3-D PROPAGATION OF PARTIAL DISCHARGE ACOUSTIC WAVE

SYED AQEEL ASHRAF [1], BRAIN G. STEWART[2], AFAQ AHMAD[3] AND J. MOHD JAHABAR[1]

[1]Faculty of Electrical Engineering, Salalah College of Technology, Salalah-211, OMAN
[2]School of Engineering, Science and Design, Glasgow Caledonian University, Glasgow, UK
[3]Department of Electrical and Computer Engineering, Sultan Qaboos University, Muscat, OMAN

Abstract – In this paper, the authors present a three dimensional numerical simulation of Partial discharge (PD) Acoustic Emission (AE) wave propagation in a model transformer. The paper helps to investigate the propagation behaviour of the AE waves at two different media with different environmental conditions. Propagation of PD Acoustic wave and its reflection, refraction and scattering are simulated and displayed. The Partial Differential Equations (PDEs) describing the signals have been solved using Finite Element Analysis (FEA). The FEA Method was used to study the characteristic of PD AE wave. This study is useful in order to develop better understanding of propagation behaviour of the PD AE waves in any of the high voltage equipment.

Key words -- Acoustic emission, Finite Element Analysis, Partial Discharges, Partial differential equations.

I. INTRODUCTION

Partial discharges (PDs) activity within high voltage power transformers can results in serious insulation damage. Understanding PD and its causes can help diagnose problems and predict the expected lifetime of a dielectric and therefore the HV equipment.[1] For insulation used in high temperature power equipment applications such as cables, transformers, and fault current limiters, PD is thought to be the primary degradation mechanism of the electrical insulation. Depending on the intensity, PDs are often accompanied by emissions of light, heat, sound and radio signals.

Recently many experiments have demonstrated AE signals as caution indicators before any catastrophic failure occurs as a consequence of PD activity [2]-[4]. But theoretical aspects of propagation modes related to AE phenomena is still largely unexplored. Therefore, we have developed mathematical simulation model of AE wave.

Acoustic techniques are relatively cheap, non invasive, simple to apply, utilized on line, immune to electromagnetic noise and can detect the presence and location of discharges in the various items of Power plant

II. PROBLEM FORMULATION

A PD activity can be assumed as a "explosion" which leads to the emission of ultrasonic pressure waves, which can be considered as shock waves having a spherical wave front. These signals travel towards sensors through various propagation materials. At boundary surfaces of different media, reflection, refraction, deflection and attenuation occur according to the acoustic impedances of the materials.

The standard Partial Differential Equation (PDE) that governs the propagation of an acoustic wave within isotropic media is given by:

$$\partial^2 P \Big/ \partial t^2 = C^2 \nabla^2 P \qquad \text{------- (1)}$$

In equation (1), P is the pressure wave field *(Pa)*, t is the time *(s)* and C is the acoustic wave velocity (ms^{-1}). This equation is a combination of three basic equations, which describe continuity, conservation of momentum, and elasticity of the medium.

The velocity, C can be determined from the density and elastic properties of the material, i.e. from the young modulus *(E)*; density of the medium (ρ); the Poisson ratio (μ); in solids and the bulk modulus *(K)*, density of the medium (ρ) and the Viscosity (η) in liquids. [5].

The above PDE can be solved and simulated using Finite Element Methods (FEM).

In numerical analysis Finte Element Method (FEM) is used for solving PDEs approximately. Solutions are approximated by either eliminating the differential equation completely (as steady state problems), or rendering the PDEs into equivalent Ordinary Differential Equations, which are then solved using standard techniques such as finite differences, etc. The use of FEM in engineering for the analysis of physical systems is commonly known as Finite Element Analysis (FEA).

In this contribution of work the FEA tool, FEMLAB has been used to solve the PDE equations (1). This software is a powerful, interactive environment for modelling and solving scientific and engineering problems based on PDEs.

III. SIMULATION RESULTS AND DISCUSSIONS

The simulation is based on two 3-D regions R_1 and R_2 of a simple propagation geometry resembling a simple HV environment with a point source PD. The main objective is to demonstrate at a very simple level the propagation characteristics of the AE in one direction within oil and also within a boundary of steel. R_1 is considered as an oil filled steel tank of size 40cm by 20cm with the thickness of the steel wall presumed to be 1cm, R_2 is assumed to be a transformer of the size 15cm by 5cm.

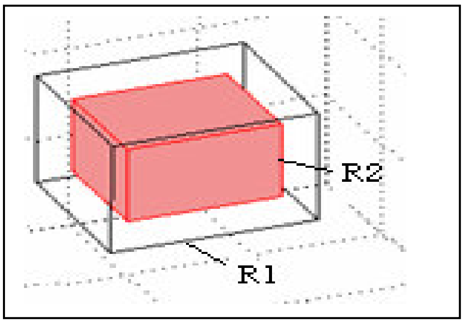

Fig.1 Investigative 3Dgeometry with regions R_1 and R_2

There are no internal obstacles considered in this simulation as this is an investigation to illustrate the propagation of simple AE within this environment. The PD can be considered as a point source and therefore the "pulse" has a spherical wave front which will be attenuated and reflected according to the acoustic impedances of the oil and steel through which it travels. It is also assumed that the pressure formula for the "explosion" of the PD moves with a spherical front is second order PDE equation (1) [6].

The **oil region** is modelled as Class-I type transformer mineral oil according to the IEC60296 Standard. The temperature is presumed to be 20^0C with a corresponding density of 965 kgm^{-3} and viscosity 15.0 cSt.

The **steel region** is modelled as AISI 4340 steel with a Young's modulus E of $205x10^9$, density ρ of 7850 kgm^{-3} and a Poisson's ratio μ of 0.28. The initial values should match the boundary conditions to keep the solution well behaved throughout the simulation.

To model the 3-Dimensional environments R_1 and R_2 in the FEM, these regions have been divided into different meshes.

It consists of 435 nodes and 674 elements and takes around 55 seconds to solve the wave equations. Clearly, the greater number of mesh nodes and elements then better the results.

The PD is modelled as a point source with mathematical form at the centre point of region R_2. The variation of the pressure of the PD wave, the reflection, refraction and scattering of the shock wave can therefore be modelled and evaluated over time, providing a clear picture of the behaviour and characteristic nature of the waves at any point in the oil or steel and at any time after the PD has occurred. The results are shown in Fig. 2, 3, and 4.

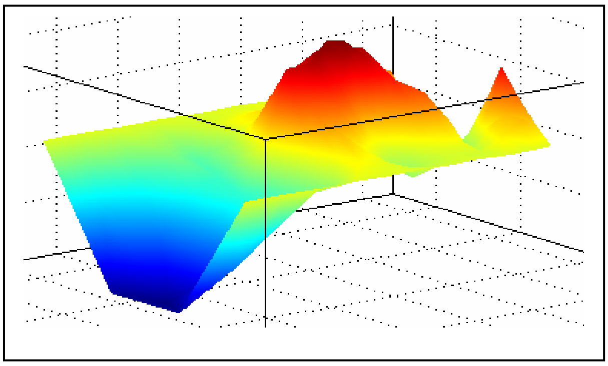

Fig. 2. Propagation of Wave in oil and steel

In Fig. 2 the acoustic shock wave is propagating in oil as described by the red colour. In this diagram the shades of blue colour tell us that the wave is propagating towards steel boundary with low pressure.

The colour change is due to attenuation of the wave in the steel which results as expected in a reduction of the propagated energy.

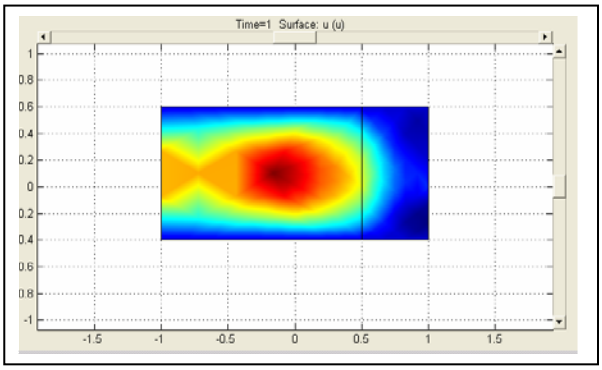

Fig. 3. Propagation of wave in 2-D regions R_1 and R_2

Fig. 3 shows the propagation of acoustic waves in two dimensional environments. Point source can be seen in the middle with black colour. Shock wave is propagating in oil as described by the red colour. Wave front is moving towards steel boundaries which can be seen with red yellow and light green colour. The wave also hits the steel tank wall R_2. Reflection and refraction can be seen with yellow and light green colours respectively.

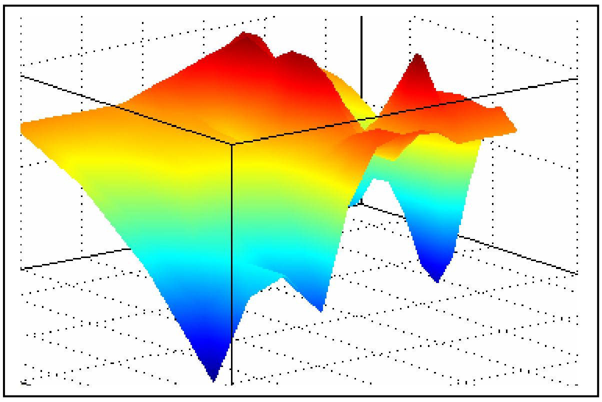

Fig.4. Variation of pressure of PD AE wave

Fig. 4, shows the variation of pressure of acoustic waves when the density and viscosity of the oil has been reduced and multiple PDs are occuring. Peaks of AE wave pressure can be seen with red colours. Larger wave fronts are due to reduced density and viscosity of the oil. As this scenario exists the difference in propagation characteristics is important to understand.

IV. CONCLUSIONS

We have presented a mathematical model for PD acoustic wave in the form of Partial differential Equations. The FEMLAB, a FEA tool, is used to simulate the propagation of the acoustic wave through the oil and steel. Animation results give a clear picture of propagation, attenuation, reflection and refraction of the wave. Future work will involve simulating with more complicated 3-D geometries in order to understand better the propagation of acoustic wave through a real transformer core.

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