XIIIth International Symposium on High Voltage Engineering, Netherlands 2003, Smit (ed.)
© 2003 Millpress, Rotterdam, ISBN 90-77017-79-8

Steep-front impulse voltage tests of composite insulators

J. Fleszynski, E. Sojda†, A. Tyman, K. Koruba
Wroclaw University of Technology, Wroclaw, Poland

Abstract: It is very important to eliminate improper insulator designs and technological faults. The most sensitive parts of non-ceramic insulators (NCIs) are their microscopic and macroscopic interfaces. In this paper our experiences with the steep-front impulse voltage test are presented. According to the IEC standard, after the action of thermo-mechanical loads samples of NCIs are subjected to steep-front impulses with steepness $s \geq 1$ kV/ns. Each impulse should cause an external flashover without any puncture of the tested NCI sample. A setup which makes it possible to produce steep-front impulse voltage with steepness in a range of 1-4 kV/ns has been constructed. Specially prepared samples of NCIs were tested by applying such impulses. The obtained results indicate that even 4 kV/ns pulses do not damage properly manufactured insulators. Moreover, the steepness is more selective than the standardised 1 kV/ns impulse for badly made insulators.

1. Introduction

Insulators have played a fundamental role in attaining the high level of reliability for power transmission and distribution lines. Therefore, it is very important to eliminate improper insulator designs and material and technological faults. The non-ceramic insulator (NCI) consists of at least two insulating parts, namely a core and a housing. The core is the insulator's internal insulating part and is designed to ensure proper mechanical characteristics. It is usually manufactured from specially prepared ECR (electrical corrosion resistant) glass fibres. The core must be resistant to possible water penetration since water may contribute to brittle fracture resulting in the breakdown of the glass fibres and consequently, in a reduction in their mechanical strength and sometimes in line drops and outages.

The housing is the insulator's external insulating part. It is made from silicon rubber. It provides the necessary creepage distance and protects the core from the exposure to the weather. Therefore there must be good bonding between the core and the housing.

It is known from both testing and service that the most sensitive parts of NCIs are their microscopic and macroscopic interfaces [1, 2]. Failures of high-voltage NCIs seem to originate at core-housing or end fitting-housing interfaces. Therefore proper standards are urgently needed to eliminate all faulty designs, materials, technologies and products.

The first international standard (originally designated as 1109 and currently bearing number 61109) specifying a testing protocol for modern NCIs was introduced in 1992 by IEC. This standard deals with definitions, test methods and acceptance criteria for composite insulators for AC overhead lines with a nominal voltage greater than 1000 V [3]. The IEC standard demands not only type and sampling tests but also design tests that take into account interfacial surfaces, connections and metal fittings as well as housing and core materials.

2. Application of steep-front impulse voltages in design tests of NCI interfaces.

According to standard IEC 61109, specimens of NCIs after dry power frequency flashover voltage (FOV) measurements, mechanical and thermo-mechanical loads and the water immersion test are subjected to the impulse voltage test and once again to the dry power AC test.

For the impulse test NCIs must be fitted with sharp-edged electrodes around the housing between the sheds and form a section of about 50 cm or less. An impulse with a steepness of at least 1 kV/ns shall be applied between the electrodes. The gap is to be stressed with 25 impulses of both polarities. Each impulse shall cause an external flashover between the electrodes. No puncture shall occur and in the repeated AC test the average FOV value shall not be smaller than 90 % of the initial value and a value of 80% must be maintained for 30 min without a puncture.

The purpose of the steep-front impulse test is to detect defects on the interfacial surfaces of manufactured insulators.

It should be assumed that the use of impulses faster than 1 kV/ns increases the probability of electrical breakdown along the core-housing interface. But with increasing voltage steepness also the probability of damage to well-made insulators increases.

Our research was based on the above assumptions. Also the conclusions from investigations of pin and cap ceramic and glass insulators by means of steep-front impulses were taken into account [4, 5].

The goals of our research were as follows: 1) to construct a steep-front impulse voltage setup, 2) to verify whether the standard steepness of 1 kV/ns is good enough to detect faulty materials and design or technological errors, 3) to check whether properly selected faster impulses can be used in design tests (whether they are harmless to well-made insulators).

3. Steep-front impulse voltage setup.

A setup which makes it possible to produce steep-front impulse voltage with steepness in a range of 1-4 kV/ns, Fig. 1, has been constructed. The steep-front impulse is generated in a "peaking circuit" with a 12-step Marx generator of standard lightning impulse voltage (1.8 MV, 15 kJ).

Figure 1: NCI specimen under steep-impulse test.

The "peaking circuit" consists of a discharge air gap (the sphere electrodes' diameter is 50 cm), a load resistor, a replaceable charge resistor and a charge capacitor. The measurement system consists of an SMR 700 kV resistive divider with a response time of 10 ns, a TDS 744A digital scope with a bandwidth of 500 MHz and a probe speed of 2 GS/s. Examples of steep-front impulse voltage oscillograms for two tested insulators are shown in Figures 1 and 2.

4. Specimens, test procedure and results

The tested NCIs were manufactured in the Wroclaw Division of the Electrotechnical Institute. The housings were made from silicone gum supplied by a well-known European firm. E-glass fibres bonded in epoxy resin were used for the central fibreglass cores. The materials of the cores were examined using the IEC dye penetration and water diffusion tests. Then a DC voltage of up to 17 kV was applied to select the best rods among the group that had passed the IEC tests [6]. The steep-front impulse tests were conducted on specimens of respectively 110 kV and 20 kV rated voltage insulators. The insulator samples were selected from both short-run and experimental

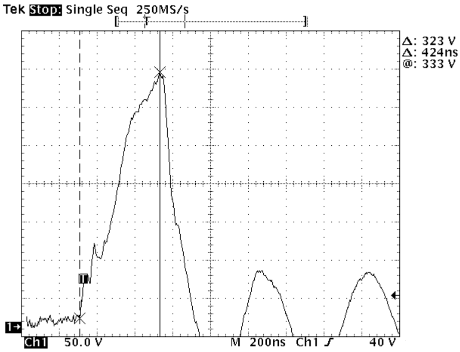

Figure 2: Flashover voltage oscillogram: insulator No. 2.2, U = 509 kV and steepness s = 1.2 kV/ns.

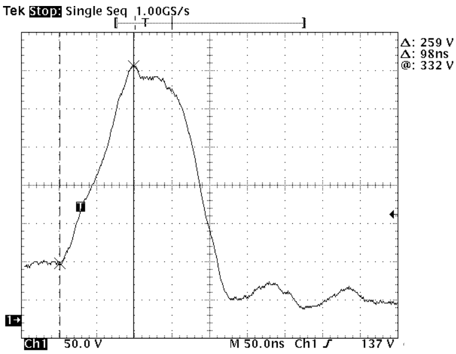

Figure 3: Flashover voltage oscillogram: insulator No. II, U = 507 kV and steepness s = 4 kV/ns.

production. Some of them were recognised as properly manufactured, in some technological faults were identified and some were damaged or made defective at their core-housing interfaces. Electrodes conforming to standard IEC 61109 were used in the tests [3]. The 110 kV NCI specimens were fitted with sharp-edged electrodes around the housing between the sheds. In the case of the 20 kV NCI specimens, the insulator metal fittings played the role of electrodes. The gap between the electrodes was 20-30 cm. Each test specimen was first tested with 10 impulses of positive polarity and then with 10 impulses of negative polarity, both of 1 kV/ns steepness. If the specimen was not punctured as a result of this, it was subjected to the next 20 impulses with 4 kV/ns steepness. The samples which passed the two impulse test series were immersed in boiling deionised water of 0.1 % salinity for 48 hours. After this exposure the steep-front impulse tests were performed again. Examples of the obtained results are shown in the Tables 1 and 2. The 110 kV (nominal voltage) NCIs are denoted by Roman numerals and the 20 kV NCIs by Arabic numerals.

Table 1: Defects of NCIs and impulse test results.

NCI No.	Type of defect	Results	
		1 kV/ns	4 kV/ns
I	Without defects	positive	positive
II	Without defects	positive	positive
III	Without defects	positive	positive
1.1	Bad casting – bubbles	positive	positive
1.2	Bad casting – bubbles	positive	positive
1.2	Bad casting + boiling	**negative**	
2.1	Housing improperly glued to core	**negative**	
2.2	As above	positive	**negative**
2.3	As above	**negative**	
3.1	Low mech. strength	positive	positive
4.1	Bent sheds	**negative**	
4.2	Bent sheds	positive	**negative**

Table 2: Specially prepared defects and results of tests.

NCI No.	Type of defect	Results	
		1 kV/ns	4 kV/ns
5.1	Housing not glued to core along whole length	positive	**negative**
5.2	Housing not glued to core along whole length	**negative**	
5.3	Housing not glued to core along whole length	**negative**	
5.4	Housing not glued to core along half length	positive	positive
5.4	Housing not glued to core along half length plus boiling	**negative**	
5.5	Housing not glued to core along half length	positive	positive
5.5	Housing not glued to core along half length plus boiling	positive	**negative**

After the voltage tests each sample was visually examined externally and internally (the housing was removed). Altogether, over 100 samples were tested and about 30 % of them were punctured as a result of the impulse tests. In the case of the punctured samples, defects which caused the development of electrical discharges along the core-housing interface were identified. It must be emphasized that about 40 % of the defective specimens withstood the 1 kV/ns steepness test and they were damaged by breakdown only when subjected to steep-front impulses of 4 kV/ns steepness. The NCI specimens after the 4 kV/ns test are shown in Figure 3.

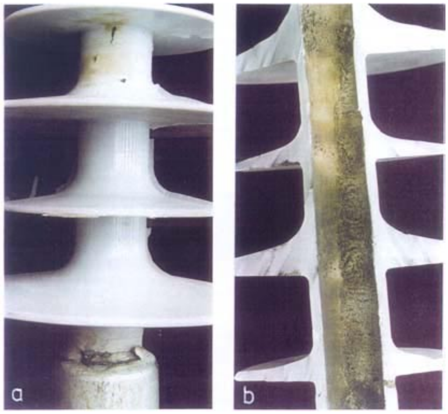

Figure 3: Trace of breakdown on housing and traces of inside discharges along core surface after 4 kV/ns steep-front impulse test.

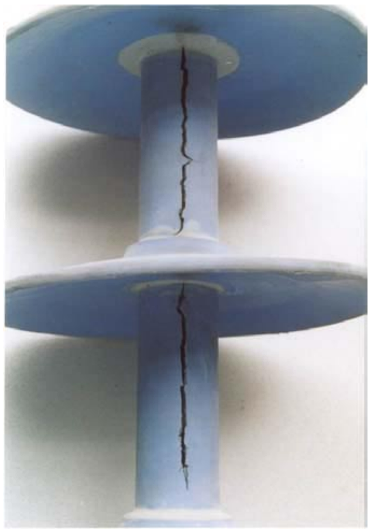

Figure 4: Example of defective (improperly glued to core) housing after 4 kV/ns steep-front impulse test.

An example of a defective (improperly glued to the core) housing after the 4 kV/ns steep-front impulse test is shown in Figure 4. A disruption of the housing between the sheds is visible.

It was found that 1 kV/ns and 4 kV/ns impulses were not able to damage properly manufactured insulators. Even a very careful visual inspection did not reveal any paths of partial punctures.

5. Conclusions

The obtained results showed that the design testing of non-ceramic insulators with faster impulses is more selective. When impulses with 4 kV/ns steepness were used, defects in the insulators which had passed the 1 kV/ns steep-front impulse test were detected.

However, the question “What level or rate of defectiveness in an insulator is acceptable for the latter to pass the design test and will be tolerable in service?” remains unanswered.

6. References

[1] R. S. Gorur, “*Where is Insulator Technology Today: What has been Accomplished, What is still Missing”,* Proceedings 2001 World Insulator Congress & Exhibition “Applying New Technologies for Better Reliability & Lower Costs, Shanghai, Nov. 18-21, 2001, pp. 1- 10.

[2] D. Windmar, *“Moving from Polymeric Material to HV Electrical Apparatus with Fully-Integrated Insulator – A case Study”,* as above, pp. 106 -114.

[3] IEC Publ. 61109 International Standard, “*Composite insulators for a.c. overhead lines with a nominal voltage greater than 1000 V – Definitions, tests methods and acceptance criteria”*

[4] IEC Publ. 1211 International Standard, “*Insulators of ceramic material or glass for overhead lines with a nominal voltage greater than 1000 V – Puncture testing”*

[5] S. Sangkasaad, “*Research and Experience with New Insulator Technologies in Thailand”,* Proceedings 2001 World Insulator Congress & Exhibition “Applying New Technologies for Better Reliability & Lower Costs, Shanghai, Nov. 18-21, 2001, pp.154 - 167.

[6] J.Fleszynski, *“Method of testing and evaluation of FRP rods of composite insulator cores,* Przeglad Elektrotechniczny, 2000, No 12, pp. 300-302. *(in polish).*

Authors address:
Wroclaw University of Technology
Institute of Electrical Engineering Fundamentals
Wybrzeze Wyspianskiego 27, 50-370 Wroclaw
Poland, Email: tyman@elektryk.ie.pwr.wroc.pl