COMPARISON BETWEEN PARTIAL DISCHARGE IN PAPER AND IMPREGNATED PAPER INSULATORS USED IN POWER TRANSFORMER WINDING BASED ON ULTRA-HIGH FREQUENCY (UHF) DETECTION METHOD

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Introduction

The main function of a power system is to supply electrical energy to its customers with an acceptable degree of reliability and quality. Among many other things, the reliability of a power system depends on trouble free transformer operation [1]. Partial discharges (PD) are one of the main causes of deterioration of insulating material in power transformer windings. Many researches already had been done to find PD mechanism, the PD detection techniques, the relationship between PD and the damage they cause to insulating materials and insulating system, the location of PD sources and the problems related to avoid external interference. Power transformer failure analysis shows that insulation failures are the main leading cause of power transformers failures [2] and it is widely accepted that the presence of partial discharge (PD) may start cracks on insulation, which leads to failure of power transformer [3]. PD and its effect on the insulation have been widely and deeply investigated for decades. It is now commonly believed that PD can induce degradation of the insulation materials due to thermal aging, chemical degradation, and physical attack by high-energy particles, and so on. As a result tree growth is initiated and eventually leads to breakdown of the insulation [4].

Main causes of occurrence of partial discharge (PD) in power transformers are shown in Figure 1.1. Figure 1.1 shows that causes of occurrence of PD in power transformer due to 1) internal discharge, internal discharge occurs due to voids or bubbles or cavities (spherical, gas filled etc) remain inside the winding insulation of power transformer, 2) surface discharge, mostly surface discharge occurs in bushing or any point on insulator surface between electrode, 3) corona discharge, corona discharge occurs because of non-uniformity of electric field on sharp edges of conductors, 4) Electrical trees, electrical trees occur due to over-stressing or overloading on power transformer [5].

Paper And Impregnated Paper Insulating Materials

Usually in power transformer winding, paper and epoxy resin materials are used as an insulation to save the power transformer from short circuit or used to separate two conductors. Paper and epoxy resin materials are frequently used as insulation because they have good non-conducting properties.

Paper Insulation

Paper is one of the first insulation material used in high voltage technology [6]. Since winding techniques are common in the cable industry, paper is used in power transformer winding and high capacity cables. It was adopted in the initial studies and investigated with special emphasis for low temperature applications. The thermal contraction of paper is
low enough such that it is near to the metals and it has elastic elongation at low temperatures without leading to mechanical problems. Moreover, paper is very cheap compared to plastic tapes. Recently, other materials have been used in prototypes specifically for large scale high temperature superconductivity (HTS) applications such as transformers and etc. However, paper can still be used in HTS transformers [7].

Impregnated Paper

Impregnated paper is one of the earliest forms of composite dielectric used in high voltage engineering since the end of nineteenth century. Paper has a very poor dielectric properties, but when impregnated with oil or an impregnated compound the properties of the composite dielectric considerably improved[8]. It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or naphthenic material. This type of insulation has almost superseded the rubber. The oil-impregnated paper is wrapped around the epoxy bounded strands. In general, this kind of epoxy-paper insulation exhibits excellent dielectric and mechanical properties, coupled with a flexible manufacturing process [9].

CST MWS Simulation

Study on the effects of paper and impregnated paper materials in power transformer winding is shown in Figure 3.1 by simulating a simplified model of a power transformer using Computer Simulation Tool Microwave Studio (CST MWS) software. On the other hand, Figure 3.2 showing the connection of antennas in power transformer winding.

Figure 3.1: Simulation of power transformer Winding using paper insulation

Figure 3.2: Connection of antennas in power transformer winding

The descriptions of the figures, the simulated high voltage winding consists of 50 helical circular turns, each turn has 3mm thickness and there are 5mm gap between the helical circular turns on the paper and impregnated paper insulating material. Two short dipole antennas with Gaussian excitation current signal in the UHF frequency range (0.3 to 3GHz) is been used to create the PD source. At the surface of the power transformer tank, probes to monitor electric fields in various positions were considered in the analysis (Gockenbach, E. and Miralikhani, K., 2013). Coordinates of short dipole antenna and probes in power transformer winding are shown in Table 3.1.

Table 3.1: Coordinates of the potential Partial Discharge (PD) locations

<table>
<thead>
<tr>
<th>Potential PD site for dipole antenna(1)</th>
<th>From (mm)</th>
<th>To (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along X-axis</td>
<td>57</td>
<td>60</td>
</tr>
<tr>
<td>Along Y-axis</td>
<td>80</td>
<td>82</td>
</tr>
<tr>
<td>Along Z-axis</td>
<td>-70</td>
<td>-75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential PD site for dipole antenna(2)</th>
<th>From (mm)</th>
<th>To (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along X-axis</td>
<td>-90</td>
<td>-93</td>
</tr>
<tr>
<td>Along Y-axis</td>
<td>-65</td>
<td>-68</td>
</tr>
<tr>
<td>Along Z-axis</td>
<td>-65</td>
<td>-68</td>
</tr>
</tbody>
</table>

Coordinates of the Antenna Positions

<table>
<thead>
<tr>
<th>Probe Index</th>
<th>x, y, z Probe coordinates (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe #1</td>
<td>(0, -150, -110)</td>
</tr>
<tr>
<td>Probe #2</td>
<td>(120, 120, -60)</td>
</tr>
</tbody>
</table>

Results

According to the above table, a short dipole antenna with UHF Gaussian excitation is placed in a supposed PD location. Then, the electromagnetic (EM) wave propagation from the paper insulation of winding is simulated and recorded at two probes positions, which are placed at the positions of the detecting antennas. Typical locations of antenna are listed in Table 3.1. The electric field signals recorded by the probes for supposed PD locations at \((x, y, z)\) coordinates \((0, -150, -110)\) mm.
Paper insulation

Following figures show the CST MWS simulated results of paper insulation, which are taken by two probes (1&2) and dipole antenna (PD source)-1&2 having coordinates which is shown in Table 3.1. Coordinates are plotted in the graph, whereby x-axis indicates the time and y-axis indicates the electric field. Figure 4.1 shows the CST MWS simulated results of PD source-1 and probe-1 that indicates that partial discharge will start about 2ns and will reach up to maximum at 2.58ns. Figure 4.2 shows CST MWS simulated result of PD source-2 and probe-1 which identifies the partial discharge will start about 1.3ns and will reach up to maximum at 1.94ns. Result in Figure 4.3 and Figure 4.4 shows the CST MWS simulated results of PD source-2 and probes-1 and probe-2, which identifies that PD will start about 1ns and 2ns and will reach up to maximum at 1.64ns and 2.90ns respectively.

Figure 4.1: Simulated result of Probe 1 & PD source 1
Figure 4.2: Simulated result of Probe1 & PD source 2
Figure 4.3: Simulated result of Probe 2 & PD source 1
Figure 4.4: Simulated result of Probe2 & PD source 2

Impregnated Paper

Following figures show the CST MWS simulated results of impregnated paper insulation, which are taken by two probes (1&2) and dipole antenna (PD source)-1&2 having coordinates which is shown in Table 3.1. Coordinates are plotted in the graph, whereby x-axis indicates the time and y-axis indicates the electric field. Figure 4.5 shows the CST MWS simulated results of PD source-1 and probe-1 that indicates that partial discharge will start about 2ns and will reach up to maximum at 2.80ns. Figure 4.6 shows CST MWS simulated result of PD source-2 and probe-1 which identifies the partial discharge will start about 1.4ns and will reach up to maximum at 3.98ns. Result in Figure 4.7 and Figure 4.8 shows the CST MWS simulated results of PD source-2 and probes-1 and probe-2, which identifies that PD will start about 1ns and 2ns and will reach up to maximum at 1.66ns and 3.07ns respectively.

Figure 4.5: Simulated result of Probe 1 & PD source 1
Figure 4.6: Simulated result of Probe1 & PD source 2
Figure 4.7: Simulated result of Probe 2 & PD source-1
Figure 4.8: Simulated result of Probe2 & PD source 2
Discussion And Conclusion

Based on the result obtain during simulation analysis, it is found that the impregnated paper insulating material have more sustainability and high strength to withstand the electrical stresses compare to paper because on impregnating the paper with oil or epoxy compound, the voids in the paper, which earlier filled with air or moisture get filled up with impregnating agent. It changes the values of relative permittivity. The main disadvantage of paper insulation is that it absorbs moisture. Due to moisture dielectric strength of paper reduced hence it lowers the resistance and will be the cause of PD in power transformer. After the analysis of CST MWS simulated results, it is found that the time taken by PD source to reach its maximum value is more in impregnated paper than paper insulation. So it is concluded that the impregnated has excellent electrical properties than paper. Therefore impregnated paper insulating materials are mostly recommended to use in power transformer.

Based on the simulation result, it is found that the electromagnetic waves can easily penetrate the insulating materials in the power transformer. Impregnated paper insulations are commonly used in the power transformer because it has low cost, low capacitance high dielectric strength and high insulation resistance. The dielectric strength only weakens after longer period of time compare to the paper insulation. Strength of the impregnated paper will only weaken after a longer period of time which makes it to be the best insulating material. Impregnated paper has a high dielectric strength to withstand the stresses that is why impregnated paper insulation is used in power transformers to reduce the maintenance cost and give longer life to power transformers

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