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Electric Field Analysis of High Voltage Insulators

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Abstract – This paper involves designing and applying electric field analysis on multiple long rod insulators. Quality HV insulators are an integral part of power systems because they separate the Transmission lines carrying high voltages from the grounded poles. They must have the ability to withstand both high electrical and mechanical stress. So for this purpose modeling of long rod insulator was done with multiple materials such as ceramic, porcelain, and fiber glass and silicon rubber. Electric field analysis can be used to determine voltage profile of each material which in turn can be used to determine how much electrical stress the material can undertake.

An attempt was made to model existing long rod insulator designs using software like Solidworks. Subsequently modifications were made to the design by changing parameters such as diameter of the insulator body, angle made by insulator cups etc. These models were then subjected to electric field analysis using finite element analysis software such as Elecnet or Comsol Multiphysics in order to identify the points where maximum electric field stress exists. Further modifications were made on order to reduce and equalize the electric field over the insulator surface.

Keywords - Voltage Profile, Insulator, Stress, Design.

FINITE ELEMENT METHOD:

- Finite Element Analysis (FEA) is a mathematical method used to solve various problems such as stress analysis, electric fields, magnetic fields etc.
- It is a fundamental tool for design engineers
- In FEA the object is divided into large number of elements composed of nodes
- The geometry of the structure is defined by coordinates if nodes and connectivity of elements.

PROCEDURE FOR FEA

- Pre-Processor: To define the geometry ,loading and boundary conditions
- Solver: System equations are constructed and solved
- Post-Processor: Graphical display of data

PROBLEM DEFINITION OF FEM ANALYSIS

- Problem Def.: To calculate Voltage for various configurations
- Dimension: 3D in XYZ plane

- Medium: Homogenous Medium
- Type of Problem: Electrostatic Problem
- Governing Equation: Laplace Equation
- Boundary Condition: Dirichlet Boundary Condition

INTRODUCTION

An insulator ideally is a substance which does not allow flow of electric charges and have no effect by electric fields. But such insulators do not exist or are not invented by man yet. So we use dielectric materials with high electrical resistance and high dielectric constants as insulators. Materials like glass, Teflon and rubber are used form electrical insulations. They do not have bulk resistivity so they cannot be used for high voltage insulation purposes.

Since we do not have ideal insulators so the materials which we use breakdown or in other words start conducting at a value higher than a given voltage. This voltage is called breakdown voltage. In words of electrical field intensity, if the field value applied to the insulator exceeds a particular threshold value at any location, the insulator may turn into partial conductor, with grave results. In such cases material can have mobile charge carriers. In air corona discharge occurs

due to breakdown of air. An electric arc is undesired electrical current. Punctures are electrical discharge in the insulators which can damage the insulators.

MATERIALS USED:

Long rod insulators are made of ceramic or porcelain having high breakdown voltage values or of composite materials.

Porcelain insulators-

Porcelain is a ceramic material made of clay heated at 1400 degree Celsius. It has density of 2.4gm/cm^3 thermal conductivity of 2.4watts/m.k tensile strength of 48 mpa and dielectric strength of 25 kv/mm

They are perfect solution where contamination is a problem. They have puncture proof body, high mechanical strength and radio and TV interference free. Their uniform voltage distribution and surface drying prevent flashover and suppress dry band arc.

Composite insulators-

They are also known as silicone rubber or polymer insulator. They are used in 100 to 500kv voltage applications especially in railway overhead lines.

The advantages of such insulators over porcelain are-

1. Excellent anti pollution performance
2. Free of cleaning and economical maintenance

Poly-propylene

Known as polypropylene, is a thermoplastic polymer is widely used in packaging labeling etc. since it has a higher melting temperature point it is used in insulation material of power cables. Stereo regular syndiotactic polypropylene (s-PP) newly developed with metallocene catalyst are usually used for such insulation. It has superior thermal and electrical properties compared to cross linked polyethylene.

Araldite-

It is a trademark of Huntsman Advanced Materials referring to a range of epoxy resins and acrylic adhesives. Recently ABB has shown that Araldite can be used for 10 to 38 kV insulators. They can be used in temperatures as low as -80°C without any cracks developing in the insulators. These insulators have a field service of 35 years

TECHNOLOGY APPLIED

COMSOL Multiphysics

It is a FEM software, solver and simulation software used for various physics and engineering simulation such as thermal field, acoustic, piezoelectric analysis. It allows coupled systems for solving PDEs. The PDEs can be entered directly or using the weak form also. It allows the user to import CAD files which can be used for simulation purposes or design the object in COMSOL. It consists of a number of modules like r.f., microfluid, heat transfer and many more.

For our use the ac/dc module is used for electric field analysis and voltage distribution analysis of various conductors. This software allows changes in materials, building initial values, modifying designs and comparative study of the insulator properties.

Methodology

The first step of the research was to collect information regarding the existing long rod insulators. Design specifications and material properties details were collected using various articles, papers and manufacturing company website. Once done, a number of insulators were designed using SolidWorks software and AutoCAD.

COMSOL 4.0 is used as the FEM software for various analyses of these insulators. First a 3D model, electrostatic physics and stationary type study is selected. Next, in geometry, AutoCAD file is imported. Once done, materials are selected for each part. The specifications of the materials can also be then the initial value of the conductor placed above the insulator is given at different voltage level. The lower surface of the insulator is then grounded. Once initial values are assigned then mesh is built using mesh building option. Once done go to result and a number of 3D plots are selected. These plots are used to show a number of simulation analysis. Once done right click and start computation. Once computation is finished analysis diagram of the insulators are shown to understand the various effects and properties of the insulators.

An insulator was designed in the COMSOL itself. For designing, the geometry is right clicked then a number of options of designing cube, prism, and cylinder are

shown. The details of the shape and the specifications were filled and build selected is clicked. Once all the parts are designed, the parts can be assembled or formed. Another method is to import some parts and build rest of the parts in comsol. Once done they can be assembled together. One model was built using such a process. Once analysis is done, further modifications can be done by changing the geometry or changing the materials of the parts. The same process is repeated for analysis. After number of modifications and analysis is done, a comparative study of the various analyses was done and the design with optimum features is selected.

Voltage Profiles:

Araldite (Insulator 2 with conductor on top)

Araldite (Insulator 1 with conductor on top)

Quartz (Insulator 1 with conductor at bottom)

Zinc Oxide (Insulator 1 with conductor at bottom)

Zinc Oxide (Insulator 2 with conductor on top)

Current Density Profile for Insulator 2:

Quartz

Electric Field Profile for Insulator 1:

Araldite (Conductor at bottom)

Inferences Drawn From Analysis:

From the analysis performed we observed stress points developed across the insulator cups for different materials and determined the voltage withstanding capability of the individual cups. It is seen that Araldite insulators have a varied voltage profile with medium to low stress extensively upon the cups. In comparison the voltage profile of quartz indicates that it has a comparatively better performance compared to araldite as an insulating material owing to its lower electrical conductivity. However there is still significant voltage appearing across the lower cups as the stress however minimal is still present. Ideally an insulator must not have any voltage across its cups i.e. each cup should have no stress whatsoever. This characteristic was found by using Zinc Oxide (ZnO) as insulator material. The voltage profile indicates that ZnO insulator does not develop any voltage across its cups thus possessing near ideal insulator behavior. The table below shows the number of cups and the individual stress each cup undergoes for application of voltage across different materials.

	Max Stress	Medium Stress	Min Stress
<u>ARALDITE</u>			
Insulator 1	0	2	2
Insulator 2	1	2	2
<u>QUARTZ</u>			
Insulator 1	0	1	3
Insulator 2	1	1	3
<u>ZnO</u>			
Insulator 1	0	0	4
Insulator 2	0	0	5

From the current density profile it can be seen that the insulators do not conduct any current whatsoever through their body. Therefore from the plot one can observe that current density through conductor is non-zero whereas current density through insulator body is zero. The Electric Field profile reveals some interesting hitherto unobserved stress points which exist at the point where the conductor joins the insulator body. From the plot it can be seen that there are some electrical stress points at the junction as indicated by the green spots on the plot.

CONCLUSION:

From the result and inference it can be said that zinc oxide used in the second design is the best insulator among all the insulators analyzed for this study. Here it has negligible or no stress at all. Thus the comparative study is useful to design long rod insulators in power transmission systems and high voltage applications.

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