Investigation of leakage current flow through wooden poles structures on overhead distribution system

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Abstract: - Insulation degradation leading to leakage current flow through the high voltage insulator is a major problem faced by various power distribution utilities. The excessive leakage current flow into the wooden supporting structures (wooden cross-arm and pole) leads to pole-top fires and subsequently power cut-off. Most prior researchers focused on flashover phenomena of insulators rather than investigation of leakage current leading to pole fire. This paper investigates the continuous current flow path originating from the high voltage conductor to various locations through the wooden pole. The results are of significance to the study of high voltage insulation whereby it extended the study of leakage current into the wooden supporting structures. Experiments were conducted on various locations of wooden pole to detect and track the leakage current flow. Also the moisture contents at these locations were measured to investigate its effect on the leakage current through the wooden pole structure.

Key-Words: -Leakage current, wooden pole structure, moisture content, insulator and moisture content

1 Introduction

Today, because of their significant advantage over steel cross arms, wooden cross arms and poles are being increasingly used on distribution lines. Their main advantage over steel cross arm include: Very low maintenance cost, better insulation, higher degree of fault protection, easily available and accessible, Cost effective and less weight. However, wooden poles and cross arms still have certain disadvantages like pole top fires problem, maintenance and age. There are number of factors responsible for pole fires in Australia and around the world. They are either electrical causes like leakage current, electrical resistivity or environmental stresses like moisture content and temperature or mechanical stresses like tensile strength. Of these, leakage current and varying moisture content of the wood at certain locations are the main cause of pole top fires on overhead power distribution lines. Fig.1 shows a wooden pole top fire sample supplied by a utility company which will be used in the future research to investigate the cause of fire.

Numerous research was carried in Australia and other parts of the world in the late 1940's find out the cause of pole fire [1,2]. Number of factors which

Fig.1 Pole Top Fire Sample

cause ignition were discussed but there was no evident experimental results to validate those findings. Various power distribution companies have experienced pole top fire due to fog, drizzle or heavy dew after spells without heavy rain. Number of alternatives such a painting the wood in the vicinity of metal wood connection with conducting paints have been proposed in the past [3] but none of them have been able to prevent pole top fires around the world.

On the other hand, chemical treatment of wooden poles & crossarm has been discussed in the past as pole fire mitigation but there are no evident results of its effect in mitigating pole top fires [3]. In previous studies [4,5], some preliminary results have been reported, however they mainly referred to investigation of leakage current through insulator with very little emphasis on flow of leakage current through wooden structure. So far, information regarding the behaviour of leakage current through wooden poles is rather limited and this paper aims to educate the problem.

The objective of the present work is to identify and investigate the various factors which lead to pole fires on overhead power distribution lines. This paper investigates the continuous current flow path originating from the high voltage conductor to various locations through the wooden pole structure. The results are of significance to the study of high voltage insulation whereby it extended the study of leakage current into the wooden supporting structures. Experiments were conducted on various locations of wooden pole to detect and track the leakage current flow. Also the moisture contents at these locations were measured to investigate its effect on the leakage current through the wooden pole structure.

2 Properties of wood

2.1 Moisture Content

Moisture content if wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of oven dry wood. Moisture content exists in wooden cross arms as liquid water (free water) or water vapour in cell lumens and cavities and as water is held chemically within cell walls. In softwoods, the moisture content of sapwood is usually greater then that of heartwood. In hardwoods, the difference in moisture content between heartwood and sapwood depends on the species.

2.2 Thermal Conductivity

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient. The thermal conductivity of wood is affected by a number of basic factors like density, moisture content, grain direction, structural irregularities such as checks and knots and temperature. Conceptually thermal conductivity increases as density, moisture content and temperature increases. The effect of temperature on thermal conductivity is relatively minor: conductivity increases about 2% to 3% per 10 C.

2.3 Electrical Conductivity

The electrical conductivity of wood varies slightly with applied voltage and approximately doubles for each temperature increase of 10 C. It varies greatly with moisture content, especially below the fibre saturation point. As the moisture content of wood increases from nearly zero to fibre saturation, electrical conductivity increases by 10^{10} to 10^{13} times. Fig.2 below shows a change in electrical resistance of wood with varying moisture content for many Australian species.

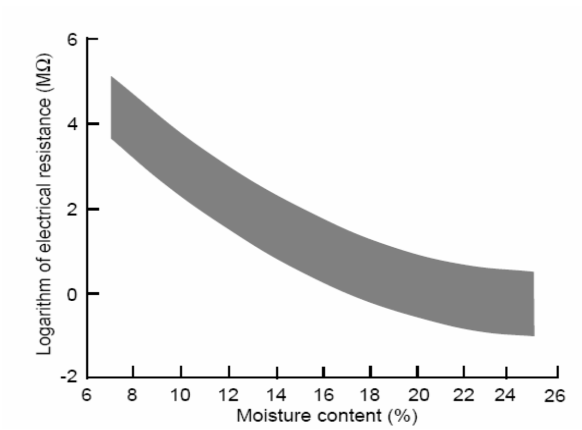

Fig.2 Variation of logarithmic electrical resistance with moisture content.

3 Experimental Set-up

The experimental set-up consists of equipment such as voltage control circuit variac, multimeter, leakage current measurement system connected to PC via a Data Acquisition Card were used. Inside the HV laboratory, a 415V/66kV, 50kVA, single phase transformer, voltage divider(1000:1) to measure the line voltage, sphere gap to protect the equipment from breakdown, resistor bank to limit transformer primary current, pollution chamber and leakage current measurement circuit were used. The experimental setup in the HV laboratory is shown below in Fig.3.

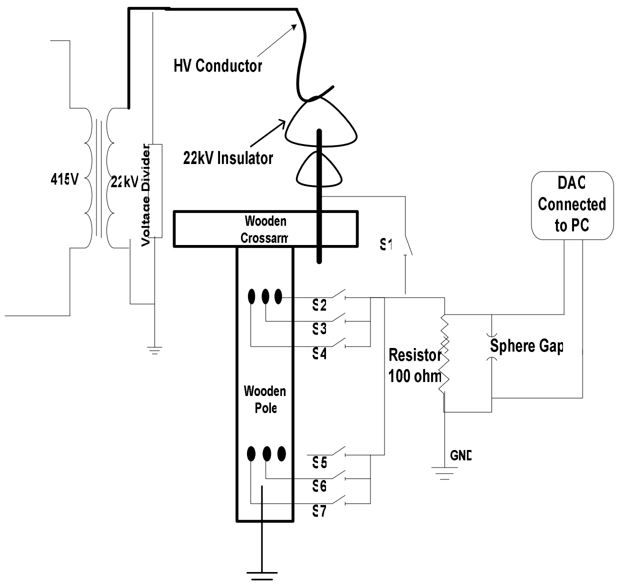

Fig.3 Arrangement of HV polluted insulator and wood testing in the HV laboratory

The switching arrangement consisting of seven switches (S1, S2, S3, S4, S5, S6 and S7) was implemented in the HV laboratory. This was done to ensure leakage current at all seven different locations (one at Insulator rod, three pole top and three pole bottom) was measured individually and one at a time.

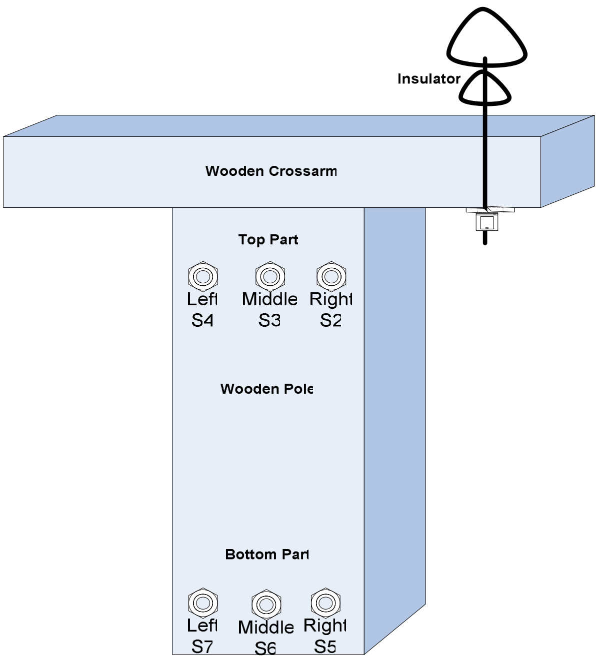

Fig.4 Drilled rod arrangement with test points in wooden pole structure for leakage current measurements

It was made sure all the other switches were in open mode except the one which is in closed mode for measurement of the leakage current at that very location. A well known technique of measuring the voltage across a 100ohm ground resistor is used. The voltage across this ground resistor is proportional to the leakage current flowing through the insulator surface and wooden pole structure.

A 30 year old hardwood pine wooden pole and cross arm sample was supplied by the utility company and was used for our laboratory testing. For leakage current measurement through wooden pole, a new technique of inserting steel rod into the wooden pole structure was carried out. The top and bottom part of the wooden pole were drilled with three holes each of similar size as shown in Fig.4. A 15mm steel rod was inserted into each drilled hole, one at a time and connected to the measurement system. This technique was used to capture and track the variation of leakage current flow inside the wooden pole.

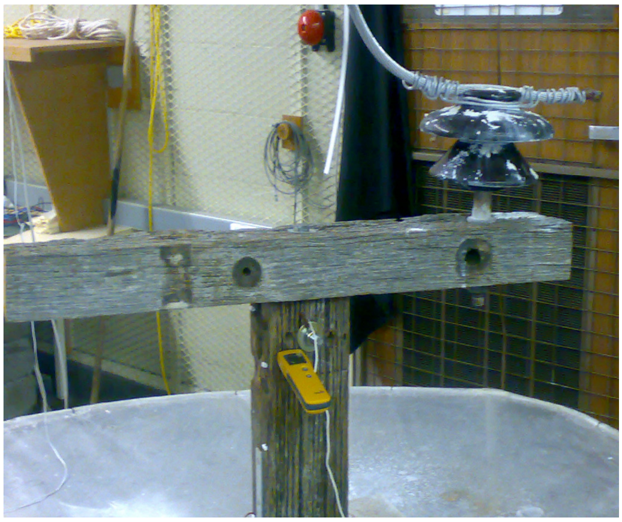

Fig.5 Testing of wooden pole inside the laboratory

In the HV laboratory, a 22kV brown pin type insulator shown in figure 5 was mounted on one end of the wooden cross arm to test the single phase line circuit and was connected to secondary of transformer via an ASCR conductor. The insulator was contaminated with a slurry consisting of 40g/l kaolin and variable NaCl according to the IEC 60-1:1989[6,7] to simulate intermediate and heavy degree of contamination. To simulate insulator contamination in coastal regions which are more prone to pole top fire, extra salt was added to the slurry and was sprayed on the insulator surface and a uniform layer of contamination was formed.

The moisture content was measured by using a GE Protimeter Timbermaster meter. Moisture measurements were taken using integral pin electrodes which were pushed into wooden pole surface at six different test point locations i.e. S2, S3, S4, S5, S6 and S7 on either side of wooden pole. The calibration of meter was checked by holding the electrode needles across the exposed wires provided by the meter manufacturer. The moisture measurements were carried out to investigate the effect of moisture content on leakage current at various locations in the wooden pole structure.

4 Results

The leakage current waveforms obtained from conducting the experiments are shown Fig. 6 to Fig.12. The first step in measuring the leakage current was a constant voltage of 22kV applied to contaminated insulator sample under normal environmental conditions. Aiming to measure the leakage current on the surface of insulator, the switch S1 was closed while all the other switches were kept open. A leakage current of 447μA magnitude was measured and its waveform was recorded on the PC as shown in Fig.6.

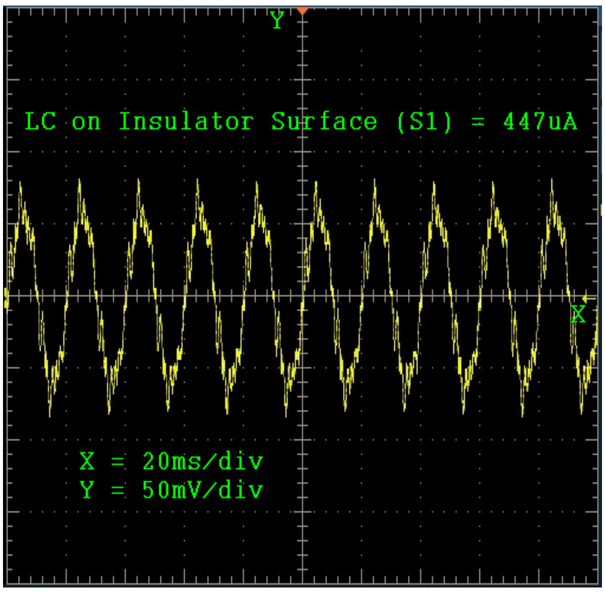

Fig.6 Leakage current waveform at insulator surface

The second step was to measure the leakage current through the top right portion of wooden pole and was done by inserting a metallic rod into the top right hole of the wooden pole and its corresponding switch S2 was closed while all remaining switches were kept open. A leakage current of 116μA was measured and its waveform is shown in Fig.7.

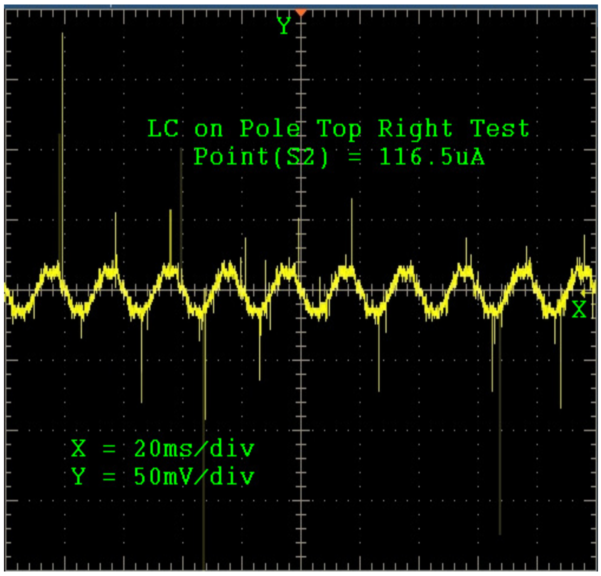

Fig.7 Leakage current waveform at pole top right test point

This second step was repeated to measure leakage current at remaining test points on the wooden structure and their corresponding switches were operated in the correct manner to avoid incorrect measurements.

A high leakage current of 126μA was measured at the top middle test point of wooden structure as shown below in Fig.8. The moisture content of 7.025% was measured at this test point. .

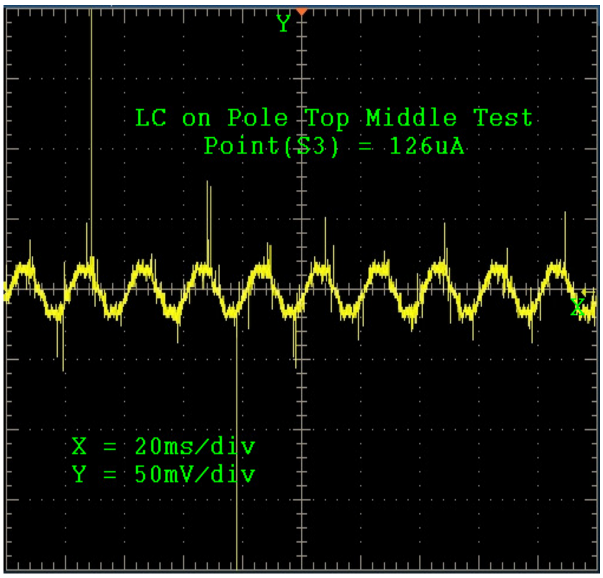

Fig.8 Leakage current waveform at pole top middle test point

A leakage current magnitude of 106.9μA was measured at the top left test point of wooden structure as shown below in Fig.9. The moisture content of 6.625% was recorded at this test point location.

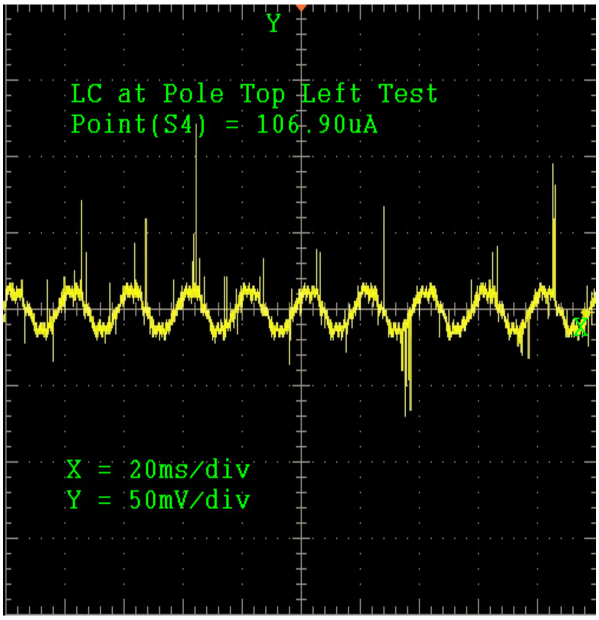

Fig. 9 Leakage current waveform at pole top left test point

The second step was again repeated to measure the leakage current at bottom right test point on the wooden pole structure (S5 was closed and remaining switches were kept open). A magnitude of 75.86μA was recorded and its waveform is shown below in Fig.10. A moisture content of 7.67% was also measured and is shown in table 1.

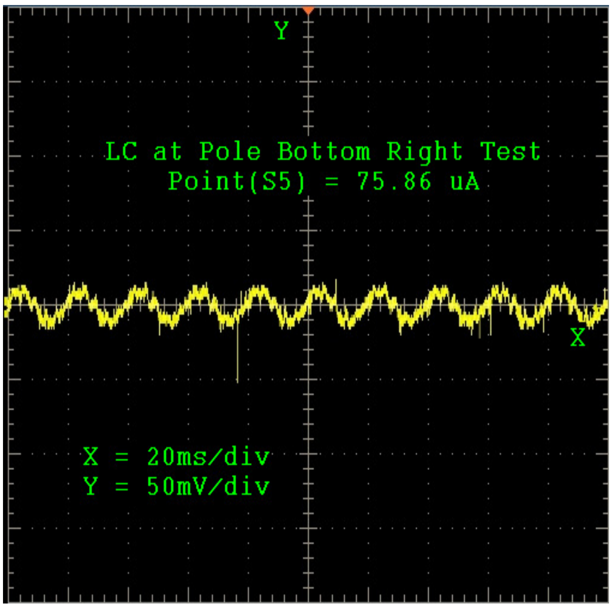

Fig.10 Leakage current waveform at pole bottom right test point

Similarly, by closing the S6 and keeping remaining switches open, a leakage current magnitude of 77.54μA was measured at bottom middle test point on wooden pole structure as shown below in below Fig.11 and a corresponding 7.75% of moisture content was measured.

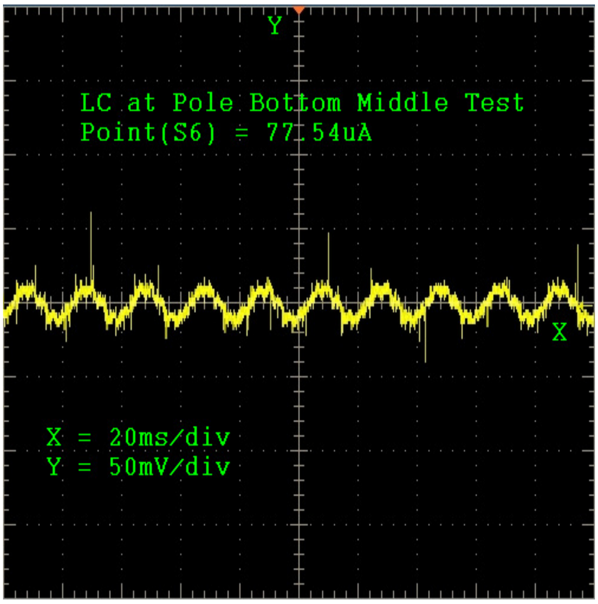

Fig.11 Leakage current waveform at pole bottom middle test point

As can be seen below in Fig.12, leakage current of 79.67μA was measured at pole bottom middle test point by ensuring closure of switch S7 and open state for remaining switches. Moisture content was also measured at this test point and found out to be 7.90%.

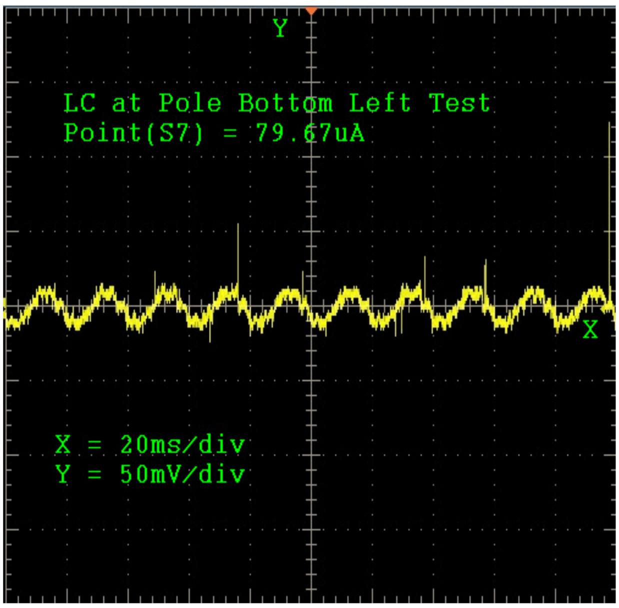

Fig.12 Leakage current waveform at pole bottom left test point

For the sake of simplicity, Results obtained from the conducting experiments are shown in Table 1.

Location(Top)	Leakage Current (µA)	Moisture Content (%)
Insulator Rod (S1)	447	
Pole Top Right (S2)	116.5	6.925
Pole Top Middle (S3)	126	7.025
Pole Top Left (S4)	106.9	6.625
Pole bottom Right (S5)	75.86	7.67
Pole bottom Middle (S6)	77.54	7.75
Pole bottom Left (S7)	79.67	7.90

Table 1 Leakage current and moisture content measurements at various locations

5 Discussion

One of the important parameter that determines the cause of wooden pole top fires is the leakage current flow through the wooden structure. Leakage current measurements were performed at various test point locations on the wooden structure. It is interesting to observe that there is a significant reduction in leakage current measured at top portion as compared to bottom portion of wooden pole. This reduction is attributed to the joule heat losses in the leakage current as it travel from surface of insulator to top and finally through to the bottom of wooden pole structure.

It was also found that the higher amount of leakage current was observed at locations with higher moisture content. It has been recognized that increase in moisture content of wooden structure lowers the electrical resistively of wooden pole structures [8]. This closely correlates with the experimental values of the leakage current and the moisture content of wooden pole. It was also observed from the waveform shown in Fig. 8 to Fig. 12, that the leakage current measured at the top portion of wooden poles consist of high frequency components as compared to the bottom porting of the wooden structure. This could be due to the smoldering at the top portion of the wooden pole however this needs further research.

6 Conclusions

Insulator contamination driven leakage currents do flow on the 22kV wooden pole structures. A higher amount of leakage current leakage was measured through pole top structure as compared to the pole bottom structure. Amount of leakage current flow through the various locations of wooden pole depends on respective moisture content levels. It was found that more leakage current was observed at areas with higher moisture content. It can be concluded that the leakage current decreases in magnitude as it travels from top to the bottom of the pole. This could be due to the heat dissipation and non linear resistance of wood structures.

As a result of these conclusions, further research is needed to be done. The influence of age of wood on leakage current flow is still a very new areas and further research will be carried out in the near future. Also further investigation of the effect of dry and wet wooden structure on leakage current will be conducted.

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