International Journal on Emerging Technologies (Special Issue on NCRIET-2015) **6**(2): 391-395(2015)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Steep-Front Impulse Voltage Tests of Glass- Fiber- Reinforced Epoxy Composite Insulators

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(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: It is very important to eliminate improper insulator designs and technological faults. The most sensitive parts of polymer composite insulators (PCIs) 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 PCIs are subjected to steep-front impulses with steepness s ≥ 1 kV/ns. Each impulse should cause an external flashover without any puncture of the tested PCI 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 PCIs 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.

Keywords: polymer composite insulators, steep-front impulse voltage, pultrusion technique

I. 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 polymer composite insulator (PCI) 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 PCIs are their microscopic and macroscopic interfaces [R. S. Gorur; 2001 and D. Windmar;]. Failures of high-voltage PCIs 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 PCIs 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 [IEC Publ. 61109 International Standard,1992]. 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.

II. APPLICATION OF STEEP-FRONT IMPULSE VOLTAGES IN DESIGN TESTS OF PCI INTERFACES

According to standard IEC 61109, specimens of PCIs 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 PCIs 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 than1 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 [IEC Publ. 1211 International Standard;1994 and S.Sangkasaad;2001].

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).

III. 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, Figure 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).

Fig. 1. PCI 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 2 and 3.

IV. EXPERIMENTAL PROCEDURES AND RESULTS

The required quantities of epoxy resin (MY740) and curing agent (HY918) were heated in a vacuum chamber for 1 h at 60°C prior to mixing. Similarly, the SiO_2, Al_2O_3 and ATH particles were dried in an hot air oven for 24 h at 110°C. Agglomerates of nanoparticles are very difficult to separate and they can infiltrate the matrix. For polymer nanocomposites, a high power dispersion methods such as ultrasonic and high speed shearing, are the simplest and most convenient methods to improve the dispersion of nanoparticles in the polymer matrix [Qian D, *et al;* 2000 and Sandler J, *et al;*1999].

In this work, fillers were dispersed in absolute ethanol by gently stirring within the container. A high shear mixer is then used at 1000 rpm for 5 min followed by ultrasonification for 40 min to achieve uniform dispersion of fillers. Sonication was carried out in an ultrasonic liquid processor using 12 mm diameter probe, with amplitude of 5 µm mode (1.1 s on, 2.5 s off) at ambient temperature.

After breaking up the agglomerates, required amount of silane coupling agent was added and allowed to hydrolys for 10 min. The mixture was then introduced to the resin in steps of small quantities along with sonication for 5 min. Further sonication was continued for 40 min. This mixture was then heated in vacuum oven at 85^{0}C to remove ethanol completely. The hardener (85 wt %), release agent and accelerator (2 wt % each) were added to the composite and mixed with high shear mixture at 3000 rpm for 15 min. Further, to improve the interfacial adhesion between glass fibers and the resin in composites, the modified glass fibers with silane coupling agent was selected prior to pultrusion. ECR-glass fiber of 75 wt% to reinforcement provided to the prepared mixture and it was achieved by pultrusion technique.

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 [R. S. Gorur; 2001]. The steep-front impulse tests were conducted on specimens of 11 kV and 33 kV rated voltage insulators. The insulator samples were selected from both short-run and experimental 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 [IEC Publ. 61109 International Standard, 1992]. The 33 kV PCI specimens were fitted with sharp-edged electrodes around the housing between the sheds. In the case of the 11 kV PCI 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 33 kV (nominal voltage) PCIs are denoted by Roman numerals and the 11 kV PCIs by Arabic numerals.

After the voltage tests each sample was visually examined externally and internally (the housing was removed). Altogether, over 10 samples were tested and about 3 % 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 4 % 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 PCI specimens after the 4 kV/ns test are shown in Figure 4.

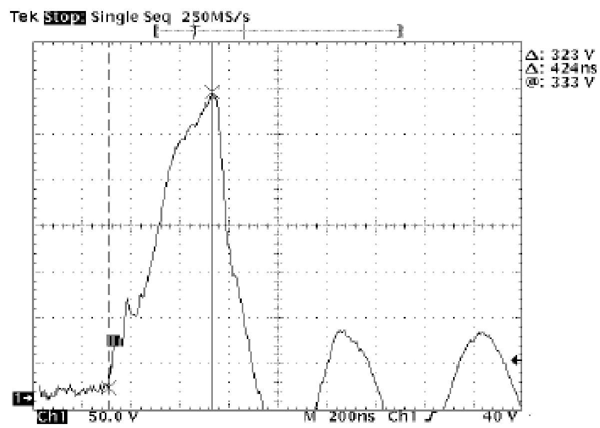

Fig. 2. Flashover voltage oscillogram: insulator No. 2.2, V = 509 kV and steepness s = 1.2 kV/ns.

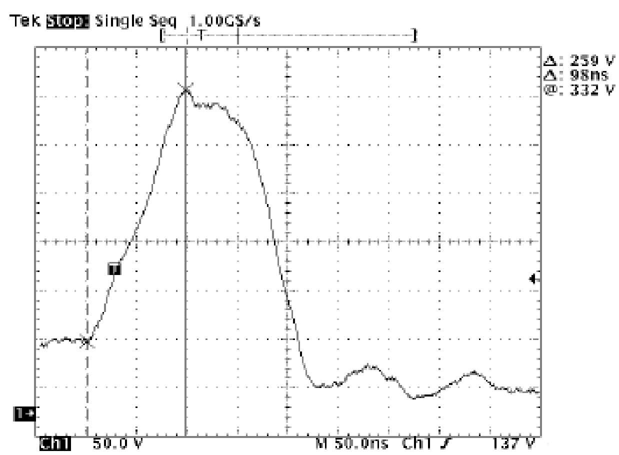

Fig. 3. Flashover voltage oscillogram: insulator No. II, V = 507 kV and steepness s = 4 kV/ns.

Table 1: Defects of PCIs and impulse test results.

PCI No.	Type of defect	Results	
		1kV/ns	4kV/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**

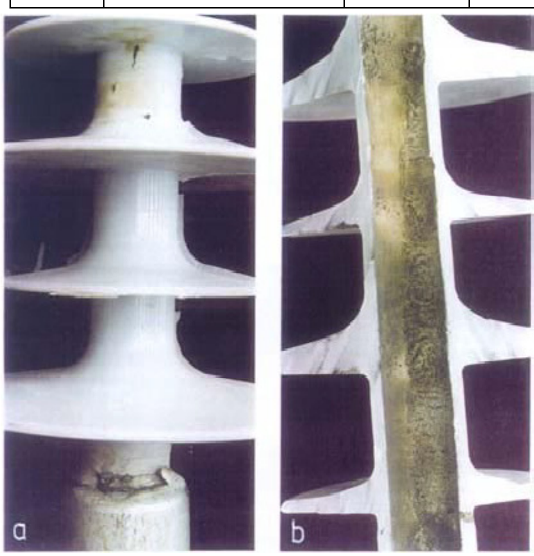

Fig. 4. Trace of breakdown on housing and traces of inside discharges along core surface after 4 kV/ns steep-front impulse test.

An example of a defective (improperly glued to the core) housing after the 4 kV/ns steep-front impulse test is shown in Figure 5. A disruption of the housing between the sheds is visible.

Table 2: Specially Prepared defects and results of tests.

PCI No.	Type of defect	Results	
		1kV/ns	4kV/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**

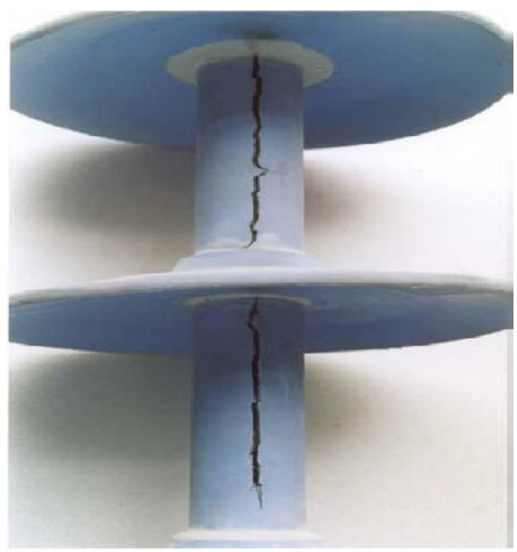

Fig. 5. Example of defective (improperly glued to core) housing after 4 kV/ns steep-front impulse test.

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.

V. CONCLUSIONS

The obtained results showed that the design testing of Glass fibre reinforced epoxy composite 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.

ACKNOWLEDGEMENT

The authors from Sri Jayachamarajendra College of Engineering are thankful to JSS Research Foundation, Mysore, and Central Power Research Institute (CPRI), Bengaluru for the financial support and encouragement.

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