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EXPERIMENTAL INVESTIGATION ON THE SURFACE DEGRADATION CHARACTERISTICS OF OIL IMPREGNATED PRESSBOARD DUE TO LIGHTNING AND SWITCHING IMPULSES

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ABSTRACT

In HVDC application the converter transformer plays a major role and its insulation system has to be designed to withstand AC, DC as well as transient overvoltage stresses. In this work the effect of transient over voltages on the oil impregnated pressboard which is one of the main insulating materials used in converter transformer. Lightning and switching over voltages are generated using impulse generator circuit and the stress withstanding capabilities of the samples have been investigated. The changes in the shape of the impulse wave during surface degradation have been observed. The degraded zone of the insulation is subjected to ATR-FTIR spectroscopy. From the characteristic peaks of the spectroscopy the by products formed in the degraded zone of the insulating material due to the effect of lightning and switching impulses have been studied. The surface tracking patterns and the insulation failure due to surface tracking have also been studied.

Keywords: converter transformer insulation, oil impregnated pressboard, ATR-FTIR spectroscopy.

INTRODUCTION

As the power demanding increasing day by day in the global energy market the generation of electricity has to be increased to meet out the required power demand. The power generated using conventional resources as well as non conventional resources have to be transmitted over long distances using EHVAC, UHVAC or HVDC transmission systems. The usage of HVDC transmission system is increasing due to the advantages such as high transmission capacity, reduced loss, reduced cost of the system etc. In HVDC system the converter transformer plays a major role. It has to be designed to withstand carefully as it is subjected to AC as well as DC stresses. Many researchers have studied the effect of power frequency AC stress and DC stresses on the insulation of converter transformer.

One of the important solid insulating materials used in the converter transformer is oil impregnated pressboard. The design of insulation to be provided in the converter transformer is critical as it is subjected to AC and DC stresses. Due to switching operation of converter circuit switching surges may also affect the insulation integrity of the converter transformer. The insulation materials used in the transformer especially solid insulation such as oil impregnated pressboard and oil impregnated paper have to withstand such sudden surges. The effect of lightning impulse is also plays a major role in the insulation design of transformer. The main cause of failure of solid dielectrics in transformer insulation is due the application of sudden surges such as Lightning surges, switching surges, surges due to line faults and the higher frequency over voltages caused due to the malfunction of protective devices[1]-[3].

The study of insulation withstanding capability due to such impulse over voltages and exploring the degradation mechanism is very important in order to improvise the design of insulation of converter transformer. In recent years little attention was focused on the study of degradation mechanism of solid transformer insulation such as oil impregnated pressboard.

During operation the transformer undergoes multi stress which will affect the physical and chemical properties of the oil impregnated pressboard. The surface discharge activity in the composite oil impregnated pressboard is a long term degradation process which may lead to permanent failure of the solid insulation. The surface discharge activity will enhance due to the effect of sudden surges and may even worsen the insulation strength. Surface tracking will cause carbonization over the surface of the insulation and due to this the conductivity over the surface will enhance which leads to permanent damage. During such degradation gaseous and solid by products will be formed and it will affect the insulation strength of transformer oil. Hence it is important to investigate the effect of lightning and switching over voltages in the degradation mechanism of solid insulation of transformers [2]-[8].

In this work, experimental investigation was carried out to study the performance of oil impregnated pressboard subjected to lightning and switching impulses. Standard lightning impulses of 1.2μs/ 50μs and switching impulses of 250μs/2500μs was generated in the single stage Marx impulse generator circuit. Fresh oil impregnated pressboard samples were prepared and it was subjected to impulse stresses. Surface degradation patterns were observed during the application of impulses. The change in the shape of the impulse waveforms during tracking and the severity of the tracked portion due to impulses were observed.

In order to understand the surface characteristic changes of the degraded oil impregnated pressboard the sample was subjected to ATR-FTIR spectroscopy. The

characteristic peaks were observed and compared with the ATR-FTIR spectrum of fresh oil impregnated pressboard. The characteristic changes clearly indicate the severity of degradation due to lightning and switches impulses.

PREPARATION OF TEST SAMPLES

The test container was fabricated for conducting the Impulse test on Oil Impregnated pressboard. Transparent Perspex sheets are used as the wall material for Test container. Perspex sheet was preferred due to its transparency, high mechanical, thermal and electrical strength. The test container along with copper pin-plane electrode configuration is shown in Figure-1.

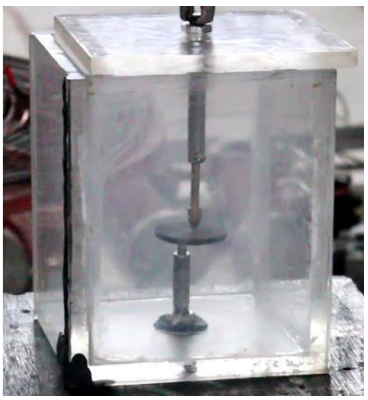

Figure-1. Test container with pin-plane electrode arrangement.

Generally high density pressboard are used in power transformers which operates above 132kV and Medium Density Pressboard are for power and distribution Transformers below 132kV and it is made from 100% cellulose based unbleached sulphate softwood pulp. Medium density pressboard was used in this study. The pressboard samples were fabricated by cutting the pressboard with a dimension of 5cm in diameter. Then the pressboard Sample was impregnated in transformer oil for about 10 days in order to improve its electrical properties. The samples were then dried before testing. The prepared oil impregnated pressboard sample is shown in Figure-2.

Figure-2. Oil impregnated pressboard sample.

The influence of electrodes on the surface discharge study of insulating material plays a major role. In this study point-plane electrode configuration is adopted in order to simulate extremely non uniform field condition. The electrodes are made up of copper conductors. The oil impregnated pressboard sample was placed between the electrodes. The impulse voltage end of the impulse generated was connected at the point electrode and the plane electrode was grounded. The point plane configuration with the Test sample is shown as Figure-3.

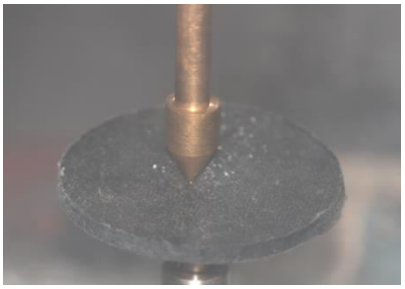

Figure-3. Pin plane configuration.

EXPERIMENTAL TEST SETUP

The pressboard sample was subjected to both Lightning Impulse and Switching Impulse over voltages with the help of Impulse generator circuit. The circuit arrangement for generating LI and SI over voltages is shown in Figure-4.

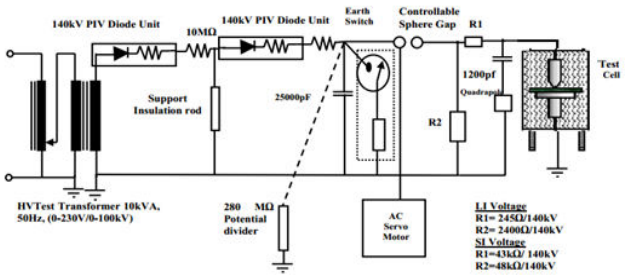

Figure-4. Impulse generator circuit with test sample.

The single stage Marx impulse generator circuit used in this study is capable of generating 140kV peak, 1.2µs/ 50µs lightning impulse voltage and 140kV peak, 250µs/ 2500µs switching impulse voltage. The test setup comprises of 10kVA, 100kV AC test transformer and two numbers of 140kV PIV diode unit, 10MΩ current limiting resistor, controllable sphere gap operated by AC servo motor, earth switch, 25000 pF and 1200pF charging capacitor and wave shaping resistors R_1 and R_2. To generate lightning impulse voltage the value of R_1 and R_2 is selected as 245Ω and 2400Ω respectively [9]-[10]. To generate switching impulse wave the value of R_1 and R_2 is selected as 43kΩ and 48kΩ respectively. The laboratory test setup to carry out impulse test on pressboard samples is as shown in Figure-5.

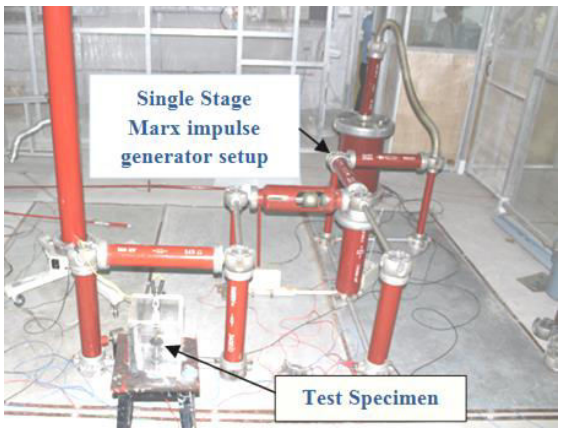

Figure-5. Laboratory setup of impulse generator circuit.

The oil impregnated press board sample is subjected to lightning and switching impulse over voltages using Impulse generator circuit. As per the preferred testing procedure, negative polarity impulse is generated and tested. 5 samples were considered for testing. Impulse test is conducted for 45 minutes per sample and the most degraded sample is taken for surface degradation studies. The sphere gap was adjusted such that the Impulse voltage applied over the test specimen is at the rate of application of impulses over the specimen is 10 impulses per minute.

The impulse generator voltage magnitude was increased in steps such that initial surface discharge is observed in the pressboard sample. Initial surface discharge activity was observed at 50kV peak lightning impulse. Figures 6 (a) - 6(d) shows the different impulse patterns observed during the surface discharge activity.

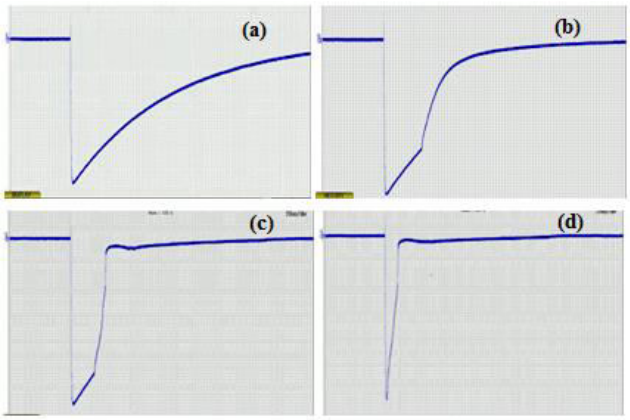

Figure-6. Lightning impulse wave during surface discharge.

Figure-6 (a) shows the initial lightning impulse waveform without any surface discharge activity. 6. (b) shows the change in shape of the impulse waveform during initial surface discharge. Due to the stress tracked regions were observed at the surface and it leads to further deterioration of the sample. Figures 6(c) and 6(d) shows the waveforms during tracking over the surface of the sample. It was observed that the shape of the waveform didn't collapse immediately, instead the shape changes depends upon the increase in surface conductivity due to tracking mechanism. It is clear from the experimental investigations that the failure of insulation is mainly depends upon the magnitude of the lightning impulse voltage and the surface resistance to tracking.

Similar experimentation is carried out by applying switching impulse by changing the wave shaping components. Initial surface discharge activity was observed at 42kV peak switching impulse. During switching impulse application it was observed that wider tracked regions were formed over the surface of the pressboard which was not observed in case of lightning impulse voltage. Though the switching transients initiate surface discharge activity at lower voltage magnitude compared to lightning impulse more tracked regions were observed at the surface compared to lightning impulses. Figure-7 (a) - (d) shows the different waveforms observed during the surface discharge activity by the application of switching impulses. Figure-7(a) shows the initial switching impulse waveform without discharge.

Figure-7(b) shows the change in shape of switching impulse waveform during initial surface discharge activity. Figures 7(c) and 7(d) shows the change in wave shape during severe tracking conditions.

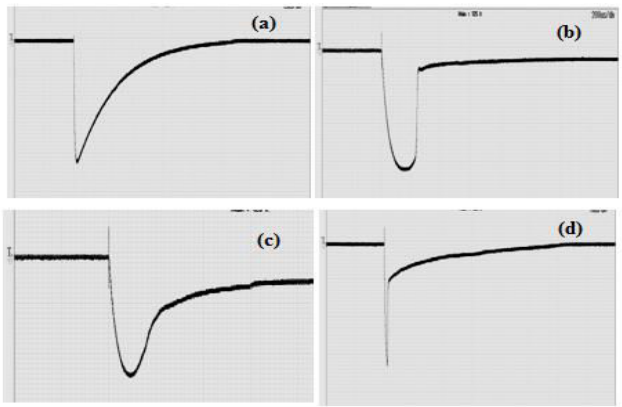

Figure-7. Switching impulse wave during surface discharge.

Figures 8(a) - 8(d) shows the surface discharge patterns recorded during experimentations. Initially the surface discharges were observed at the edges of the pressboard instead over the surface. Figure-8(a) shows the initial discharge patterns. As time progresses the discharges were observed at the tip of the pin electrode and the discharges were observed over the surface in an irregular manner.

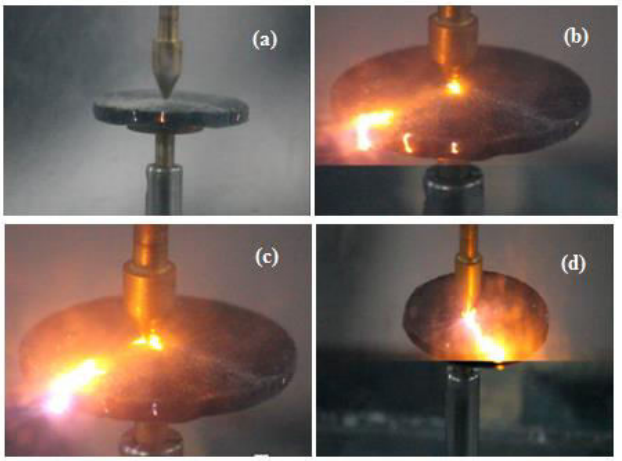

Figure-8. Surface discharge patterns during testing.

During the application of lightning impulses the discharges initially spread over the surface in an irregular pattern. After sometime the discharges were found to follow only a specific region in the surface. The other portion of the pressboard was not affected by the discharges. But in case of switching impulses the discharges spread over the surface in an irregular way and it creates tracking patterns in a wider region compared to lightning impulses. Figures 8(b) and 8(c) shows the surface discharge during switching impulse. It is clear from figure that the pattern covers wider region. Figure 8.(d) shows the surface discharge pattern during lightning impulse. The discharge region confined to a particular portion of the pressboard. A continuous arc through the surface of the specimen was observed. Though the other part of the insulation was not affected the degradation caused by lightning impulse was severe.

Figures 9(a) - 9(d) shows the degraded regions over the surface of the pressboard due to lightning and switching impulses.

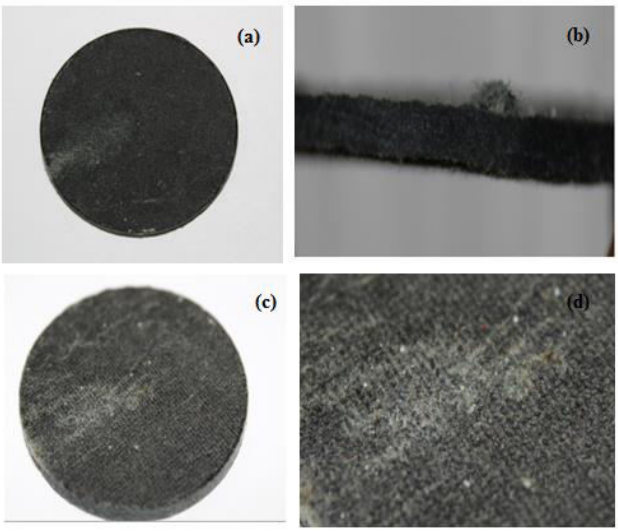

Figure-9. Degraded region over the surface of the pressboard.

Figure-9(a) shows the oil impregnated subjected to lightning impulses. It is clear from the photograph that the tracking over the surface of the specimen was observed over a narrow region. But the physical damage caused by the lightning impulse is severe. Figure-9(b) shows the peel off region in the surface of the oil impregnated pressboard.

Figure-9(c) shows the oil impregnated pressboard sample subjected to switching impulse. It is clear from the photograph that the tracking over the surface of the specimen was observed over a wider region compared to the sample subjected to lightning impulse. Almost 40 percent of the surface was degraded during testing. But the severity of the physical damage at the surface was less compared to lightning impulse samples. No peel off region was observed at the surface of the specimen subjected to switching impulses.

The surface degradation phenomenon not only depends upon the magnitude of the impulse. It also depends upon the front and tail time of the impulse. More analysis is required with different switching transient over voltages with different front and tail time [11]-[12].

ATR-FTIR SPECTROSCOPY ANALYSIS

ATR-FTIR spectroscopy provides a wavelength spectrum of a functional group that is formed at the surface of the degraded portion of the samples. Figure-10(a)- 10(c) shows the ATR-FTIR spectra obtained at the degraded region of the oil impregnated pressboard samples. The spectra clearly indicate the functional group formed due to characteristic changes that occur due to ageing. In general, the characteristic peaks for Alkanes and carboxylic acids formation appear in the range 2850 and 3000 cm-^{1}, alcohols, carboxylic acids, esters, ethers are detected in the range 1320 and 1000 cm-^{1}, alkenes are present in range 1000 and 650 cm-^{1}, aromatic compounds, primary and secondary aminesare detected in the range 900-675 cm-^{1} and alkyl halides are detected in the range 850-550 cm-^{1} and 700-610 cm-^{1}.

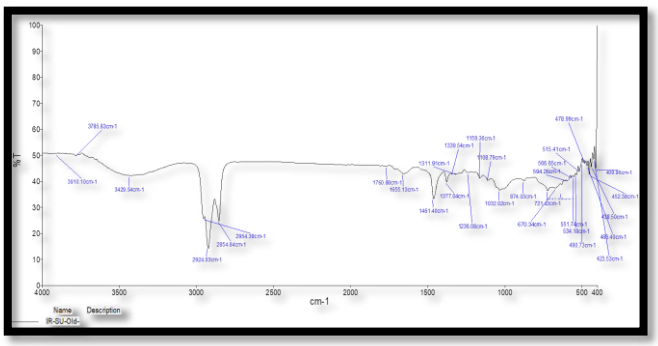

Figure-10. (a) ATR-FTIR analysis of fresh pressboard.

ATR-FTIR spectroscopy was carried out on fresh sample, surface degraded sample due to lightning impulses and switching impulses. Figure-10 (a) shows the ATR-FTIR spectra of fresh sample. It is clear that the characteristic peaks appears in the range 3000-2800 cm-1 corresponds to presence of alkenes due to C-H stretch.

Alkanes are also detected from the characteristic peaks which occur in the range 146cm-1 to 1370 cm-1.

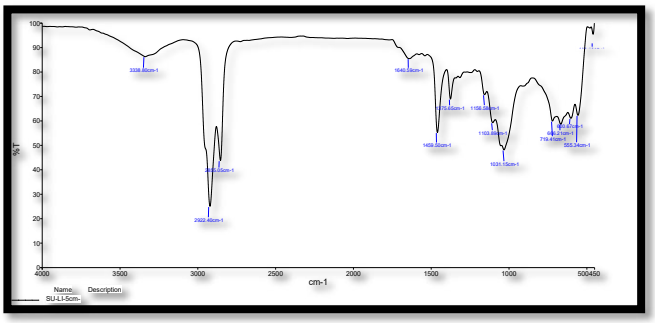

Figure-10. (b)ATR-FTIR Analysis of LI degraded pressboard.

Figure-10 (a) shows the ATR-FTIR spectra of sample subjected to lightning impulse voltage. When the degraded zone of the subjected to ATR-FTIR spectroscopy, alkanes and aldehydes formations are detected in the range 2900-2800 cm-1 due to C-H stretch. Alcohols and carboxylic acid formation are detected in the range 1320-1000cm-1. Alcohols, carboxylic acids, esters, ethers are detected in the range 1320-1000 cm-1 due to C-O stretch. The formation of alkyl halides are detected in the range 690-515cm-1.

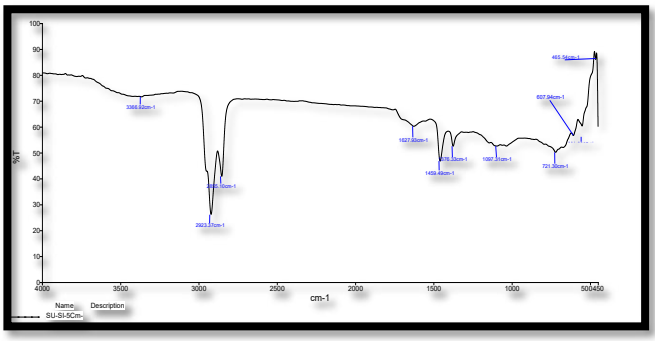

Figure-10. (c)ATR-FTIR Analysis of SI degraded pressboard.

When the degraded zone of the lightning impulse tested specimen subjected to ATR-FTIR spectroscopy alkanes and aldehydes formations are detected in the range 2900-2800 cm-1 due to C-H stretch. Alcohols and carboxylic acid formation are detected in the range 1320-1000cm-1. But the change in %T was minimum compared to lightning impulse samples.

CONCLUSIONS

This work deals with the effect of lightning and switching impulse in the surface degradation of oil impregnated pressboard. It is clear from the experimental investigations that the effect of lightning and switching impulses in degrading the surface of the insulation is distinctly different. The wave shapes during tracking was recorded. It is inferred from the wave shapes that during initial surface discharge the pattern of the impulse was not significantly changing. But during the severe discharge condition due to the failure of the surface resistance the change in shape of impulse waveforms have been observed. ATR-FTIR spectroscopy studies have been carried out to investigate the by product formed due to the surface degradation. It is clear from the studies that the degraded oil impregnated pressboard releases alcohols and carboxylic acids which will react with transformer oil and reduces the life of the insulation.

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