Incipient Fault Detection in 33/11kV Power Transformers by Using Combined Dissolved Gas Analysis Technique and Acoustic Partial Discharge Measurement and Validated Through Untanking

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***Abstract-* Power transformer consists of components which are under consistent thermal and electrical stresses. The major component which degrades under these stresses is the paper insulation of the power transformer. The electrical fault can develop into thermal fault such as localized insulation burning or hot-spots. Any fault in the transformer can be detected by using Dissolved Gas Analysis technique. In this paper, the detection of electrical and thermal faults in 14 units of 33/11kV, 30 MVA and 15MVA transformers were done by using Dissolved Gas Analysis (DGA). Then, the acoustic partial discharge test was carried out to detect the activity and locate the source of the electrical fault. All the transformers were untanked and the inspection was done. From the inspection done, there were a few incipient faults detected such as overheating due to loose connection, sharp edges, insulation burning, choking effect due to moisture and surface tracking in On-Load Tap Changer (OLTC) compartment.. As a conclusion, the combination of the acoustic partial discharge technique and DGA technique have proved to be a useful tool in detecting and locating incipient faults in the power transformer.**

Keywords: Partial Discharge, Arcing, Dissolved Gas Analysis, On Load Tap Changer (OLTC)

I. Introduction

Power transformer experiences consistent thermal and electrical stresses. The major component which degrades under these stresses is the paper insulation of the power transformer. The insulation paper determines the life of the power transformer. The degradation of the paper insulation will be accelerated with the presence of electrical fault. Electrical fault in power transformer can be categorized into two which are Partial Discharge and Arcing.

The Partial Discharge (PD) is the pre-breakdown of the paper insulation. A PD in a transformer occurs when the electric field in a localized area changed in such a way that localized current stream is produced. This localized current will produce current pulses that are measurable at the output of the transformer. PD can be classified into three categories which are voids, coronas due to sharp edge or floating components and surface tracking. However, the detection of the PD created by floating component and sharp edges did not yield any useful information about the insulation because their appearance is not directly related to the condition of the insulation. Besides, the PD due to the floating components and sharp edges will give rise to the Hydrogen and Methane content in the insulation oil. This will eventually give a false alarm on the insulation breakdown. Insulation breakdown happened mainly due to PD in voids and small cracks. Voids are defined as gaps in dielectric material which less dense than the dielectric material itself such as gas bubbles in oil that fills the transformer tank, or cracks in the paper insulation. The void region has a lower dielectric constant than the surrounding material, which creates capacitance.

A partial discharge can then occur when the electric field difference across the void if it exceeds minimum breakdown field strength. A PD will eventually develop into arcing. Any electrical fault in the transformer can be detected by using Dissolved Gas Analysis technique. The DGA can be used to differentiate between the types of faults in the transformer. However, DGA alone is not conclusive in determining the electrical fault in the transformer. As a complement, acoustic partial discharge technique was used to detect the electrical fault in the transformer. In this paper, the detection of electrical and thermal faults in 14 units of 33/11kV, 30 MVA and 15MVA transformers were done by using Dissolved Gas

Analysis (DGA). Then, the acoustic partial discharge test was carried out to detect the activity and locate the source of the electrical fault. Finally, the transformers were untanked for inspection and repairing.

II. ACOUSTIC DETECTION OF PARTIAL DISCHARGE [1]

The main advantage of the acoustic PD detection of partial discharge is the location of the discharge occurrence. The principle of the acoustic PD detection is the detection of the pressure waves generated by the discharge within the insulation which appears as a small explosion. The explosion will excite a mechanical wave, and propagates through the insulation. The speed of the acoustic wave propagation depends on the surrounding medium [1]. The acoustic wave is shown in Figure 1. The acoustic features such as duration, rise time, counts, energy and amplitude are used in partial discharge detection. In acoustic PD detection, one need to consider the reflection and refraction, geometrical spreading of the wave and absorption in the materials which will lead to changes of sound propagation.

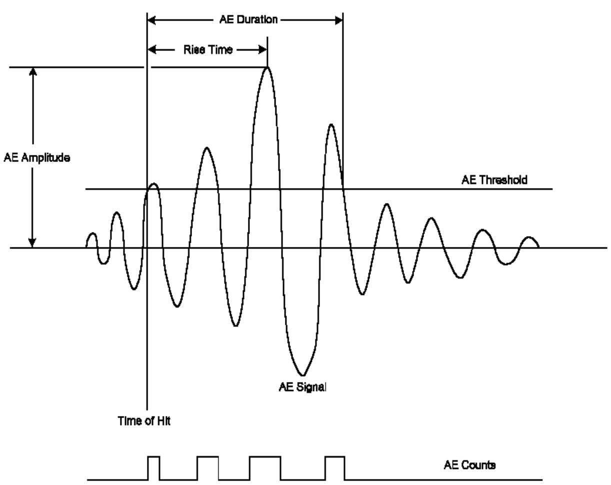

Figure 1: Acoustic Wave [1]

The PD impulses has a short duration resulting compression wave has frequencies in the ultrasonic region [2]. The frequency range is between 10 Hz and 300 kHz. In air and gases, microphones are usually used as sensors. On the other hand, piezoelectric transducers as acoustic emission (AE) sensors offer the best sensitivity for detection of ultrasonic waves in the enclosure [2].

A. Design of Acoustic PD Instrumentation [1]

Acoustic partial discharge detection apparatus consists of a sensor, filter, preamplifier, and some type of data acquisition instrument as shown in Figure 2.

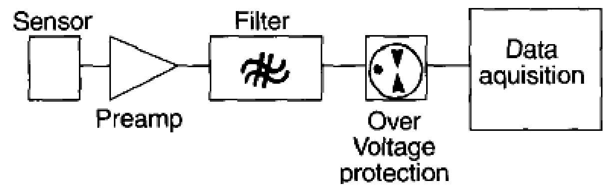

Figure 2: Acoustic PD Detection Circuit [1]

The system frequency response (time constant) determines most system detection characteristics. The amplitude and frequency characteristic of the signal that arrives at the sensor and the ambient mechanical background noise determines the sensitivity and signal-to-noise ratio. Acoustic signals generally decrease at high frequencies due to absorption [1]. This effect is more for apparatus with large distances between PD sources and the sensor.

On the other hand, the acoustic noise increases at lower frequencies. The system is optimized through a tradeoff between bandwidth, signal, and noise (Figure 3). Absorption often limits the sensitivity and the thermal noise of amplifiers increases as the square root of the bandwidth. This thermal noise can influence the signal to noise ratio. Sometimes, one discharge often results in multiple signals that propagate along different paths to the sensor. The frequency response of the system also determines which frequency components are detected. As the speed of sound and propagation path vary with wave type and frequency, the choice of sensor and bandwidth determines the appearance of the signals.

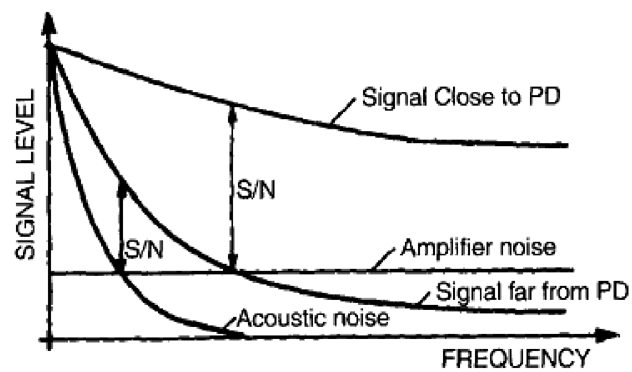

Figure 3: Signal and Noise vs. Frequency, Indicating the Basis for Determining the Acoustic Detection Bandwidth that Provides Optimum Signal to Noise Ratio [1]

B. Location of Discharges [3]

The possibility of PD activity location is one of the major features of acoustic discharge detection. Location can be based on either measurement of the signal arrival time at a sensor (Figure 4(a) and 4(b)) or on measurement of signal level. The intensity of the wave decreases as a function of distance from the source when a wave propagates through a structure, [1].

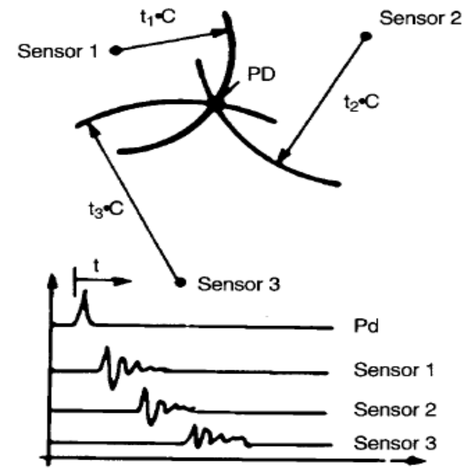

Figure 4 (a): Triangulation of Source Location Based on Time of Flight Measurements Based on Measurement of both Electric and Acoustic Methods [1]

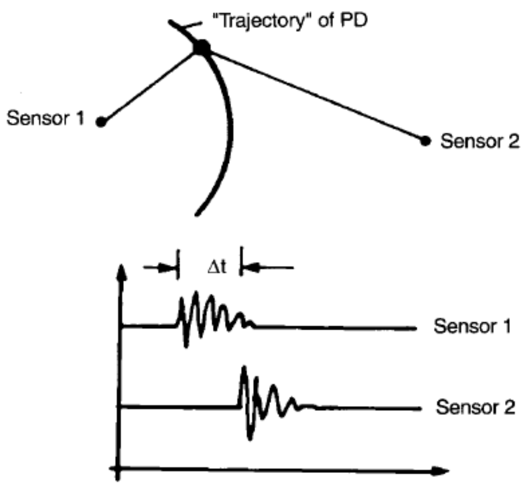

Figure 4 (b): Triangulation of Source Location Based on Time of Flight Measurements Based on Acoustic Methods [1]

This results from several mechanisms including geometrical spreading of the acoustic wave, acoustic absorption (conversion of acoustic energy to heat), and scattering of the wavefront. These phenomena result in a reduction of the intensity of the wave as it moves away from the source. In practical situations, a location based on a time-of-flight measurement requires two or more simultaneous measurements in order to use triangulation to determine the source location. Additional option which will ease the PD detection is to measure the electrical signal simultaneously with the acoustic signal. If the acoustic propagation velocity is known, then calculation of the source location will become simple.

However, different wave components travel along different paths in a structure which makes the location determination becomes complicated. If the electrical signal cannot be detected, a triangulation can be carried out as a simultaneous measurement with several acoustic sensors. In a locus, the source must be located on a hyperboloid between the two sensors. This can be determined from analyses of time lag of the signal. All locations on a hyperboloid have the same time lag between the signal arrivals at the two sensors. If the signal is repetitive, one of two sensors can be moved until the acoustic pulses arrive simultaneously at the two sensors where the location of the PD source is in between them. The simple rule is the signal magnitude will be high if it is close to the source. Then, only one sensor is required and is moved around until the position for maximum signal is located. The frequency of the signal will be higher as it reaches closer to the source.

C. Triangular Method for Location [1]

The triangulation method is time consuming and the result of the PD detection may diverge from it location [1]. As an alternative, the location calculation is derived from the time-distance relationship implied by the velocity of the sound wave. The absolute arrival time, t, of a hit in an event can combine with the velocity, v, of the sound wave to calculate the distance, d, from the sensor to the source [1] as in equation (1).

$$d = v \times t \tag{1}$$

The distance between two points depends on the dimension of the object. The majority of the location modes are a variation of 2 dimensional source locations in a plane. In many cases the 2D plane will wrap around a 3 dimensional object. For two points in 2D, the distance equation is just the Pythagorean Theorem expressed in Cartesian coordinates as:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{2}$$

This calculation is complicated because the exact time the event origination is unknown. To overcome this problem, all the times are considered relative to the first hit in the event. Each arrival time difference for each sensor is referred relatively to the distance from the first hit sensor. For the second hit sensor as relative to the first hit sensor, a difference equation can be written as:

$$t_2 - t_1 = (d_2 - d_1)/v \tag{3}$$

The distance equation (2) can be combined with the difference equation (3) to get:

$$t_2 - t_1 = \left[\sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2} \; - \; \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2}\right]/v \tag{4}$$

where x_s and y_s are the unknown coordinates of the source. The equation contains two unknown and cannot be solved by itself. To get a second equation with the same 2 unknowns, a 3[rd] hit is added to the event to get:

$$t_3 - t_1 = \left[\sqrt{(x_3 - x_s)^2 + (y_3 - y_s)^2} \; - \; \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2} \right] / v \quad (5)$$

These simultaneous equations can then be solved for x_s and y_s .The problem with this approach is that it gives more than one source location per event and if there is any error in the timing values, the source location can be wildly incorrect [1]. A better approach would be to average the data to produce a single location. The equation given in (5) can be solved by using multiple regressions. However, it does not actually average the results of multiple 3 hit calculations directly. If more hits are considered, the equation (4) and (5) and can be generalized as:

$$t_t - t_1 = \left[\sqrt{(x_t - x_s)^2 + (y_t - y_s)^2} \; - \; \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2} \right] / v \quad (6)$$

where t_t is the time of arrival for the other sensors.

III. FIELD TESTING

A field test was conducted on 14 units of transformer suspected experiencing partial discharge activity. These transformers have been selected based on its hydrogen and methane level, which are more than 100 ppm and 50 ppm respectively [4]. The equipment and the software layout for the acoustic PD testing are shown in Figure 5 and Figure 6 respectively.

The location of the sensors should be similar with the layout. After the sensors has been attach to the transformer tank, automatic sensor test (AST) was performed. This is to check the operation of the sensors and the cabling connections to the sensors. The test was run for 24 hours so that it can capture the whole day loading cycle of the transformer. At the same time, oil sample was taken to capture the condition of the oil during testing. After the testing completed, AST was performed to check the condition of the sensors. A threshold of 45dB was used for the acoustic testing.

Figure 5: The Acoustic PD equipment and sensors

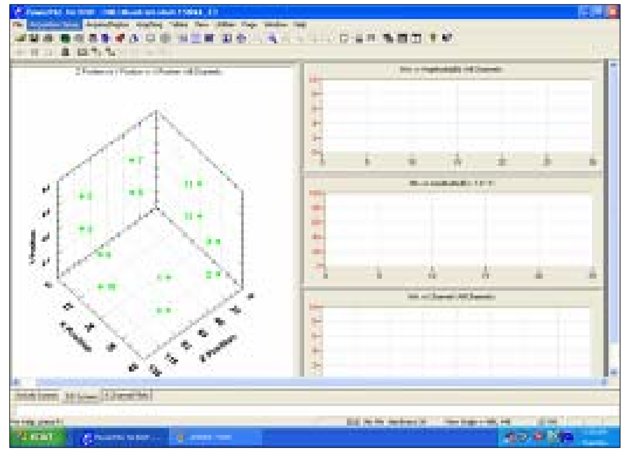

Figure 6: Software layout [6]

IV. RESULTS AND DISCUSSION

The acoustic partial discharge test was done on 14 units of transformer for 24hrs. Oil samples were taken and sent to the lab. The DGA interpretation was done by using Roger Ratio, IEC Ratio, IEEE ratio, Duval Triangle, Key Gas Analysis and Doernenburg ratio. In addition, the transformers were untanked to perform the inspection internally. Table I summarizes the oil test results and the untanking findings.

TABLE I: DGA INTERPRETATION AND UNTANKING FINDINGS.

Tx	Oil DGA Interpretation	Untanking Findings
T1	Overheating and Partial Discharge	Loose Connection at On Load Tap Changer (OLTC) termination
T2	Partial Discharge	Sharp Edge at OLTC termination
T3	Partial Discharge and Arcing	OLTC moving contact tracking
T4	Partial Discharge and Arcing	OLTC moving contact tracking
T5	Overheating	Burned Insulation
T6	Partial Discharge	Wrong Cable lug sizing at OLTC termination
T7	Partial Discharge	Wrong Cable lug sizing at OLTC termination
T8	Partial Discharge	High Moisture and Insulation Burning
T9	Partial Discharge	High Moisture and Insulation Burning
T10	Partial Discharge	Wrong Cable lug sizing at OLTC termination
T11	Partial Discharge	Wrong Cable lug sizing at OLTC termination
T12	Overheating	Burned Insulation
T13	Partial Discharge	Sharp Edge at OLTC termination
T14	Partial Discharge	Sharp Edge at OLTC termination

T1 faced some problem with its OLTC termination. The OLTC termination was loose thus created some discharge and hotspot (Figure 7).

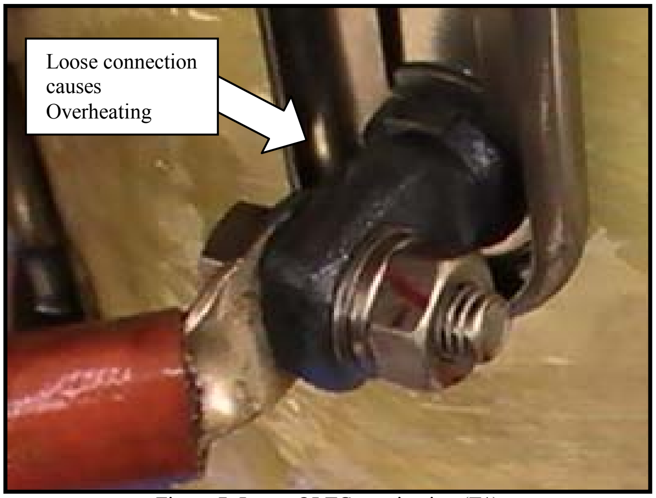

Figure 7: Loose OLTC termination (T1)

For the transformer T2, T13 and T14, partial discharge was detected due to sharp edges at the OLTC termination (Figure 8). This type of partial discharge is called corona and will give rise to the hydrogen and methane content in the insulating oil. However, no secondary damage was detected due to this cause.

For the transformer T3 and T4, some electrical discharge signals were picked-up by the acoustic partial discharge equipment from On-Load Tap Changer (OLTC) tank. The OLTC compartments were opened and some tracking observed at the moving contact. The tracking is due to the contaminated OLTC oil which becomes conductive (Figure 9).

For the transformers T6, T7, T10 and T11, some discharges were observed and distributed around the OLTC compartment. The untanking findings revealed that the discharges are due to wrong cable lug sizes used at the termination. The wrongly sized cable lugs created air gap at the termination (Figure 10).

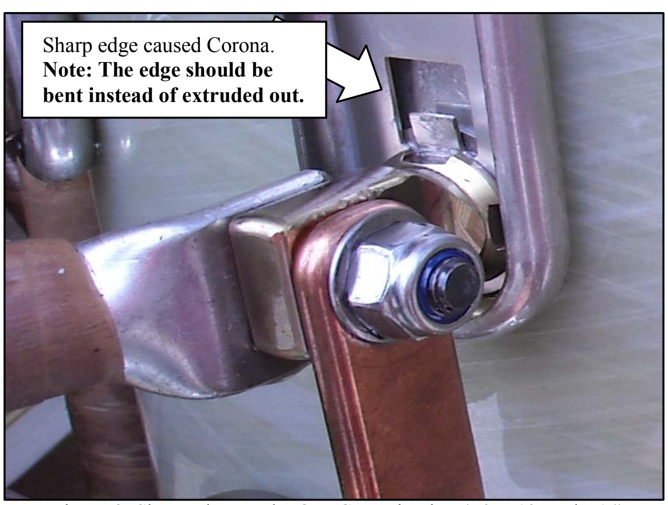

Figure 8: Sharp edges at the OLTC termination (T2, T13, and T14)

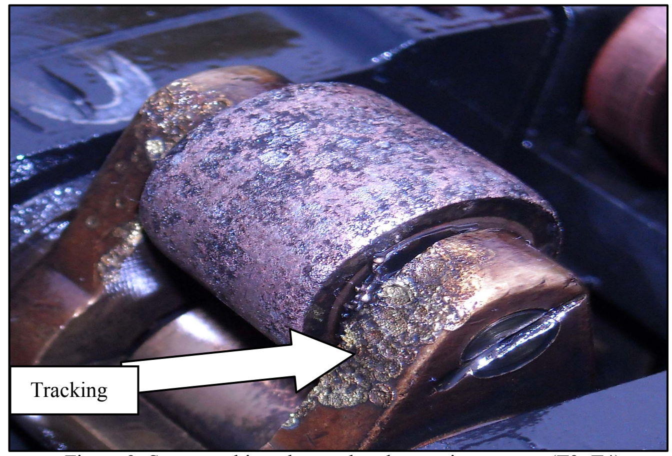

Figure 9: Some tracking observed at the moving contact (T3, T4)

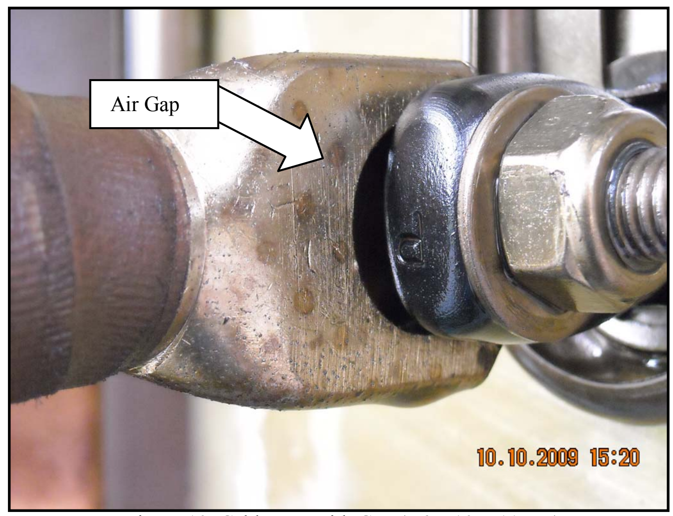

Figure 10: Cable Lug with Gap (T6, T10, T11, T7)

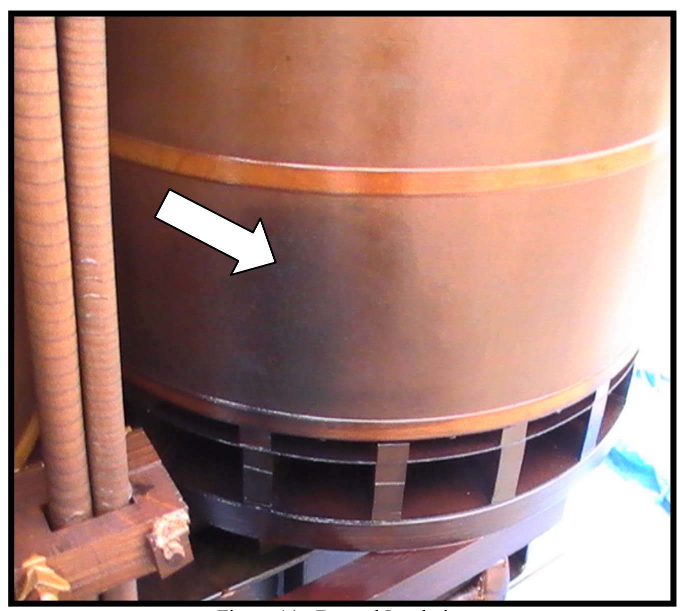
Figure 11 : Burned Insulation

The remaining transformers (T5,T8,T9,T12) had experienced overheating due to PD and some insulation burnings were detected. These transformers have been proposed to be repaired in the factory (Figure 11 and Figure 12).

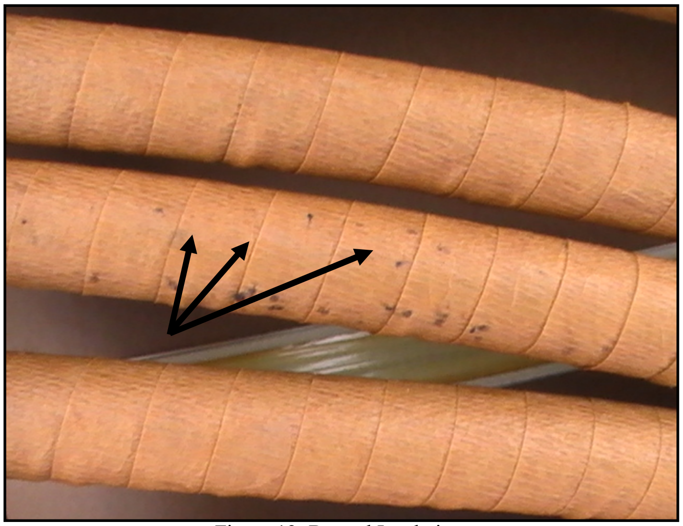

Figure 12: Burned Insulation

From the untanking and internal inspection, it has been observed that most of the PD activities in the transformers are due to the manufacturing defect. The defects shown in Figure 7, Figure 8 and Figure 10 can be avoided during the manufacturing process. These kinds of defects will give a false alarm on the occurrence of PD in the transformer. Furthermore, the PD activity due to the latter can degrade the oil thus will reduce the insulation integrity of the transformer.

V. CONCLUSION

Based on the internal inspection done on 14 transformers, it has been found that most incipient faults can be prevented during the manufacturing process. Typical defect observed during the untanking were sharp edges, loose contacts and wrong cable lug sizing. These kinds of defects will give a false alarm on the occurrence of PD in the transformer. On the other hand, the lack of OLTC maintenance caused internal tracking due to degraded insulating oil.

The acoustic partial discharge technique proves to be a useful tool in confirming the presence of partial discharges in the power transformer. This is supported with the detection of incipient faults which have been validated through physical inspection. The input from the acoustic partial discharge measurement served as additional information in diagnosing the transformer incipient faults.

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