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Research paper

Analysis of Partial Discharge Due to Movement of Spherical Particle in Power Transformer Using Computational Fluid Dynamics

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Abstract

Power transformer is costly and very important equipment in power sector. Failure of power transformer causes colossal damage to the power system. One of the important reasons for transformer failure is event of Partial Discharge (PD) in the transformer. Numbers of non-conducting and conducting particle are available in the transformer. Conducting particles available in the transformer or mineral oil entering into winding space, strike the energized winding of the transformer cause PD to occur. Movement pattern of particle administrates the probability of particle striking the winding. Analysis of movement of particles proximate to HV winding helps in understanding the occurrence of PD. This paper deals with tracking of aluminum and copper particles of various sizes available inside the transformer.

Keywords: *Power transformer, Particle movement, Partial Discharge, CFD*

1. Introduction

Power transformers are used in generation substations to step-up the generated power. Hence these transformers work with very high voltage levels. Failure of this transformer causes disturbance to entire network entire network connected to it. These transformers are well tested before they are placed in the field. Number of transformers fails in the field due to aberrant operating conditions. Partial Discharge (PD) is one of the causes for failure of HV transformers. PD is caused due to voids, gas bubbles, chemical vapor and conducting particles in the insulating system of the transformer. Mineral oil is used as fluid insulation and as a coolant in the transformers. Conducting particles in the transformer oil dislodge by the flow of oil in the winding area. When the conducting particle strikes the energized winding, it acquires electric stress formed on it. When this stress exceeds the dielectric strength of the insulating oil, partial discharge occurs. Occurrence of PD is governed by fluid flow in the transformer. As a part of analysis of PD, research works have been carried out to track the particles in the conductor space in the field of Gas Insulated Substations (GIS) and transformers. Swarnalatha et al. [1] formulated a model to simulate wire–like particle in three phase Gas Insulated Busduct (GIB) using Monte-Carlo technique. Dislodgment of particle in a crusted electrode system is calculated to be less than that in the non-coated system. Eslami et al. [2] determined that wall hydrodynamic effect and iconic conductivity of dielectric liquid are deciding the movement of the particle. Cao et al. [3] investigated the behavior pattern of magnetic particle under the two gradient magnetic fields produced by different permanent magnets using Monte-Carlo simulations. Results are found to be in line with the results of microscopic visualization. In an investigation [4], a theoretical model is created to analyze the movement of small spherical particle of 0.5 mm in transformer oil with AC field in 8 mm electrode gap. The calculated result is compared with the experimental measurement. It was reported that drag force in the transformer oil accounts for relatively closer resemblance at lower stress and dispersion at higher stress. From the theoretical results the observed behaviour of particle cloud formation and dispersion at electrical stress is in the range from 1 to 3 MV/m.

Junhao Li et al. [5] analyzed the movement of spherical particle under different applied voltages. Results show that under the given condition, the particle movement is changed from oscillations to jumping with increase in field intensity. Various PD patterns with voltage are reported at each stage. Sarathi and Koperundevi reported [6] that particle does not create partial discharge under DC or AC voltages when the particle lies over the barrier insulation. Authors measured Broadband UHF signals generated by partial discharges due to particle movement in mineral oil, at high applied electric fields. It is reported that the frequency content of the signal lies in the entire UHF range of 300 MHz - 3GHz.

This paper deals with analysis of trajectory of various particles with respect to initial position and size of the particle using computational fluid dynamics (CFD).

2. Simulation

The transformer considered for investigation is 100 MVA, 11 /132 /220 kV, three winding power transformer. This transformer consists of three windings, namely, Low Voltage (LV), Intermediate voltage (IV) and High Voltage (HV) winding. Only HV winding is considered for this analysis as voltage of the winding has high influence on the commencement of PD. HV winding of this transformer is divided into two symmetrical half coils. Hence, one half of the HV winding is considered for CFD simulation. This half winding consists of 58 interlinked discs placed with apportioned gaps. Winding structure of the transformer given in figure 1. It shows the split in HV winding as Non-standard (NS) and standard (S) coil.

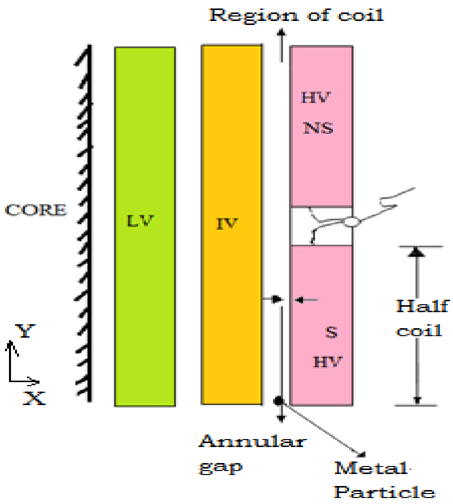


Fig. 1: Winding structure of 3 winding auto transformer

58 discs in half coil are arranged into 28 disc pairs. Transformer oil is allowed to flow in the gap between pressboard and winding and also in the winding gap. There are two types of oil flows used in transformers; non-directed and directed oil flow. Non-directed oil flow is considered for present simulation. Aluminum and copper particles of spherical shape are considered to be available at the bottom of the winding and enter the winding region along with transformer oil. Particle of different sizes are considered and their movement is tracked using ANSYS software.

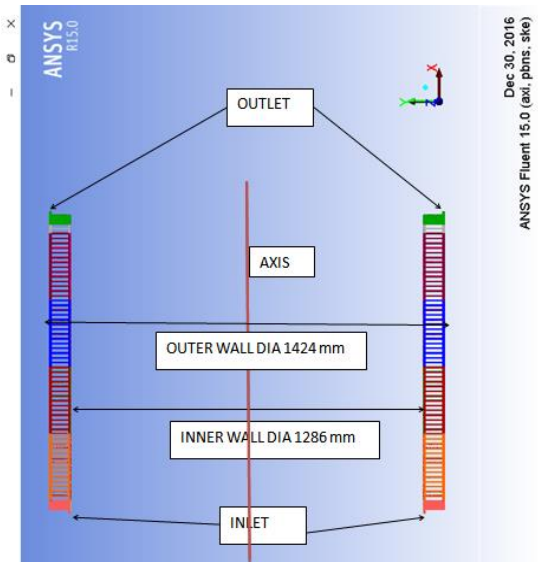


Fig. 2: 2D cross section of transformer winding

The total gap between first pressboard cylinder and winding discs is 8 mm. 2D model of transformer CFD simulation is sown in figure 2. The mesh is constructed using ANSYS – ICEM tool. Mesh is constructed with 1,32,035 cells with orthogonal quality of 0.866. Fluid flow is generated using ANSYS –FLUENT tool.
Aluminum and copper particles of diameter of 1mm, 2mm and 4 mm are considered to be available at the bottom entry of the transformer. Initial position of the particle is considered to be 1 mm , 4mm and 6 mm from pressboard cylinder which is at the distance of 8 mm from the HV winding disc. When energized, each disc in the winding holds the corresponding voltages. Voltage increases from bottom to top where the discs are numbered from top to bottom.

3. Results

Simulations are carried out to track the particle in the HV winding area using FLUENT tool of ANSYS. Particle is considered to start from bottom entry of the transformer with the velocity of 1 m/sec. Figure 3 shows the movement of aluminum particle of 1 mm diameter starting from 2 mm gap from pressboard. The structure is tilted about 900 for a better viewing of complete structure. While staring from 2 mm gap, particle is observed to enter from bottom and leaving through the outlet at the top without striking any disc.

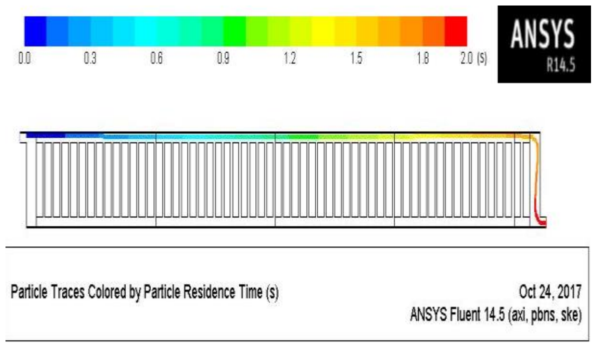


Fig. 3: Tracking of aluminum particle of d=1 mm and g=2 mm

Particle tracking is indicated by means of particle residence time in the transformer. Figure 4 show the tracking of the same particle for the starting position of 6mm from pressboard cylinder.

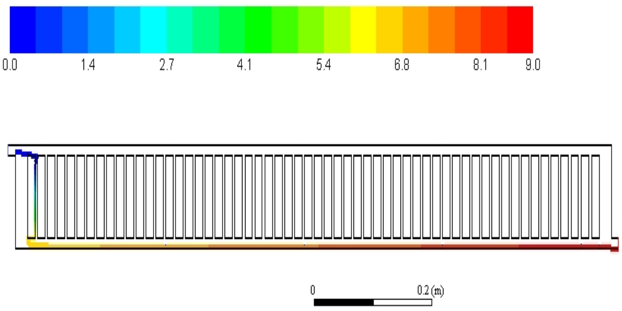


Fig. 4: Tracking of aluminum particle d=1 mm and g=2 mm

From figure 3 it can be noted that the particle follows the path of particle in figure 2 for the gap value of 6mm from pressboard. In both the cases particle travels through the complete height of the winding. When starting from 6mm particle hits disc 57 then falls on disc 58. It falls on the other side of disc 58 due to lack of drift towards upward as oil and particle are allowed to enter at the same time. Once the oil flow reaches the other side of the disc particle is taken up to the exit at the top. Figure 5 gives the tracking of aluminum particle of 4 mm diameter starting at 2 mm gap. Particle hits disc 1 (top) and faces a downward movement due to comparatively higher weight by increased particle size.
Collectively, aluminum particles of diameter 1, 2 and 4 mm while starting from 2 mm and 6 mm tries to escape through the outlet either through inner or outer cylinder gaps, except that the particle of 4mm diameter starts from 6 mm gap,particle hits disc 55 and after many oscillations it settles on disc 56 as shown in figure 6.

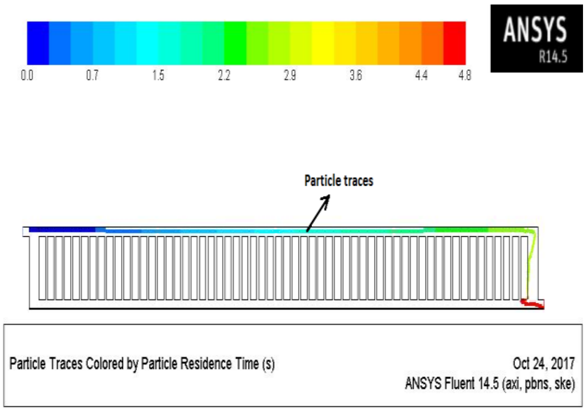


Fig. 5: Tracking of aluminum particle d=4 mm and g=2 mm

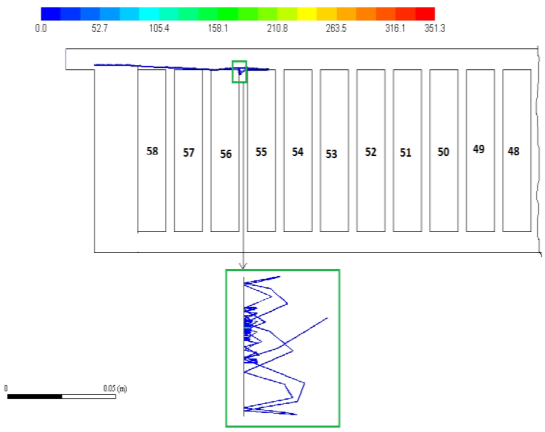


Fig. 6: Tracking of aluminum particle d=4 mm and g=6 mm

Similar analysis has been carried out for copper particles of 1, 2 and 4 mm diameter staring at 2 and 6mm.Copper has higher density than aluminum. Hence weight of copper particle is higher than weight of the aluminum particle of same geometry. This makes trajectory of both the particles differ for same initial condition.

Figure 7 shows the movement of copper particle of 1 mm diameter starting from 2 mm gap from inner pressboard cylinder. Particle moves up to top of the winding and settles on disc 1.

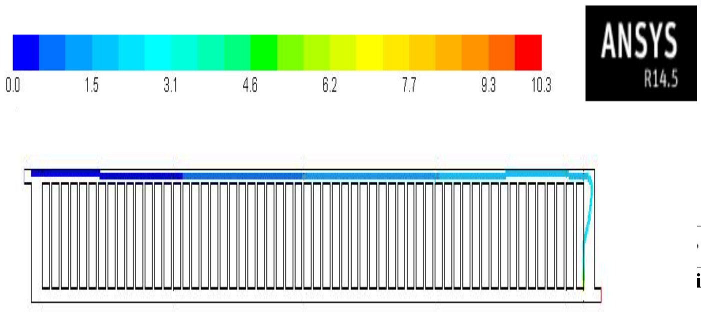


Fig. 7: Tracking of copper particle d=1 mm and g=2 mm

Figure 8, 9 and 10 show the trajectories of copper particles of 2 and 4mm for starting points of 2 and 6 mm. From figure 8 it is observed that when the particle size is increased from 1 mm diameter to 2 mm it moves up to disc 56, falls on disc 57 with oscillation, moves further on 57 and falls on the bottom cover of the winding and settles down. Oil force in the other side is not found to be sufficient to lift the particle along with and hence it settles at the bottom cover.

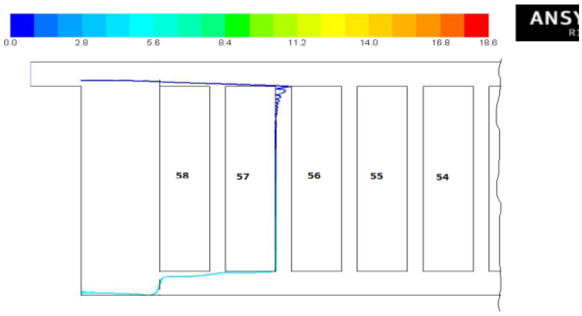


Fig. 8: Tracking of copper particle d=2 mm and g=6mm

Trajectory of copper spherical particle of 4 mm diameter starting from 2 mm gap is presented in figure 9. The particle is guided by wall hydrodynamic forces falls back after striking disc 52. It takes diversion at the bottom due to the oil moving to the outer radius of the winding. As oil hits disc 58 from bottom and bounce back, the same pattern is followed by the particle and results in oscillatory movements. Finally, particle settles down at the bottom as the resultant force of the oil is not sufficient to lift the particle further. Movement of the same particle when starting form 6 mm gap is shown in figure 10. Particle touches disc 56 from inner side and falls on 57. It moves further in radial direction with oscillations and falls on the bottom of the winding. Oscillations can be observed at the bottom, just before settling of the particle. This is due to oil forces which try to lift the particle in upward direction.

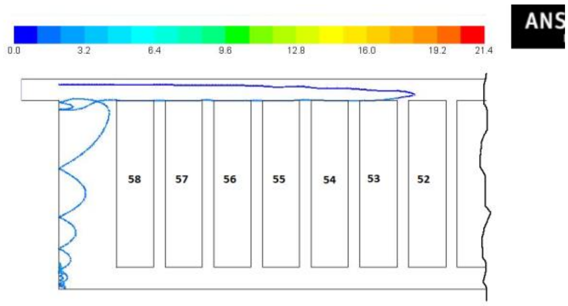
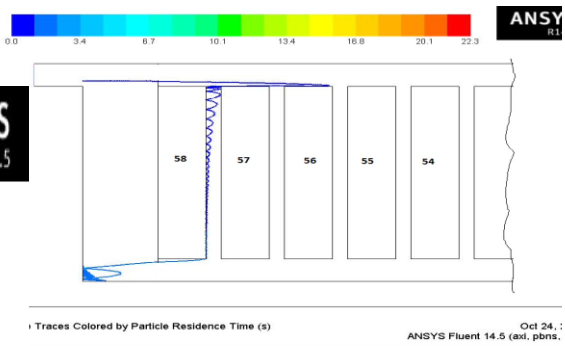


Fig. 9: Tracking of copper particle d=4 mm and g=2mm



ig. 10: Tracking of copper particle d=4 mm and g=6mm

Every disc in the winding assigned with the voltage. Disc at the top (disc 1) has the highest voltage and the bottom most (disc 58) is assigned the Lowest. A particle strikes the disc acquires electric stress proportionate to the corresponding disc of impact. If the accumulated stress is greater than threshold stress of the given transformer (70 kV/cm), partial discharge is considered to be initiated. Stress formed on the particle is calculated by

$$E_{mic} = \frac{(V_1 - V_2)}{d} \quad \text{----(1)}$$

Where,

V1 = Voltage of electrode 1

V2 = Voltage of electrode 2
d = Distance between electrodes

Table 1 consolidates the point of impact and stress formed on the aluminum particle.

Table I : Trajectory of aluminum particle

	Diameter of the particle					
	1 (mm)		2 (mm)		4 (mm)	
Initial position (from pressboard)	2 mm	6 mm	2 mm	6 mm	2 mm	6 mm
Disc of impact	-	57	1	57	1	55
Position after strike	Exit through outlet	Exit through other side	Settles on disc	Exit through other side	Exit through outlet	Settles on disc 56
Voltage of disc of impact	-	77.10	126.8	77.10	126.8	78.88
Stress acquired kV/cm	-	0.56	4.96	0.56	4.96	0.36

From Table 1 it can be seen that PD is not initiated by considered aluminum particle at normal operating conditions. Table 2 presents the point of impact and stress formed on the copper particle.

Table II: Trajectory of copper particle

	Diameter of the particle					
	1 (mm)		2 (mm)		4 (mm)	
Initial position (from pressboard)	**2 mm**	**6 mm**	**2 mm**	**6 mm**	**2 mm**	**6 mm**
Disc of impact	1	57	1	57	53	56
Position after strike	Exit through outlet	Exit through other side	Exit through outlet	Settles at bottom	Settles at bottom	Settles at bottom
Voltage of disc of impact	126.8	77.10	126.8	77.10	84.23	77.99
Stress acquired kV/cm	-	0.56	4.96	0.56	0.23	0.37

4. Conclusion

Copper and aluminum particles with different diameters are tracked inside the HV winding of a given 100 MVA transformer. Initial velocity of the particle is considered as 1 m/sec. Particle is considered to start from 2 mm and 6 mm from inner pressboard. From the trajectories following points can be noted,

Movement of the particle is administrated by oil forces and wall hydrodynamic forces.

Aluminum particles are able to travel the complete height of the winding for the given velocity and copper particles found to fall back on the bottom cover. This is due to the fact that the density of copper is greater than that of aluminum. Hence copper particle need additional lift force to move upward.

Due to lighter weight, movement of aluminum particle in radial direction is restricted and settles on the disc, where as for the same given condition copper particle shows free movement in radial direction.

For the given conditions, both aluminum and copper particles are not initiating PD at normal operating condition.

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