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COMPARISON OF FIELD AUGMENTATION FACTOR FOR DIFFERENT LIQUID INSULATIONS IN POWER TRANSFORMER

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ABSTRACT

Transformers are used to step up and step down voltage as per the requirement of power. Power transformers are High Voltage (HV) transformers which are used to step up power in power stations. These transformers suffer due to many issues of failures. One of the reasons for failure of these transformers are considered to be partial discharge (PD). Partial discharge happen due to number of reasons and discharge due to availability of tiny conductors is considered in this paper. These tiny conductors are considered to flow from bottom of the transformer to top of the transformer. When such conductor comes in contact with transformer winding, electrical stress is formed. When this stress surpasses the breakdown strength of the insulating medium partial discharge occurs. Breakdown strength of the insulating medium is a factor which changes due to practical issues at the field. The present work deals with occurrence of partial discharge in traditional mineral oil, synthetic ester and silicon oil.

Key words: Power transformer, synthetic ester, silicon oil, computational fluid dynamics, partial discharge.

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1. INTRODUCTION

Power Transformers are high power high cost equipment's in electrical power system. Power Transformers are subjected to different abnormal conditions while operating in fields. Transformers are tested for their capability before they are installed at fields. However these transformers fail due to different abnormal conditions irrespective of age. One of the reasons of failure at field is partial discharge (PD) caused by conducting particles existing in insulating medium. Small conducting properties enter into the transformer along with transformer and flow from bottom to top with the oil.

When is conducting particles come in contact with high voltage winding electrical stress is formed around the conductor. If this electrical stress caused by the conductor contact exceeds threshold level of breakdown strength of insulating medium then results in partial discharge. The breakdown strength of the insulating medium is depending on the age of the transformer and insulating medium. Strength of the insulating medium degrades due to wear and tear operation of transformer. Hence predetermined strength of insulating medium becomes not applicable in all cases of transformer operation. Hence point of occurrence of partial discharge is a factor of breakdown strength of the insulator. Degradation of breakdown strength is accounted as augmentation factor of field. Research work by Sveningsson and Podenok [1] gives an extensive method to calculate field enhancement factor and stress on particle of various length / radius (L/R) ratio. The voltage of breakdown initiated by the particle contagion is calculated by the streamer formation criterion [2]. The experimental study carried out in the laboratory with using the pressure vessel and negative high voltage DC source. The measured breakdown voltage for different particle size agreed well with the calculation of breakdown voltage. A latest work published [3] provides an analysis of PD against magnitude of applied voltage. Life of oil immersed insulating paper is tested by the authors under different AC voltages. Experimental results indicate that the life of the oil immersed paper decreases exponentially with increase in magnitude of applied voltage. In a latest work done [4], different transformer coolants are tested for flow distribution and pressure drop over a given winding model using CFD. Among them, the synthetic ester is found to be better in suppressing flow due to its higher viscosity. Synthetic ester found to give more uniform flow distribution with the higher pressure drop. This work deals with calculation of field augmentation required for partial discharge due to copper spherical particle present in mineral oil and synthetic ester.

2. SIMULATION

A 100 MVA 11/132/220 kV transformer is considered for this work. This is a three winding transformer which has low, middle and high voltage winding. Insulating oil is considered to flow inside the transformer in between winding space. For this work only high voltage winding is considered as only this winding is having significant voltage levels to instigate PD. This winding is divided into two parts. One part is having standard coil and the other has non-standard coil. At the junction of these two coils zero potential is measured. Only one half of the entire winding is represented in this work as the other is the identical to the considered winding. This part has 58 coils which are represented electrically as 29 disc pairs. Voltage of the disc is increasing from bottom to top. Simulation is carried out on the computational fluid dynamics environment using ANSYS software. Position of HV winding is shown in figure 1.

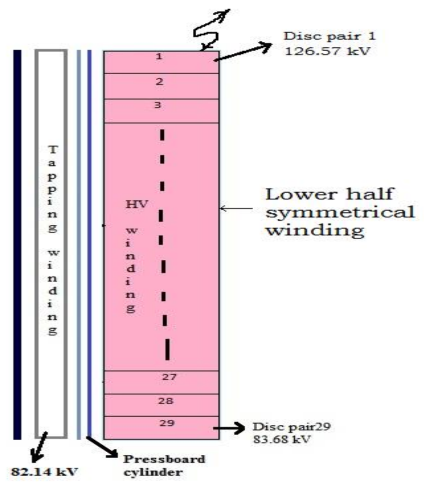

Figure 1 Winding structure of three winding

The coil is wound around the pressboard and it is simulated in two dimension as shown in figure 2. Oil is allowed to enter from the bottom side of the transformer coil. This oil flows towards up and exits through top. Many tiny conducting particles are found available in the oil. When the age of the oil increases, the numbers of these types of conductors are increased. Oil filled in the transformer is generally hydrocarbon oil. However, many researchers have been recommending synthetic esters and silicon oil. Hence the characteristics of these oils with respect to PD due to spherical particle are simulated.

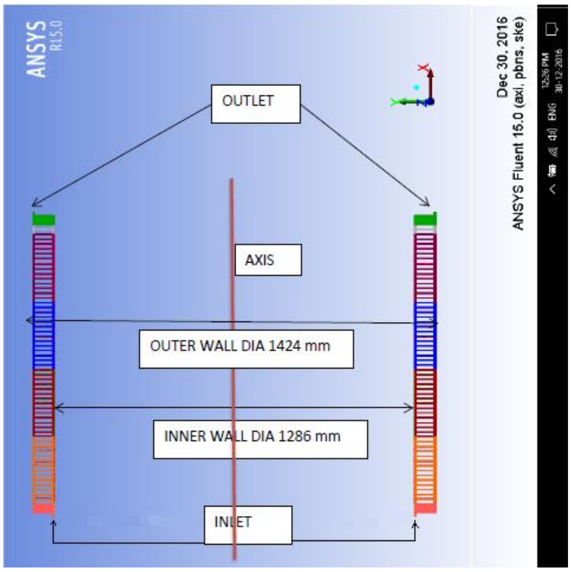

Figure 2 Structure of ANSYS simulated transformer winding

Breakdown strength of mineral oil, ester and silicon oil is different. Breakdown strength of the insulating medium is degrading with the age of the transformer. This degrade is considered as field augmentation in this work. Field augmentation is defined as a factor that needs to be multiplies to the actual stress developed in order to obtain the PD stress. PD stress is the amount of stress with is just beyond the threshold value of oil breakdown voltage.

3. RESULTS

Copper and Aluminum particles of spherical and cylindrical particles of 1mm dimension are considered. Initial position of the particle is considered to be 4 mm from the inner pressboard. Figure 3 shows the tracking of spherical particle in mineral oil. Particle strikes disc 52 and settle on the disc. Stress on the particle is calculated with respect to the adjacent coil as an effect of capacitance build.

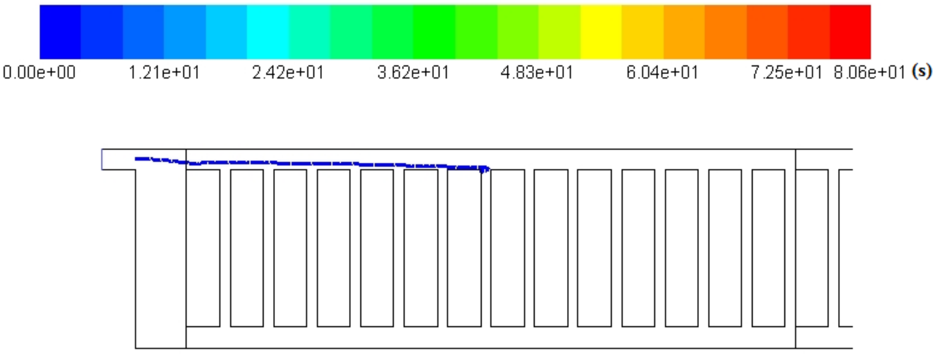

Figure 3 Tracking of copper spherical particle in mineral oil

Figure 4 and 5 show the tracking of the same particle in synthetic ester and silicon oil respectively. It is observed that in synthetic ester particle reaches disc 51 and in silicon oil particle reaches to the top disc(1). In all the cases initial position is considered to be 4 mm from pressboard.

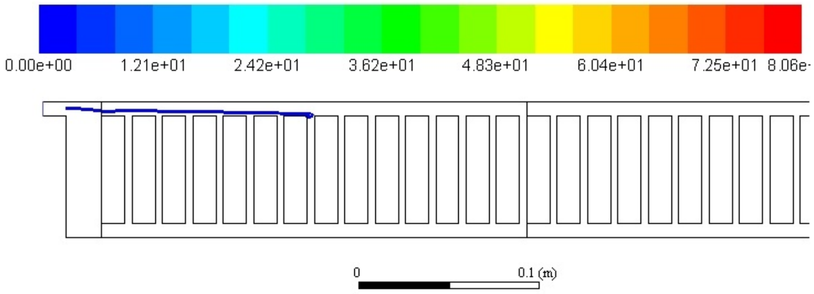

Figure 4 Tracking of copper spherical particle in synthetic ester

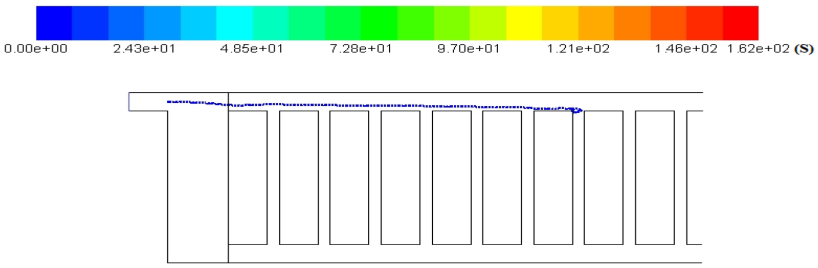

Figure 5 Tracking of copper spherical particle in silicon oil

Similar simulations are carried out on cylindrical shaped particles of 1mm length and 0.5 mm radius. Tracings are shown in figure 6, 7 and 8 respectively.

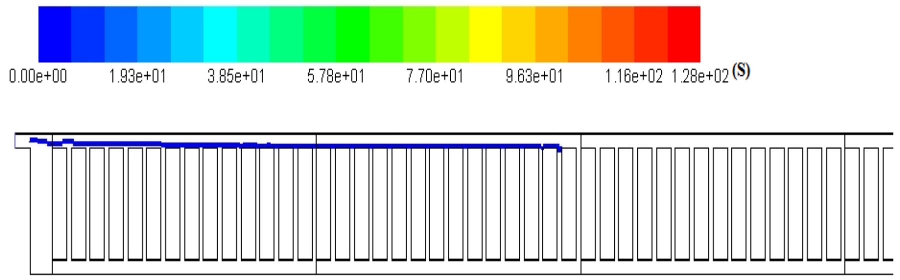

Figure 6 Tracking of aluminum cylindrical particle in mineral oil

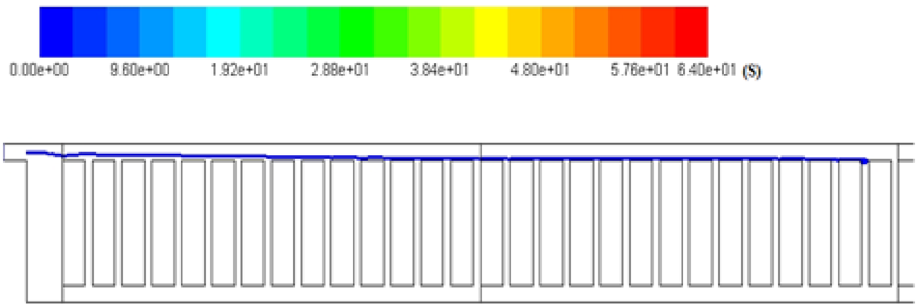

Figure 7 Tracking of aluminum cylindrical particle in synthetic ester

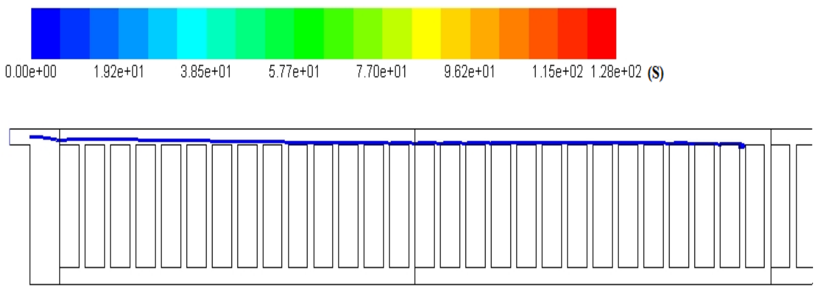

Figure 8 Tracking of aluminum cylindrical particle in silicon oil

Results obtained for tracing of copper and aluminum particles of spherical and cylinder shapes in mineral oil, synthetic ester and silicon oil are listed in table 1 and 2 respectively. Tables also gives actual stress developed on the particle and the field augmentation required to have a PD stress at that point of contact. Break down voltages of considered mineral oil, synthetic ester and silicon oil is 70 kV/cm, 75 kV/cm and 50 kV/cm respectively.

Table 1 Results obtained for spherical particles

Name of the fluent	Name of the particle	Place of final settlement	Disc voltage	Stress	% of PD stress	Required field augmentation
Mineral oil	CU	52	82.342	0.22	0.3%	318
	AL	32	99.862	1.97	2.8%	36
Synthetic ester	CU	51	83.218	0.22	0.3%	340
	AL	1	127.016	4.96	6.6%	16
Silicon oil	CU	1	127.016	4.96	9.9%	11
	AL	1	127.016	4.96	9.9%	11

Table 2 Results obtained for cylindrical particles

Name of the fluent	Name of the particle	Place of final settlement	Disc voltage	Stress	% of PD stress	Required field augmentation
Mineral oil	CU	52	82.342	0.22	0.3%	318
	AL	32	99.862	1.97	2.8%	36
Synthetic ester	CU	52	82.342	0.22	0.3%	340
	AL	32	99.862	1.97	2.6%	39
Silicon oil	CU	52	82.342	0.22	0.4%	227
	AL	32	99.862	1.97	3.9%	26

4. DISCUSSIONS

Spherical and cylindrical shaped copper and aluminum conductors of 1 mm size are simulated in the HV winding of transformer. Initial position of the transformer is considered to be 4 mm from pressboard cylinder. From the results illustrated in Table 1 and 2, it can be seen that copper particles touches discs 52, 51 and 1 where as aluminum particles reach disc 32 in most of the cases. Final settling point of particle is based on the oil velocity and viscosity of oil. Velocity of the oil considered here is 0.5 m/sec. Maximum and minimum field augmentation required for PD stress in traditional mineral oil is 318 and 36 respectively. These values for synthetic ester are 340 and 16 respectively. In case of silicon oil above values are noted as 227 and 11.

5. CONCLUSION

Movement of tiny conducting particles of copper and aluminum materials are simulated in mineral oil, synthetic ester and silicon oil using CFD. From the result following things are observed.

- Though the viscosity is different for above oils, almost similar trajectories are shown by particles
- Aluminum particles reach higher discs than copper particles. This is due to the fact that density of copper is higher than aluminum. Hence weight of the copper is higher and reaches less height than aluminum for the same oil force.
- Highest field augmentation required is 340, which is obtained for synthetic ester.
- The lowest field augmentation required is 11, obtained for silicon oil.
- Aluminum particles shows higher probability of PD than copper particles

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