3-D Simulation of thermal stress for EHV GIS (Gas Insulated Subsystem) Busbar

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Abstract- **The Extra High Voltage (EHV) Gas Insulated Switchgear (GIS) plays a vital role in power networks, designed to meet the significant need for enhancing the compactness and reliability of substations. The security and reliability of GIS has direct impact on smooth operation of power systems. The GIS mainly use SF6 gas because of its arc quenching properties and high dielectric strength. Nonetheless, a critical issue affecting Gas Insulated Switchgear (GIS) is the excessive heat generated in the busbar connection components, circuit breakers, and isolating switch contact components, significantly impeding the progress of GIS technology. Typically, the ampacity of the busbar is restricted by the highest permissible operating temperature, a factor that must be anticipated in accordance with the requirements outlined in the IEC 6227 standard. Firstly, A Three Dimensional model of sub-aspect bus in GIS is built to calculate Multiphysics fields including electromagnetic field, flow field and thermal field in steady-state supported by finite element analysis (FEA) with the help of ANSYS MAXWELL and ANSYS FLUENT. Then the temperature elevation attributes within Gas Insulated Switchgear (GIS) and the impact of load current on the magnetic flux density and heat dispersion, were analysed in addition to that the effect of gas pressure and ambient temperature on the heat distribution were also observed.**

The results show that the load current has linear relation with heating power loss and temperature rise. The Ambient temperature and gas pressure show barely and effect on temperature rise. The results of this research work are valuable for accurately interpreting on-site infrared temperature measurements, with substantial practical applications in engineering.

Keywords: Multiphysics, Heat transfer, Temperature rise, Finite Element Analysis (FEA), ANSYS Software.

1.INTRODUCTION

As the economy and industry continue to experience rapid growth, there is an ongoing rise in the demand for power system installed capacity. Concurrently, power transmission technology is advancing swiftly, featuring substantial capacity, extended distances, and elevated voltage levels to meet these escalating demands [1]. Exclusively the need for very high voltage capacity systems such as above 100 kV is booming, because of their less carbon foot print, reliable operation and minimal maintenance. It is a known fact that the design and development of any equipment have implications that need to be assessed comprehensively to ensure alignment between the engineering aspects of the task and the technical requirements of the power system [2].

When an electric current passes through the high-voltage conductor within a gas-insulated transmission line (GIL), it generates Joule heating. This heating effect diminishes the insulation's performance, potentially resulting in partial discharge and, in more severe cases, insulation breakdown, ultimately compromising the reliability of the equipment. Hence, performing a comprehensive steady-state thermal assessment of the Extra High Voltage (EHV) Gas Insulated Switchgear (GIS) busbar element is essential for revealing the complex interactions between temperature, current, and structural variables.

Currently, researchers are actively exploring calculation methods for Gas-Insulated Lines (GIL), which can generally be categorized into two main approaches i.e. calculations involving a solitary physical field and calculations involving the coupling of multiple physical fields. When it's uncertain how additional physical fields may impact the simulation or computational accuracy, the single physical field calculation approach can be utilized. However, it's important to note that steady-state thermal analysis of GIL represents a complex Multiphysics coupling problem, incorporating the electromagnetic field, fluid dynamics, and thermal fields, making it imperative to consider these interrelated factors for a comprehensive understanding.

There are numerous prior studies in recent years, have explored the very high voltage Gas Insulated System busbar technology in many respects such as eddy current and thermal field analysis [3], Chakira et al performed a computational analysis of the thermal distribution in GIL and conducted a comparison between the outcomes and experimental measurements. Because this mathematical computation only addressed conduction of heat between solids and not the SF6 gas convection, the experimental findings did not align with the simulation results [4], Kim et al introduced a technique for computing the temperature increase in a GIS busbar through a connected analytical approach that links the magnetic field with the thermal field [5].References [6]-[9], developed a model that couples the electromagnetic field with the flow field in GIS for both two-dimensional and three-dimensional bus configurations. The coupling calculations considered factors such as contact resistance, natural convection, and radiation.

In summary, the study of GIS busbar depended on practical calculations and experimental data. This approach is straightforward and simple , but it does not adequately reflect the distribution of internal field of a GIS busbar element . Some studies that combine both electromagnetic and thermal field problems fail to account for internal movement of gas and effect of gas pressure in the busbar. Furthermore, there were few reports on the effect of temperature change on other parameters within Multiphysics fields such as current, magnetic flux density, and flow velocity.

The proposed research aims to establish a method for forecasting the temperature distribution within a 252 kV sub-aspect busbar in Gas Insulated Switchgear (GIS). This approach incorporates considerations of the power loss due to electromagnetic field , its effect on temperature distribution of the system it also aims to study the gas flow field employing a 3-D multi-physics model combining multiple physical domains based on the Finite Element Method (FEM).

The study involves the determination of temperature rise patterns in both the conductors and the enclosure under various load currents and ambient temperatures. Additionally, it examines how load current, environmental temperature, and gas pressure influence the temperature rise characteristics within the GIS.

2.THEORY

2.1. GIL HEAT TRANSFER ANALYSIS

A. HEAT SOURCE MODEL

The primary cause of temperature elevation in GIS bus bars is attributed to power dissipation within the main conductor. This power loss within the GIS bus bar results from the combined effects of current flowing through conductor current and eddy currents within the enclosure. Magnetic analysis techniques are employed to ascertain and quantify these power losses.

$$\nabla \times \frac{1}{\mu}(\nabla \times A) = J \quad (1)$$

$$\int \frac{|\overline{J}|^2}{\sigma} \, dS \; (W/m) \quad (2)$$

$$\overline{J} = \overline{J_S} + \overline{J_E} \quad (3)$$

$$\delta = \sqrt{\frac{\rho}{\pi . f . \mu}} \quad (4)$$

In this context, where $\overline{J}$ represents density of source current, $\overline{J_S}$ denotes the density of load current , $\overline{J_E}$ signifies the density of current induced by the magnetic field, A is a vector representing magnetic potential, μ represents the permeability of the medium , σ denotes conductivity, w signifies angular frequency, and δ represents the skin depth.

B. MODEL FOR HEAT TRANSFER

The heat transfer mechanisms in Gas Insulated Lines (GIL) can be primarily categorized into three modes: conduction, convection, and radiation. Through a specific conduction mechanism, heat is transported to the external contact surface, achieving a state of thermal equilibrium. As energy is transferred to this surface, it leads to a temperature contrast between the central conductor's surface and the high-pressure SF6 gas.

Natural convection plays a crucial role in transferring heat to the surrounding SF6 gas, resulting in an increase in gas temperature. Subsequently, the SF6 gas conveys this increase in temperature to the surface of the enclosure to facilitate thermal transfer. As the SF6 gas makes contact with the enclosure , heat is transferred to the enclosure material through a combination of convection and radiation. Subsequently, through heat conduction, this heat moves from the inner side to the outer side of the enclosure consequently, establishing a temperature difference with the surrounding air . Eventually, this heat is dissipated into the air adjacent to the enclosure outer surface through convection and radiation.

The natural convection of sulphur hexafluoride gas within GIS can be effectively simulated by formulating a set of equations, incorporating equations for conserving mass, momentum, and energy. These equations describe and capture the dynamics of the heat transfer process.

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho V) = 0 \tag{5}$$

$$\frac{\partial}{\partial t}(\rho C_P T) + \nabla.(\rho\, C_P\, VT) = \nabla.(\lambda\, \nabla T) + Q \tag{6}$$

In this context, where V represents the velocity vector with its components along the co-ordinate axes Vx, Vy, and Vz along x, y, and z axes respectively, Cp denotes specific heat, p signifies pressure of gas, µ represents viscosity of dynamic fluid, T stands for Temperature in kelvin scale , λ denotes thermal conductivity, and Q represents the heat source distributed throughout the volume.

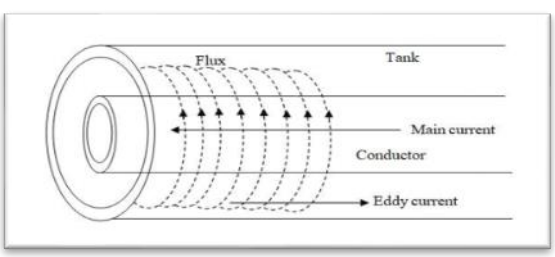


Fig.1.Current profile in GIS Bus bar

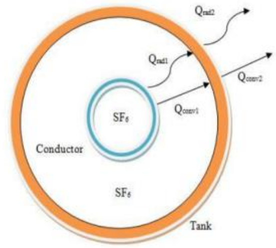


Fig.2.Heat transfer mechanism in GIS Busbar

3.SIMULATION MODEL

This research was carried out utilizing ANSYS Maxwell 20.0 and ANSYS Fluent, both integrated within ANSYS Workbench 21.0.The model is initially constructed as illustrated in Figure 3,using the available mechanical templates within SolidWorks, a comprehensive computer-aided design (CAD) and computer-aided engineering (CAE) software program. The in the MAXWELL interface the selection of the region of electromagnetic field can be tailored according to the desired level of precision and the specific solver employed. Upon the finalization of the necessary model, materials are introduced into the model as input, thus initiating the next phase of the process. To avoid colliding meshes, the cloning operation is conducted as depicted in Fig.4. Following that, the boundaries and conditions of symmetry are defined. The excitation is fed into the main conductor as the main current flows through it.

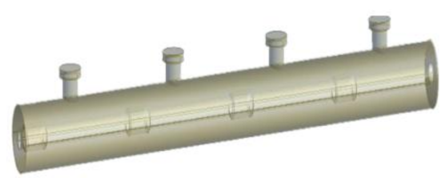


Fig.3. CAD model of 252 kV

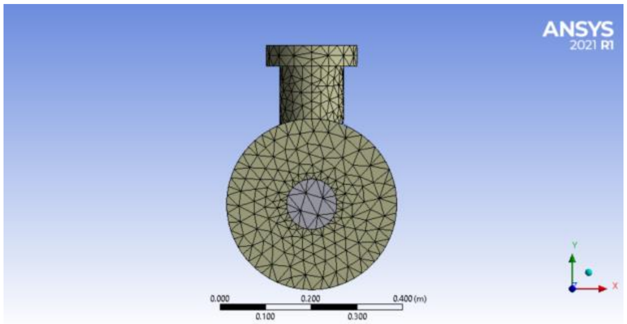


Fig .4. Tetrahedron meshing of 20 mm

Table.1.Parameters of Air and SF6

Parameter	**SF6**	**AIR**
Density (kg/m^3)	13.5	1.026
Dynamicviscosity (m^2/s)	1.31e-6˚	19.6e-6
Thermal conductivity(W/m.K)	0.0153	0.0257
Specificheat (J/kg˚C)	37	10
Relative permeability	1	1

4.RESULTS AND ANALYSIS

When the Gas-Insulated Switchgear (GIS) is powered on, a consistent temperature increase occurs as a result of heat generated due to power loss and its subsequent dissipation. To calculate this temperature rise both within the conductor and the GIS enclosure, a comprehensive 3-D multiphysics coupled model was developed.

In this model, the GIS losses were computed using Maxwell's equations, while the evaluation of thermal dissipation within the GIS was done using Fluent, a computational fluid dynamics software. The Fluent calculator employed a solver that considered factors such as pressure of gas its absolute velocity for a steady-state time frame. Furthermore, the model employed the k-ε turbulence model to account for the effects of convection diffusion , with gravity acting in the vertical direction along the radial axis of the GIS.

A. The influence of electrical load current on the thermal behaviour of Gas Insulated Switchgear (GIS)

According to the heat flow study, the heat is associated with the current flowing through the central conductor is directly proportional to the temperature rise within GIL. The quantitative relationship between conductor temperature and load current is investigated, and the influence of different load currents is considered comprehensively.

The simulation results show power losses of 550.72 W, 317.53 W, and 138.83 W for current values of 2000 A, 1500 A, and 1000 A, respectively. This power loss can be simulated using ANSYS MAXWELL system tool and verified by approximate analytical calculations using maxwell equations and considering energy balance equation.. Figure 5 illustrates the distribution of temperature rise in both the conductor and its enclosure of the GIS under different current levels.

At current levels of 2000 A, 1500 A, and 1000 A, the highest temperature increase in the conductors is recorded at 65.8°C, 35.8°C, and 25.08°C, respectively. Meanwhile, the highest temperature rise in the shell occurs at 16.5°C, 10.3°C, and 4.2°C for currents of 2000 A, 1500 A, and 1000 A, respectively.

Notably, the temperature rise experiences an exponential decrease as he longitudinal gap between the conductor and enclosure increases, eventually reaching a stable state. The Nusselt number serves as a tool for analytically determining heat transfer coefficients that vary with temperature at boundaries. The Fig 6 depicts the temperature rise patterns at different locations on the conductor surface its surroundings and also on the surface of the enclosure.

Fig.5.Temparature distribution for different load currents

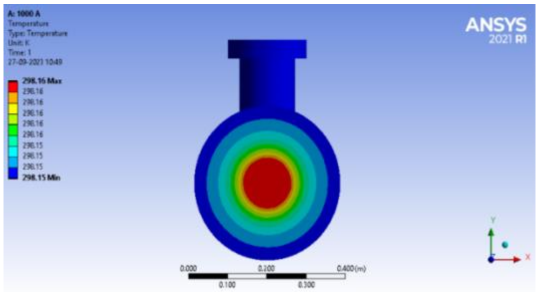


Fig.5.a. For load current of 1000A

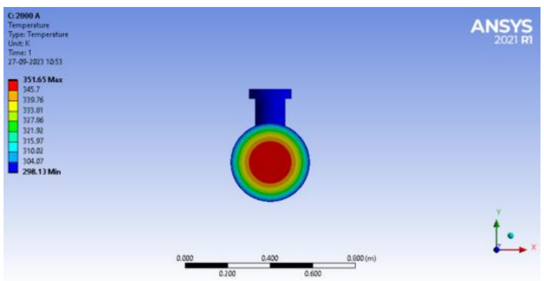


Fig.5.b. For load current of 1500A

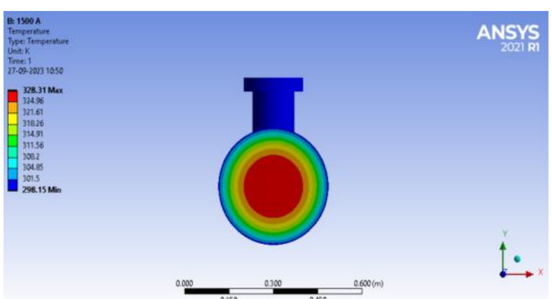


Fig.5.c. For load current of 2000A

Fig. 6. Characteristics of temperature rise in both the conductor and the enclosure.

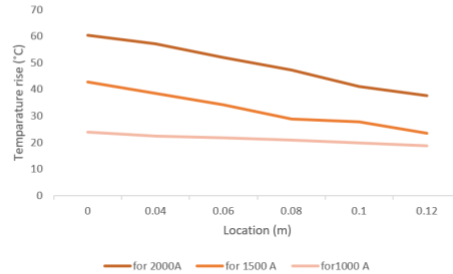


Fig.6. a. Temperature rise across the conductor

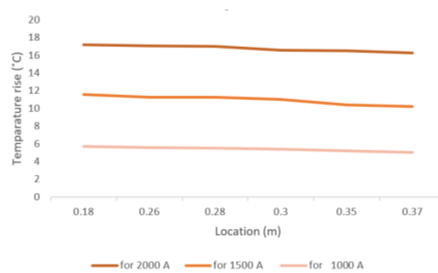


Fig.6.b. Temperature rise across the enclosure.

B. The impact of ambient temperature on temperature rise attributes of Gas Insulated Switchgear

The operational use of the Gas Insulated Subsystem in an outdoor environment experiences fluctuations in ambient temperature throughout the seasons. To investigate the influence of fluctuating ambient temperatures on the temperature rise properties of both the conductor and the enclosure within the Gas Insulated Switchgear (GIS), a temperature range spanning from -10°C to 50°C was employed for the temperature rise calculations. [10]These calculations are done considering an over heating defect on the surface of conductor as depicted in Fig.7.in one case and in other case an insulator shield is considered around the conductor[11].

Figure 9 depicts the temperature Distribution of SF6 at varying ambient temperatures considering the defect .The distribution of temperature rise in the conductor with insulator shield across different ambient temperatures is graphically represented . Notably, there are minor fluctuations in the temperature rise levels of both the conductors and shells at various ambient temperatures, while the general trends remain consistent.

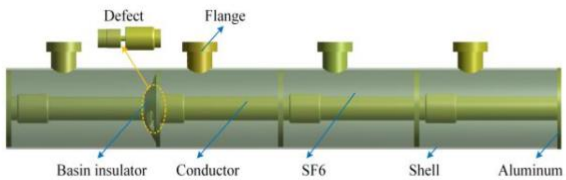


Fig.7. simulated model of over heating defect.

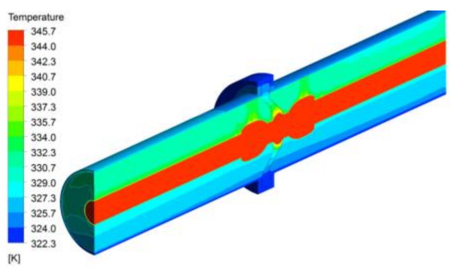
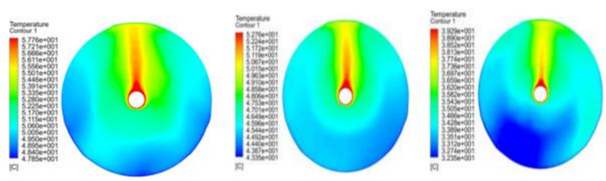


Fig.8.Simulation results for GIL temperature distribution with insulator.



a.(48°C) b.(30°C) c.(10°C)

Fig.9 . Temperature Distribution of SF6 at Varying Ambient Temperatures

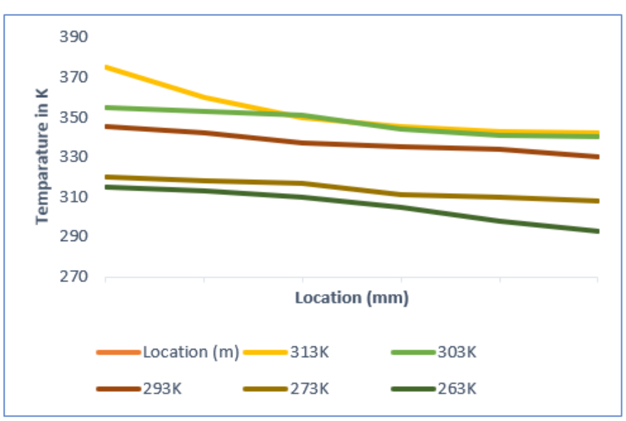


Fig.10.Temperature distribution of insulator with different ambient temperatures.

C. The impact of varying inner and outer diameters of both conductor and enclosure on the temperature rise characteristics of GIS .

Case 1: Effects of varying the conducting Rod's diameters.

When the GIS busbar equipment functions under its specified current rating, it generates heat due to power loss in the conductor due to joule heat and eddy currents generated. To understand the effects of altering the diameters of the conducting rod and to calculate the resulting temperature rise, the inner diameter is adjusted from 60 mm to 90 mm, and the outer diameter is changed from 110 mm to 125 mm.The inner and outer diameters of the enclosure are fixed at 360 mm and 372 mm, respectively. These diameter modifications impact the cross-sectional area, subsequently influencing the temperature rise.[12]

If the outer diameter of the conducting rod is 110mm, reducing the inner diameter will lower the temperature rise. Additionally, for a fixed inner diameter of 90 mm temperature rise reduces as outside diameter increases. However, altering the outer diameter of the conducting rod has significant impacts temperature rise.

Case 2: Effects of varying busbar enclosure's diameters.

The dimensions of the busbar enclosure affect the convection and heat radiation of SF6 gas because the cross section area is affected due to change of dimensions of enclosure. To investigate how altering busbar enclosure sizes influences temperature distribution, the inner diameter was varied from 340 mm to 360 mm and the outer diameter from 372 mm to 390 mm. The conductor had fixed inner and outer diameters of 90 mm and 110mm.

When the outside diameter of the conducting rod is set at 332mm, the temperature rises as the inner diameter increases. Additionally, a fixed inner diameter of 320mm reduces temperature rise as outside diameter increases.

Temperature rise is more evident when the outer diameter of the busbar enclosure changes

CONCLUSIONS

There is a direct relationship between the magnitude of the current and factors such as heating power loss, SF6 convection diffusion rate, and temperature rise in the conductor and shell surface. It was found that with increase in load current the maximum temperature of conducting rod increased significantly. The increase in temperature of conductor heats up the SF6 in vicinity ,and due to this the density of SF6 is reduces and its convection diffusion rate increases significantly .the enclosure temperature rise is also linearly dependent on load current.Within the range of ambient temperatures spanning from 263 K to 313 K, a linear correlation exists. This implies that changes in ambient temperature can notably impact the overall temperature of the insulator. However, it has a minimal influence on the temperature rise effect and the overall temperature distribution.

The change in outer diameters of the conducting rod and enclosure has more influence on temperature rise compared to inner diameters.

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