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Abstract: - In this paper, Gas insulated Switchgear bus bar has been investigated using 3D coupled multi-physics finite element analysis. The coupled field analysis involved consecutive multi-physics interactions. The interaction is characterized as a two-way sequential electromagnetic-thermal field coupling. The temperature rise in the GIS bus bar is due to the Joule’s losses in the conductor and induced eddy current in the tank. The power losses in a bus bar configuration solved by magnetic field analysis are the input to the thermal analysis. The heat transfer calculation using the fluid analysis is done by considering the natural convection and the radiation from the tank to atmosphere. Consequently, temperature distributions by coupled field multi-physics have good agreement with result of temperature rise test.

Key-Words: Multi-physics, CFD, FLUENT, MAXWELL, GIS Bus bar, Coupled Analysis

1. Introduction

Long payback period, capital investment is relatively large compare to other industries, the reliability of the product is very important, and the power equipment industry is a technology intensive industry with high added value. Power equipment with the complexity and diversity of the classical method based on the experience of the existing design, there is a limit. Therefore, based on the conditions of various design variables in the design analysis and design technology development is essential.

The basis of Gas Insulated Switchgear(GIS) to supply power to the GIS bus bar is the insulation design and power design. Power design is a technology that enables them to work safely withstanding the thermal stress exerted on the GIS bus bar design. For the power design, conductor and bus bar diameter, tank diameter, tank thickness and shape variables such as the material of the tank, such as the design variables must be determined.

Dielectric limiting factor than the design variables is an even greater impact on the thermal limiting factor. Therefore, it is very important to accurately predict the temperature rise inside and outside rated current GIS bus bar.[1]

The electromagnetic thermal field analysis is required to design in many applications for electrical equipment such as reactors, induction furnaces, electrical machines and power cable having high power frequency and less size.
2. The Electromagnetic Field Analysis

2.1 Governing Equations

First, GIS bus bar is long enough in the axial direction under the assumption that in order to calculate the losses, causing in the temperature rise of the GIS bus bar. The assumption makes lead to a linear, steady-state, time harmonic electromagnetic field which is governed by Maxwell’s equation with displacement current neglected. (Quasi static Maxwell’s equation, can be expressed as equation (1) to (3))

\[ \mathbf{\nabla} \times \mathbf{H} = \mathbf{j} \]  \hspace{1cm} (1)
\[ \mathbf{\nabla} \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]  \hspace{1cm} (2)
\[ \mathbf{\nabla} \cdot \mathbf{B} = 0 \]  \hspace{1cm} (3)

Magnetic field intensity \( \mathbf{H} \) and the magnetic flux density \( \mathbf{B} \), the following equation is expressed as (4)

\[ \mathbf{H} = \frac{1}{\mu} \mathbf{B} \]  \hspace{1cm} (4)

here, \( \mu \) is permeability.

On the other hand, the induced eddy current in a conductor \( \mathbf{j}_e \) is shown in the following equation (5)

\[ \mathbf{j}_e = \sigma \mathbf{E} \]  \hspace{1cm} (5)

The governing equation from which (6) is expressed as the following equation.

\[ \mathbf{\nabla} \times \left( \frac{1}{\mu} \mathbf{\nabla} \times \mathbf{A} \right) = \mathbf{j}_s + \mathbf{j}_e = \mathbf{j}_s - \sigma (\mathbf{\nabla} \varphi + \frac{\partial \mathbf{A}}{\partial t}) \]  \hspace{1cm} (6)

here, \( \mathbf{j}_s \) is power current density, \( \mathbf{j}_e \) is eddy current density and \( \varphi \) is scalar potential. [3]

2.2 Skin Effect

The phenomenon known as skin effect in electromagnetics manifests in the uneven distribution of the time varied current in a conductor. The AC distribution causes the conductor resistance to exceed its DC value and produces higher losses. Calculating the field and Joule heating losses accurately requires that the finite element mesh be fine enough at the surface of the conductor to capture the surface phenomena. It is essential for the power apparatus designer to be able to predict losses and forces. In order to calculate the skin effect at the conductor, the skin depth equation is solved as

\[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]  \hspace{1cm} (7)

here, \( f \) is frequency (Hz), \( \mu \) is absolute permeability (H/m) and \( \sigma \) is conductivity (S/m)

2.3 Power Losses

The analysis model consist of one-pole encapsulated conductor and a steel tank, whose inside spaces are filled with SF6 gas while its outer surface is surrounded with air. When the current flows through the conductor, power loss is generated at the conductor regions due to the source current and the induced eddy current. Heating loss should be exactly calculated because power loss of conductor regions, calculated by the magnetic field analysis, is used as the input data to predict the temperature rise for the thermal analysis. [4]

\[ Q = \text{Re} \left( \frac{1}{\lambda n} \sum_{n=1}^{n} [j] \cdot [j^*] \right) \]  \hspace{1cm} (8)

3. Thermal Analysis

Electromagnetic and thermal analysis of the GIS bus bar is fundamentally mutual coupling. Electromagnetic analysis of each physical properties vary depending on the temperature. Specific values calculated by assuming the temperature on the physical properties of each to get the result of the loss of power.

3.1 Continuity equations

SF6 gas inside the GIS bus bar for conservation of mass, the continuity equation can be expressed as follows.
\[ \nabla \cdot (\rho \vec{V}) = 0 \quad (9) \]

here, \( \rho \) is density and \( \vec{V} \) is velocity

### 3.2 Momentum equations

SF6 gas GIS bus bar internal circulation of the internal gas momentum equation can be expressed as follows.

\[ \rho \frac{D\vec{V}}{Dt} = -\nabla p + \mu \nabla^2 \vec{V} \quad (10) \]

here, \( \vec{g} \) is gravity, \( p \) is pressure and \( \mu \) is coefficient of viscosity

### 3.3 Energy equations

When passed by conduction, convection and radiation, the heat generated from the GIS bus bar internal energy equation can be expressed as follows.

\[ \rho C_p \frac{DT}{Dt} = \nabla^2 (kT) + \mu \phi + q' \quad (11) \]

here, \( C_p \) is specific heat at constant pressure, \( k \) is thermal conductivity, \( \phi \) is dissipation function and \( q' \) is energy per unit volume

The heat generation in each component by Joule heating was assumed to be evenly distributed over the each component volume. Generally resistance was varied with temperature. In order to consider this effect, resistance was estimated from the following equation.

\[ Q^J = \text{Re} \left( \frac{1}{2n} \sum_{i=-1}^{n} [P] J^* \right) \quad (12) \]
\[ R = \rho_e \left[ 1 + C (T - T_{ref}) \right] A \quad (13) \]

here, \( \rho_e \) is resistivity and \( C \) is temperature coefficient of electrical resistance. \[4\]

### 4. Simulation Model

#### 4.1 Modeling of GIS busbar

The rated normal current is 4000A [rms]. Fig 3 shows the analysis model of GIS bus bar. The filling pressure is 5 bar and gas is filled SF6. 3D Cad tool is used for modeling GIS bus bar with Pro/E and it shows the material of each part in GIS DS/ES parts.

![Fig.2 The Flow Chat of Coupling](image)

![Fig.3 Model of GIS DS/ES parts and material properties](image)
4.2 Mesh Generation

ANSYS to create the tetra mesh and half symmetry model mesh approximately 6,000,000 cells. Polyhedral mesh in order to reduce the mesh to change is reduced to about 1,000,000 cells. (FLUENT convert option) [5],[6],[7]

![Fig.4A Mesh Generation of GIS DS/ES parts](image)

5. Result

Concentration of magnetic flux appears under the influence of the eddy current, eddy current due to the impact affects the current flowing in the bus bar. Rather than the center of the current resulting from the influence of the skin effect outer with an increase in the current density. Result due to the outer conductor, the current density was increased.

![Fig.5 Magnetic flux density distribution (left) and Loss calculation of distribution (right)](image)

Post processing in FLUENT depicts Fig.6. As shown in the figure, the temperature distribution in one-pole encapsulated bus bar and eddy current flowing through tank are represented.

![Fig.6 Temperature distribution for GIS bus bar Tank](image)

![Fig.7 Temperature distribution of conductors in GIS bus bar parts compare of each methods.](image)

Fig.7 shows the graphical representation of the temperature distribution along the current path from source conductor to terminal conductor for 4000A [rms], 60 [Hz] in GIS bus bar. The temperature distribution can be evaluated at any point. Compared to the results of the simulation model, it was a good agreement with measurement data at all of position. 1st multi-physics simulation is test calculation of multi-physics with coarse mesh and model. Only thermal simulation is calculation of thermal and fluid without electro-magnetic results.

6. Conclusion

This paper proposes an electromagnetic thermal coupled field analysis to predict the temperature rise in GIS bus bar. The multi-physics analysis, as shown in Fig.7, only thermal analysis than almost certainly have 10% less accurate. The calculated temperature distribution in GIS bus bar shows good agreement with measured one over whole parts. Through this paper, the temperature rise caused by tanks of magnetic and nonmagnetic differences are predictable. Also, this proposed method is used to conduction design in GIS bus bar system.

References:


[3] Guidance concerning the permissible temperature rise for parts of electrical...


