Analysis of Correlationship between Partial Discharge and Ozone Emission in High Voltage Motor Stator Windings as the Index of the Insulation Diagnosis

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ABSTRACT

In this study, it turned out that the magnitude of Partial Discharges(PD) and the emission of Ozone(O_3) were in a strong positive relation by performing insulation diagnostic tests on artificially defect high voltage motor stator windings. In this sense, the O_3 measurements can be a powerful index of the insulation deterioration during normal operation especially in case of surface PD activity.

1. INTRODUCTION

Many electrical diagnostic tests have been performed to evaluate the health of insulation systems for rotating machine stator windings. In general, Insulation Resistance(IR), Polarization Index(PI), Dissipation Factor(DF), AC current test and PD test have been conducted and analyzed to assess the soundness of insulation systems as had been shown(Kim, H. D. (2014), Kim, H. D., Kong, T. S., Ju, Y.H., & Kim, B. H. (2011), Kim, H. D., & Kong, T. S. (2012), Kim, H. D., & Kong, T. S. (2014)). Also, it is well known that the O_3 is produced when the electric discharge occurs in air and studies are still going on the correlations between PD and O_3 emission as works in this topic(Lépine, L., Lessard-Déziel, D., Bélec, M., Guddemi, C., & Nguyen, D.N.(2007), Millet, C., Nguyen, D.N., Lépine, L., Lessard-Déziel, D., & Guddemi, C.(2008)).

In this paper, electrical and chemical insulation diagnostic tests were carried out on 6.6kV motor stator windings. The insulation condition of stator windings was assessed by performing both of electrical and chemical diagnosis at the same time to investigate the relationship between them.

2. CONSTRUCTION OF EXPERIMENTAL SPECIMEN

A 6.6kV rotating motor stator windings were designed to have artificially made voids in stator winding insulations to figure out the characteristics of defect windings compared to commercially well-made stator windings. A 6.6kV phase U winding was intended to have no defects on winding insulations like commercially well-designed windings. On the other hand, phase V and phase W winding insulations were made without taping semi-conductive coatings to simulate slot discharges.

3. EXPERIMENTAL PROCEDURE

Before performing high voltage tests, DC insulation diagnostic tests(IR and PI) were conducted on each phase winding as a pre-check for the endurance of high voltage tests. PI value was obtained by the ratio of IR for 10min to 1min. The experiments were conducted by utilizing DC Megger(KEW3128, KYORITSU) applying DC 5kV under the conditions of ambient temperature 19℃, humidity 27%.

After DC insulation diagnostic tests, AC insulation diagnostic tests(DF, AC current and PD) were performed to figure out the characteristics of defect stator windings(phase V&W) and compare those with a well-designed stator winding(phase U). The AC insulation diagnostic tests were performed under the condition of applying the test voltage until the breakdown of winding insulations for each phase. The high voltage supply and control system, Schering Bridge(Type 2820, Haefely Test AG) were used to estimate values of the DF and AC current. The experiments were conducted under the conditions of ambient temperature 5℃, humidity 45%.

Finally, the O_3 measurements along with PD tests had been estimated by applying the AC voltage until the breakdown of the insulation system on each phase to relate PD magnitude to O_3 concentrations. The PD detector(LDS-6, Double) connected to coupling capacitor(1,000pF) was set up for measuring the magnitude and pattern of PD. For the O_3 measurement, a ozone detector(OEM-106, 2B Technologies), specially designed housing and ventilation systems were composed for the accurate estimation of O_3 concentration. The wind velocity at the outlet were set to be 1.5m/s to purge the ozone particles not to be affected by the accumulation of ozone molecules around the surface of slots and end windings.

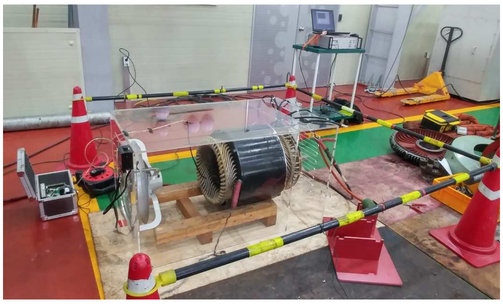

Figure 1. Test apparatus for estimation of PD and O_3

4. TEST RESULT AND DISCUSSION

The DC insulation diagnostic test results show that the IR and PI value of each phases meet the standard criteria.(IR:100MΩ, PI:2[IEEE43]) So, the AC insulation diagnostic tests were proceeded as sufficient strength for high voltage tests was obtained.

Table 1. IR and PI tests

Phase	IR[GΩ]		PI
	1min.	10min.	
Phase U	67	233	3.48
Phase V	32	176	5.54
Phase W	144	709	4.97

4.1. Estimation of Dissipation Factor and Δtanδ

The value of Δtanδ is obtained by subtracting DF at 1.91kV from DF at 6.6kV.

Table 2. DF and Δtanδ

Voltage [kV]	DF[%]		
	Phase U	Phase V	Phase W
0.95	0.85	1.91	2.75
1.91	0.87	1.98	2.85
2.86	0.88	2.26	3.11
3.81	0.88	3.63	4.38
4.76	0.93	6.00	5.89
5.50	0.97	7.08	7.06
6.00	1.00	8.06	7.86
6.60	1.06	8.95	8.86
Δtanδ	0.19	6.97	6.01

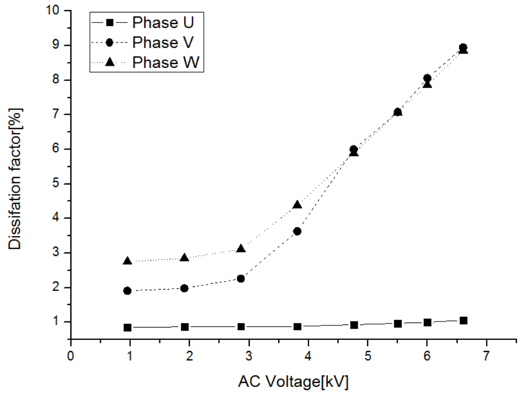

Figure 2. Characteristics of the Δtanδ-voltage

4.2. Estimation of AC current and ΔI

ΔI is obtained by the following equations:

$$\Delta I=(I-I_O)/I_O*100[\%]$$

where Io means the AC current at rated voltage assuming it is proportional to applied voltage.

Table 3. Estimation of AC current and ΔI

Voltage [kV]	AC current[mA]		
	Phase U	Phase V	Phase W
0.95	4.117	3.079	3.083
1.91	8.262	6.183	6.190
2.86	12.380	9.288	9.297
3.81	16.530	12.51	12.520
4.76	20.620	16.02	15.890
5.50	23.850	18.83	18.660
6.00	26.020	20.84	20.610
6.60	28.640	23.26	23.020
ΔI	0.32	8.15	7.08

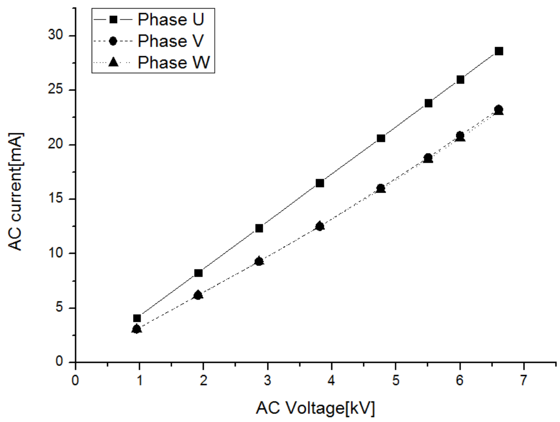

Figure 3. Characteristics of the AC current-voltage

Apparently, phase U showed the best insulation quality in the sense that both values of the $\Delta\tan\delta$ and ΔI were far lower than other phases. Also, it has been analyzed for phase V to be under the most severe insulation deterioration than phase W on the average.

4.3. Correlationship between PD and O_3 Emission in High Voltage Motor Stator Windings

The PD test results at rated voltage showed that phase V had the most severe defects than any other phase. Also, it has been analyzed to have the pattern of slot discharge as expected. Actually, the phase V and W winding insulations were designed and made to have severe gaps between windings and the core by eliminating semi-conductive tapes. The PD magnitude for phase V and W were in a range between 10,000 and 30,000pC which indicates a relatively cautionary level while that for phase U was below 10,000pC which indicates good conditions. Note that the result of PD test is in line with the DF and AC current test above.

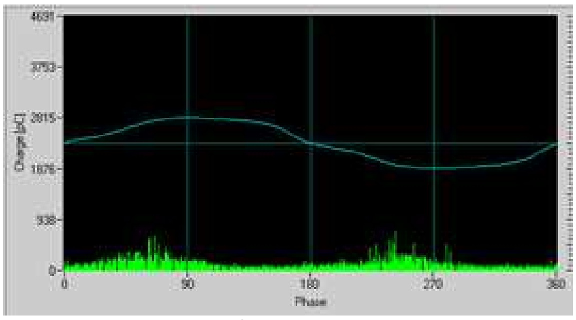

Figure 4. PD pattern for Phase U(1,663pC at 6.6kV)

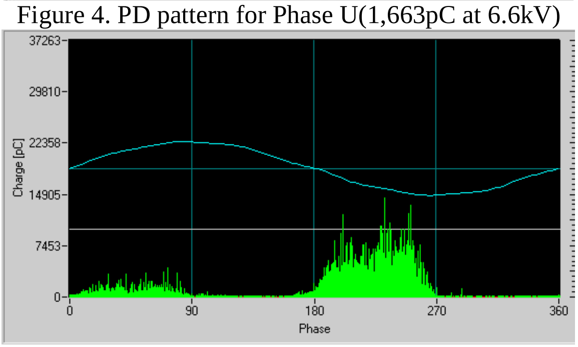

Figure 5. PD pattern for Phase V(21,442pC at 6.6kV)

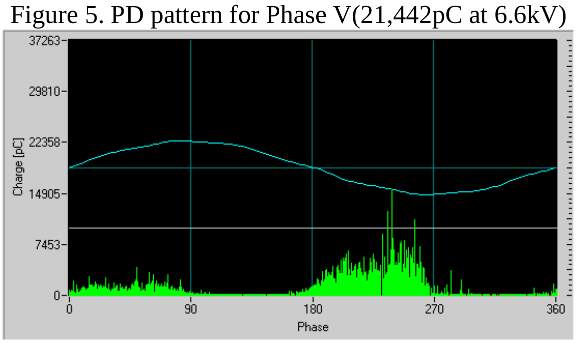

Figure 6. PD pattern for W-phase(17,624pC at 6.6kV)

Also, the PD magnitude and the O_3 gas emission have been measured at the same time and classified to prove the correlationship between them by applying AC voltage step by step up to 16kV for recording. It has been proved that the PD magnitude and the emission of O_3 are in a strong positive relation. Note the ratio of O_3 emission over PD value at 16kV. The ratio for phase V and W is far higher than phase U. It means that the O_3 produced mainly in the region of surface because electrical discharge and UV radiation react with oxygen to transform O_2 into O_3 around the air.

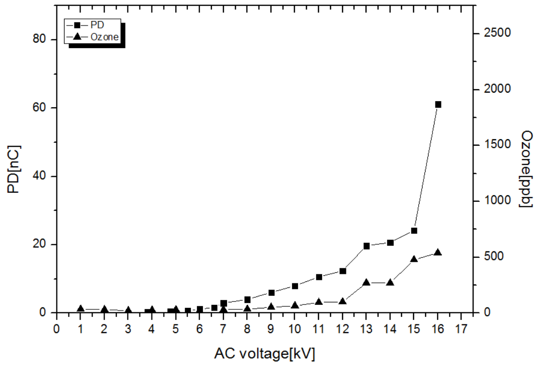

Figure 7. Estimation of PD and O_3 for U-phase (PD=61nC,O_3=540ppb at 16kV[O_3/PD≒8.9])

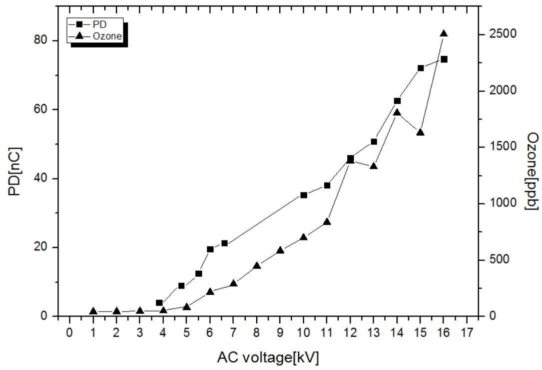

Figure 8. Estimation of PD and O_3 for V-phase (PD=75nC,O_3=2,505ppb at 16kV[O_3/PD=33.4])

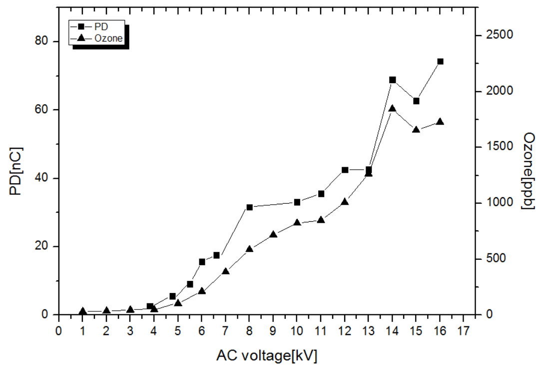

Figure 9. Estimation of PD and O_3 for W-phase (PD=74nC,O_3=1,727ppb at 16kV[O_3/PD≒23.3])

5. CONCLUSION

The AC insulation diagnostic tests showed that phase V had the severe voids on the windings than the other phases. Also, it has been analyzed that phase V have the traditional pattern of slot discharges. The phase W appeared to be the pattern of slot discharges as well, its pattern was rather weaker than the phase V. In contrast to both of the phase V and W windings, phase U stator windings had the internal discharge pattern typical for general windings. In other words, phase U stator winding has been considered to be in the most healthy insulation strength than other phases. It is no wondered that phase U insulation was broken down at the voltage of 31kV while phase V and W were broken down at the voltage of 21kV and 18kV when applying AC voltage until the breakdown of main insulations, respectively.

From the experimental results, it is clear that the ozone measurement is one of the powerful indices of the insulation deterioration on high voltage rotating machines during normal operation especially in case of slot discharges. In addition, the ozone measurements can be a helpful chemical insulation diagnosis in the sense that it’s rarely interfered by the electrical noise usually produced by surrounding facilities unlike PD tests.

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BIOGRAPHIES

Soo-Hoh Lee received his B.S. degrees in Electrical Engineering from Kyungbook National University, Daegu, Korea in 2010, and M.S. degree in Design of Wind Turbine Generator from POSTECH, Pohang, Korea in 2012. He worked for the Department of Rotating Machinery Development, Hyundai Heavy Industry from 2012 to 2016. Since 2016, he has been working for the Korea Electric Power Corporation(KEPCO). He is a researcher with the Technical Experts Center, KEPCO Research Institute, Daejeon, Korea.

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