative (+)

The presented results show that the thermomechanical properties of the insulators subjected to the power arc test did not deteriorate. This applies to the insulators with and without protective fittings.

Another mechanical test was the rupture test applied to the insulators after power arc tests (with and without arcing horns). The test results are presented in table 3.

Table 3. Results of tension test carried out on insulators after power arc tests

Insulator type	Mechanical load [kN]		Assessment of insulator
	SML	To rupture	
Type 1 after arc test	120	195	Insulator withstands nominal load SML=120 kN for 1 min. At 195 kN end fitting comes unstuck. Insulator was found to be undeformed. **Insulator receives passing grade.**
Type 2 (B) after arc test	120	195	Insulator withstands nominal load SML=120 kN for 1 min. At 195 kN comes unstuck. Permanent deformation of end fitting. **Insulator receives passing grade.**

The above test results show that the exposure of composite insulators to arcing does not result in a reduction in their mechanical strength.

V. CONCLUSIONS

The tests have shown that composite insulators are much more resistant to arcing than porcelain insulators.

Porcelain insulators exposed to arcing sustain permanent mechanical damage.

Under the high power-arc temperature the silicon surfaces of composite insulators become degraded (erosion, the formation of a dark coating of cristobalite). Nevertheless these changes do not result in the lowering of the electric strength of the insulators.

It was also found that the insulators subjected to the power arc tests did not lose their mechanical properties.

ACKNOWLEDGEMENT

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