

ANALYSIS OF PARTIAL DISCHARGE SIGNAL BY FDTD TECHNIQUE

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Abstract - Partial Discharge (PD) is one of the main causes for eventual equipment failure and it occurs where the electric field exceeds the local dielectric strength of the insulation. The Finite Difference Time Domain (FDTD) technique, which is a widely used electromagnetic computational method, has been used to model propagation of PD discharges generated in the form of a Gaussian pulse. The wave propagation in free space in the two dimensions and in three dimensions is realized and presented in this work. The Perfectly Matched Layer (PML) which is a flexible and efficient Absorbing Boundary Condition (ABC) has been incorporated in the simulations. Further work is carried out by considering obstacles in path of electromagnetic wave for the analysis of propagated PD waves.

Keywords - *Electrical Insulation, Partial Discharge, Electromagnetic Wave, FDTD, UHF, PML*

I. INTRODUCTION

Partial discharge is a High Voltage (HV) Phenomenon [1]. According to IEC 60270, “Partial Discharge is a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor”. PD is caused due to existence of void or cavity in insulation and insulating materials gradually degrades due to cumulative effect of electrical, chemical and thermal stress [2,5]. These continuous PD activities may result in breakdown of insulating materials which lead the whole equipment towards failure.

The method of detection of PD may be electrical, chemical, acoustic, UHF (Ultra High Frequency) or a combination of these methods. Among these acoustic and UHF is widely used because of its accuracy and wide range of detection. These methods employ EM (Electro Magnetic) sensors to detect the radiation emitted from PD activity and it has been shown to provide valuable information on the condition of insulators [3]. To analyze electromagnetic wave FDTD technique is used which allows an accurate investigation of EM fields in dielectric medium [4]. The Gaussian pulse model for PD has been used for simulating the EM radiation that propagates in insulating medium.

In this work, FDTD is used to study the EM radiation emitted from a PD source. The PD event was approximated by a Gaussian pulse. The radiation spectrum of the Gaussian source located within an insulating material is investigated. The impact of the dielectric material and the obstacles parameters on the radiation pattern and the power density is presented. The propagation of EM waves from obstacles within insulating materials is assessed. The aim of this work is to improve the assessment of remaining service life of HV insulators based on their fault level reflected in the radiation pattern.

II. FDTD FORMULATION

A. Finite Difference Time Domain Technique

In 1966 Yee proposed a technique to solve Maxwell's curl equations using FDTD technique [6]. The FDTD formulation is a convenient method for solving electromagnetic field problems. This method is widely applied to the field of electromagnetic computation, can be used to simulate the electric and magnetic fields within defined simulation space and specified boundary condition.

The equations are solved in a leapfrog manner means the electric field is computed for a given instant in time and the magnetic field is obtained for the next instant in time, and the process is repeated over and over again [7]. The FDTD technique is based on approximations which permit replacing differential equations by finite difference equations through which one can analyze pattern of electromagnetic PD pulse.

B. Yee's FDTD Technique

There are number of finite-difference schemes for Maxwell's equations, but the Yee's scheme persists as is very robust and versatile. In Yee's scheme, the model is first divided into many small cubes. For simplicity the cubes are assumed to be of same size. The region being modeled is represented by two interleaved grids of discrete points [7]. One grid contains the point at which the magnetic field is evaluated. The basic element of the FDTD space lattice is shown in Figure 1. Yee positions the components of 'E' and 'H' fields about a unit cell of the lattice. 'E' and 'H' fields are evaluated at alternate half time steps, such that all field components get calculated in each time step Δt and both electrical and magnetic field surrounding each other.

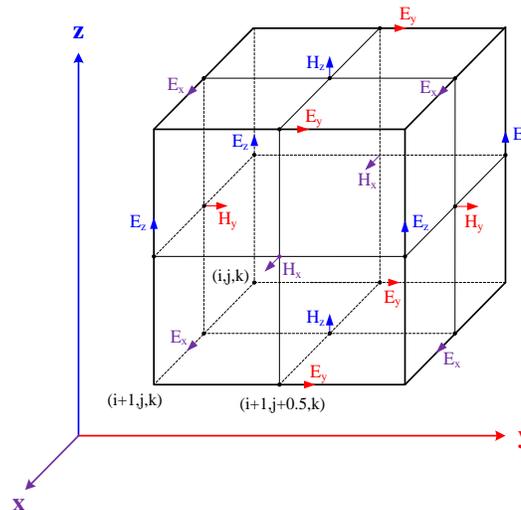


Figure 1 Yee's Cell

III. SIMULATION IN 1D AND 2D

A. Simulation in One Dimension

Maxwell curls equation for an isentropic medium can be written as:

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H} - \vec{J} \quad (1)$$

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E} \quad (2)$$

In one dimension space, electromagnetic wave is made up of E_x and H_y through time dependent Maxwell curl equation which becomes scalar equation as follow:

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\epsilon_0} \frac{\partial H_y}{\partial z} \quad (3)$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu_0} \frac{\partial E_x}{\partial z} \quad (4)$$

Here electric field is oriented in x direction and magnetic field is oriented in y direction and both traveling in z direction. Taking central difference approximation for time and space and then modified the obtained equation by given term:

$$\bar{E} = \sqrt{\frac{\epsilon_0}{\mu_0}} (E) \quad (5)$$

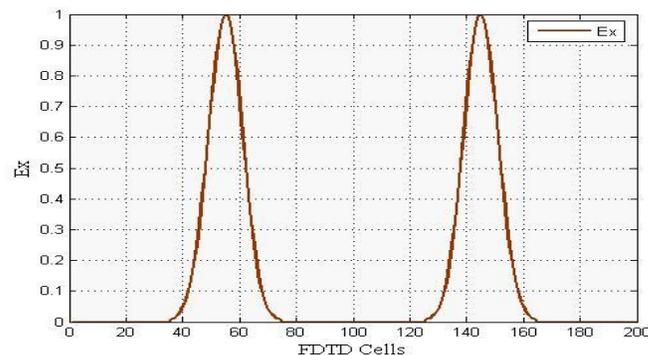
For the electromagnetic wave to propagate a distance of one cell, it requires minimum time of $\Delta t = \frac{\Delta x}{c}$. Where ' Δx ' is the cell size and ' c ' is the velocity of wave in the medium. In free space the wave travels with velocity of light.

$$\bar{E}_x^{n+\frac{1}{2}}(k) = \bar{E}_x^{n-\frac{1}{2}}(k) - \frac{\Delta t}{\sqrt{\epsilon_0 \mu_0} \cdot \Delta x} \left[H_y^n(k + \frac{1}{2}) - H_y^n(k - \frac{1}{2}) \right] \quad (6)$$

$$H_y^{n+1}(k + \frac{1}{2}) = H_y^n(k + \frac{1}{2}) - \frac{\Delta t}{\sqrt{\epsilon_0 \mu_0} \cdot \Delta x} \left[E_x^{n+\frac{1}{2}}(k+1) - E_x^{n+\frac{1}{2}}(k) \right] \quad (7)$$

Finally we can obtain above equation of E and H field which have been criticized and implemented in program using MATLAB. Initial conditions used for simulation are given below,

- Problem space dimension: 200 cells
- Source: Gaussian pulse



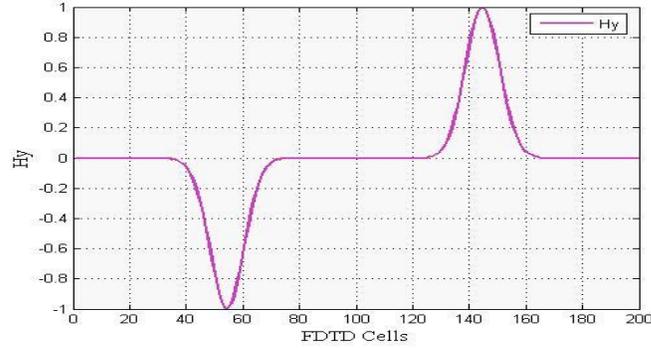


Figure 2 E_x and H_y field after 130 time steps in 1D

B. Simulation in Two Dimension

In two-dimensional simulations, we choose Transverse Magnetic (TM) mode which is composed of E_z , H_x , and H_y [7].

$$\frac{\partial D_z}{\partial t} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \right] \quad (8)$$

$$\frac{\partial H_x}{\partial t} = -\frac{1}{\sqrt{\epsilon_0 \mu_0}} \frac{\partial E_z}{\partial y} \quad (9)$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\sqrt{\epsilon_0 \mu_0}} \frac{\partial E_z}{\partial x} \quad (10)$$

Same as in 1D simulation central difference approximation for time and space is taken and then modified the obtained equation by μ and ϵ .

$$H_x^{n+1} \left(i, j + \frac{1}{2} \right) = H_x^n \left(i, j + \frac{1}{2} \right) - 0.5 \left[E_x^{n+\frac{1}{2}}(i, j+1) - E_x^{n+\frac{1}{2}}(i, j) \right] \quad (11)$$

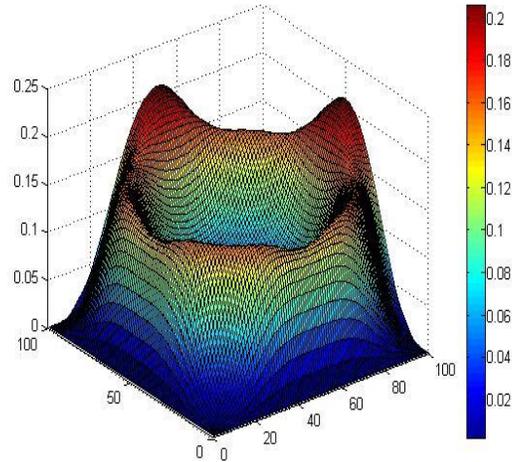
$$H_y^{n+1} \left(i + \frac{1}{2}, j \right) = H_y^n \left(i + \frac{1}{2}, j \right) - 0.5 \left[E_z^{n+\frac{1}{2}}(i+1, j) - E_z^{n+\frac{1}{2}}(i, j) \right] \quad (12)$$

The final equation obtained of E and H field are shown in Equation (11) and (12) which are criticized and implemented in MATLAB program.

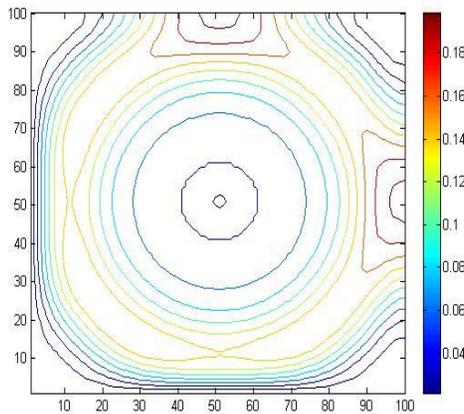
Initial conditions used for simulation are given below,

- Problem space dimension: 100×100 cells
- Cell size: 0.01 meter

- Source: Gaussian pulse
- $\epsilon_0 : 8.8 \times 10^{-12}$ farad/mete



(a) Ez Field



(b) Contour of Ez Field

Figure 3 Field Plot after 130 time steps without PML in 2D

Here from Figure 3, it is observed that the pulse reached at the boundary and reflected. The contour graph is neither concentric nor symmetric about the center because wave is reflected from the boundary of problem space which can be addressed by implementation of Absorbing Boundary Conditions (ABCs).

C. Simulation in Two Dimension with PML

Absorbing boundary conditions are needed to keep outgoing electric field ‘ E ’ and magnetic field ‘ H ’ from being reflected back into the problem space. The basic requirement of FDTD technique is that while calculating ‘ E ’ field, one need to know the surrounding ‘ H ’ field. As the wave propagates outward, it will finally come to the edge of the problem space [7]. The use of a Perfectly Matched Layer (PML) as absorbing boundary condition helps to avoid the problem of reflections from the boundary in this work.

When wave is propagated in one medium strikes the boundary of another medium, reflection is generated. The reflection coefficient depends on the intrinsic impedance of the media and is given by the following equation.

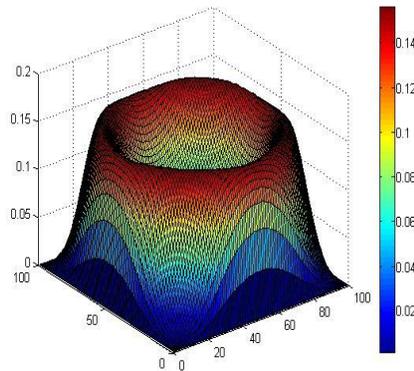
$$\Gamma = \frac{\eta_A - \eta_B}{\eta_A + \eta_B}$$

Where η_a = intrinsic impedance of medium A

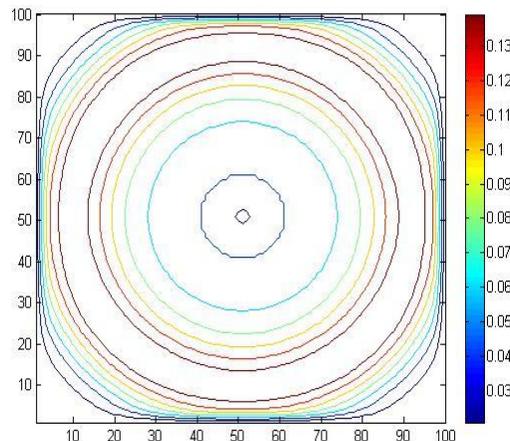
$$\eta_b = \text{intrinsic impedance of medium B} \quad \eta = \sqrt{\frac{\mu}{\epsilon}}$$

A medium that is lossy so the pulse will die out before it hits the boundary. This is accomplished by making both μ and ϵ equation complex.

So, MATLAB program is implemented with PML to avoid reflection in problem space as shown in Figure 4. In MATLAB program 5 PML layers are used to avoid reflection.



(a) *Ez Field*



(b) *Contour of Ez Field*

Figure 4 Field Plot after 130 time steps with PML in 2D

Comparison of Figure 3 and Figure 4 shows how the reflections get eliminated with the use of PML. The outgoing contour in Figure 4(b) is circular and only when the wave gets within 5 points PML of the problem space.

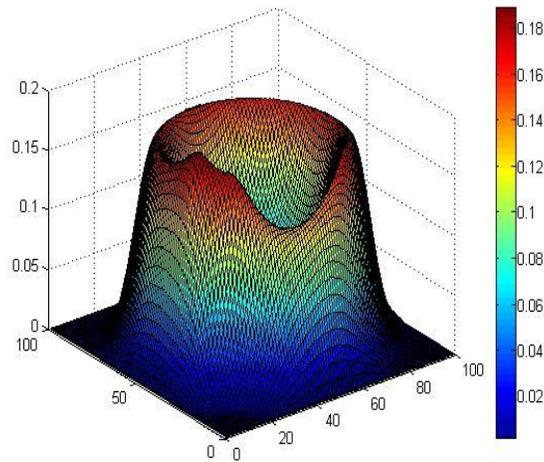
IV. SIMULATION IN 2D WITH OBSTACLES

To simulate the simple Gaussian pulse wave (PD Source) interacting with an object or obstacles, one have to specified the object according to its electromagnetic properties, the dielectric constant and the conductivity. For instance, here we simulating the Gaussian wave striking with a dielectric material with hard surface which do not allow any electromagnetic wave to pass from it.

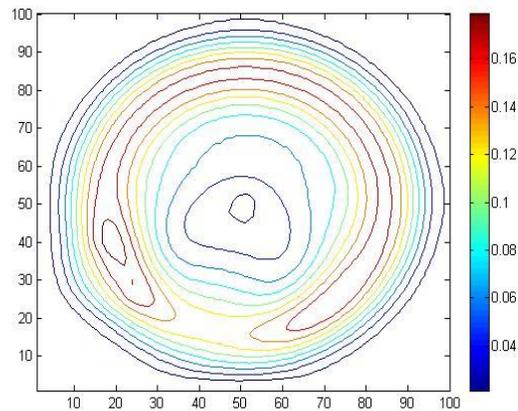
Here, the problem space is first initialized as a free space. Form Figure 5 we can observe that when electromagnetic wave is interacting with impurity than it can't pass through it and reflected back so the sensor mounted on the surface of problem space can't get proper PD signal.

Initial conditions used for simulation are same as 2D simulation and obstacles parameters as below,

- Impurity Type: Circular
- $\epsilon_r = 2.2$



(a) Ez Field



(b) Contour of Ez Field

Figure 5 Field Plot after 130 time steps with Geometry in 2D

V. CONCLUSION

The FDTD technique is used to simulate propagation of PD signals modeled as Gaussian pulse. FDTD implemented in MATLAB program for 1D, 2D to study wave propagation characteristic in free space. To resolve the reflection problem in 2D, Perfectly Matched Layer (PML) condition has been implemented to avoid the reflection of wave. Moreover, the obstacles are added in free problem space to analyze effect of obstacles in PD wave propagation in 2D.

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