Characteristics of Insulation Diagnosis and Failure in Generator Stator Windings

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Abstract: In order to evaluate the insulation deterioration in the stator windings of a 70MVA, 13.8kV generator which has been operated for long periods of time, diagnostic and AC breakdown tests were performed at phases A, B and C. The tests included measurements of AC current, dissipation factor, partial discharge (PD) magnitude and capacitance. ΔI and Δtanδ in all three phases (A, B and C) of generator stator windings showed that they were in good condition but PD magnitude indicated bad level to the insulation condition. Overall analysis of the results suggested that the generator stator windings were indicated the careful condition and patterns of the PD in all three phases were analyzed to be surface discharge. After the diagnostic tests, an AC overvoltage test was performed by gradually increasing the voltage applied to the generator stator windings until electrical insulation failure occurred, in order to determine the breakdown voltage. The breakdown voltage at phases A, B and C of generator stator windings occurred at 33.8kV, 31.9kV, and 28.3kV, respectively. The breakdown voltage was higher than that expected for good-quality windings in a 13.8kV class generator. There was a strong correlation between the breakdown voltage and various electrical characteristics in the diagnostic tests.

1 INTRODUCTION

Sudden electrical breakdown of the stator winding in a generator under operation can result in significant financial losses to utilities due to unplanned downtime, and can seriously harm the reliability of the power system. Failures in generator stator windings occur as a result of insulation deterioration initiated by voids that are created in the insulation material from the combined effects of thermal, electrical, mechanical, and environmental stresses during long-term operation [1, 2].

Many on-line and off-line insulation diagnostic tests have been developed and used over a long period of time for insulation quality assessment. Some commonly used off-line tests for verifying the condition of the insulation include the insulation resistance, polarization index (PI), AC current, dissipation factor, and partial discharge (PD) tests whose results are comprehensively analyzed to evaluate the overall insulation deterioration. These diagnostic tests are also performed regularly in Korea for assessing the insulation condition of generator stator windings, and the Japanese deterioration judgment criterion has been used for assessment [3].

In this paper, diagnostic and AC breakdown tests were carried out on stator windings of gas turbine generator (70 MVA, 13.8 kV) in a thermal power plant. The insulation condition of generator stator windings was assessed by analyzing the correlation between breakdown voltage and electrical characteristics of the diagnostic tests.

2 EXPERIMENTAL PROCEDURE

Generator has been in service for more than 35 years. The diagnostic tests included measurements of polarization index (PI), AC current, dissipation factor (tanδ) and partial discharge (PD) magnitude. PI was measured using an automatic insulation tester (Megger, S1-5010) at DC 5kV for each phase before applying AC voltage to the stator windings. Devices such as the Schering bridge (Tettex Instruments), coupling capacitor and PD detector (Tettex Instruments, TE 571) were used to measure the AC current, dissipation factor and PD magnitude. The Schering bridge consists of a HV supply (Type 5283), bridge (Type 2818) and resonating inductor (Type 5285). AC voltage was applied to the generator stator windings through a schering bridge connected to the windings while the coupling capacitor (Tettex Instruments, 4,000pF) amplified the signals from the windings by sending it to the coupling unit (Tettex Instruments, AKV 572) for the PD detector to analyze the PD magnitude and pattern. The frequency band of the PD detector ranged from 40 kHz to 400 kHz. Since the magnitude of the PD in generator stator windings ranges between 90,900 and 92,000 pC at 1.25 times of the line-to-ground voltage, it was measured in a general laboratory where background noise ranged between 990 and 1,000pC. The diagnostic and AC breakdown tests were carried out on the stator windings from generator at a voltage between 1.0 to 33.8 kV. After the diagnostic tests were completed, a variable HV supply (AC 50kV) and a bridge (Type 2819) were used to gradually increase the AC voltage applied to each phase of generator in 1kV intervals until electrical breakdown occurred in the stator windings to measure the AC current, dissipation factor and the breakdown voltage. The diagnostic test method that provides a good estimate of the breakdown voltage for generator stator insulation was investigated based on this data.

3 TEST RESULTS AND DISCUSSION

The insulation condition indicators measured from the diagnostics tests include the PI, the increase rate of charging current (ΔI), the increase of dissipation factor (Δtanδ), the maximum PD magnitude and the voltage at which charging current increases abruptly (P_{i1}, P_{i2}) : the first turning point voltage (P_{i1}) and the second turning point voltage (P_{i2}). The insulation condition can be assessed by comparing the diagnostic test results between the three phases of generator stator windings [4].

Table 1: Test results of PI and AC current in generator

Generator	PI	ΔI[%] at 13.8kV	ΔI[%] at 28.6kV	P_{i1}[kV]	P_{i2}[kV]
Phase A	1.47	1.79	4.69	8.1	23.2
Phase B	1.13	1.89	5.16	8.0	23.0
Phase C	1.23	2.69	6.04	7.8	22.7

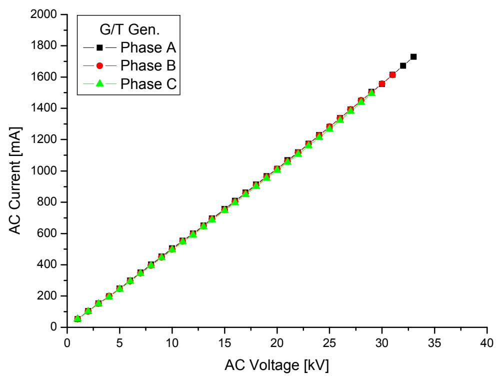

Figure 1: Comparison of AC current vs. voltage characteristics in generator

The PI will also tend to be low, in the range of 1.13 to 1.47 as shown in Table 1. The PI (below 2.0) of generator indicated that the stator winding is contaminated or soaked with water [5]. Figure 1 shows the change in current where the three phases encapsulated AC voltage was gradually increased in generator until insulation breakdown occurred. As can be seen from Figure 1, there are two turning points (P_{i1}, P_{i2}) where AC current soared suddenly. As summarized in Table 1, ΔI ranged among 1.79%, 1.89%, and 2.69% in generator at 13.8kV while ΔI at 28.6kV ranged among 4.69%, 5.16% and 6.04%, respectively. The ΔI of below 12% in 13.8kV generator is usually considered to indicate healthy insulation [6]; however, generator was determined to be in good condition because their ΔI was low with values between 1.79% and 2.69% at 13.8kV.

The P_{i1} voltage in phases A, B, and C of generator was 8.1kV, 8.0kV and 7.8kV, respectively, and their P_{i2} voltage were 23.2kV, 23.0kV, and 22.7kV, respectively. As the shown in Figure 1, the AC current vs. voltage traces for generator was almost linear. These results indicate that the stator winding insulation of generator is in very good condition.

The change in the dissipation factor while AC voltage applied to the stator winding was gradually increased until it reached the breakdown voltage, as shown in Figure 2. The Δtanδ had to be calculated based on the data from a 13.8kV generator. As it can be seen from Figure 2, the dissipation factor increased about 5kV. The Δtanδ measurements were among 1.46%, 1.71% and 1.68% at 13.8kV (according to [6], Δtanδ above 6.5% is considered to indicate bad insulation condition) as shown in Table 2. Therefore, the insulation condition of the stator winding for all three phases of generator was assessed to be in good condition because their Δtanδ values were below 2.0% at 13.8kV. As in the ΔI case, Δtanδ in phases A, B, and C of generator was fairly low with 2.98%, 4.03%, and 3.77%, respectively, when the generator was analyzed based on the Δtanδ measurement at 28.6kV.

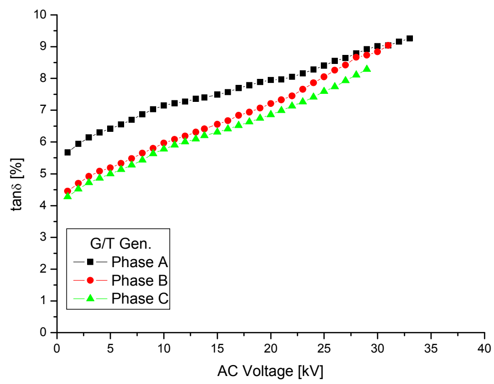

Figure 2: Comparison of tanδ vs. voltage characteristics in generator

Table 2: Test results of dissipation factor and capacitance in generator

Generator	Δtanδ[%] at 13.8kV	Δtanδ[%] at 28.6kV	tanδ increase voltage [kV]	ΔC[%] at 13.8kV	ΔC[%] at 28.6kV
Phase A	1.46	2.98	5	1.49	4.43
Phase B	1.71	4.03	5	1.67	5.27
Phase C	1.68	3.77	5	1.70	5.41

The capacitances measured as a function of applied voltage (up to 33.8kV) in three phases of generator stator windings is shown in Figure 3. The

ΔC had to be calculated based on the data from a generator. As it can be seen from Figure 3, the capacitances increased abruptly about 5kV. At 13.8kV, the ΔC measurements in phases A, B, and C of generator were among 1.49%, 1.67% and 1.70%, respectively. As in the Δtanδ case, ΔC in phases A, B, and C of generator was fairly low with 4.43%, 5.27%, and 5.41%, respectively, when the generator was analyzed based on the ΔC measurement at 28.6kV. The values of the capacitance and dissipation factor in three phases A, B, and C of generator increased at similar test voltages, as shown in Figures 2 and 3.

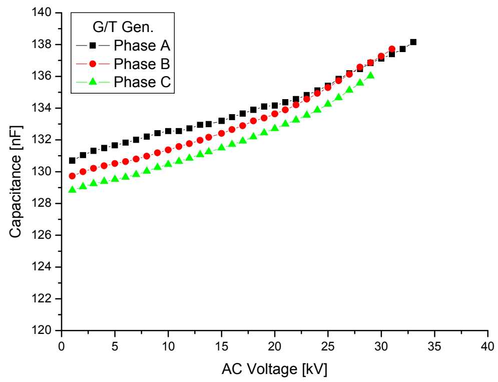

Figure 3: Comparison of capacitance vs. voltage characteristics in generator

The discharge inception voltage (DIV) and PD magnitude were measured while three phases encapsulated AC voltage was applied to the stator windings and the results are summarized in Table 3. The discharge inception voltage (DIV) refers to the voltage when the PD magnitude starts to exceed the background noise level of hundreds of pC, and goes above 1,000pC. As can be seen from Figure 2, since dissipation factor increases the range of about 5kV, DIV is also expected to occur within this range. The DIV measurements at the site were from 5.1kV and 5.4kV, as predicted. The PD magnitude in phases A, B, and C of generator ranged among 90,900, 91,000, and 92,000pC at 10kV (1.25 times of the line-to-ground voltage). Since the PD magnitude above 30,000pC at 10kV is considered to indicate bad insulation condition [6].

Table 3: Test results of noise, PD magnitude and breakdown voltage in generator

Generator	System Noise [pC]	DIV [kV]	PD Magnitude [pC] E/√3	PD Magnitude [pC] 1.25E/√3	Breakdown Voltage [kV]
Phase A	990	5.4	88,000	90,900	33.8
Phase B	1,000	5.2	87,000	91,000	31.9
Phase C	1,000	5.1	87,000	92,000	29.3

The PD pattern was attributed to surface discharge. Surface discharge occurs in the end winding. It is normally caused by dust or other contaminants, is enhanced by a bad performance of the stress grading paint [2, 7]. The values of the PI, AC current, dissipation factor, and PD magnitude in the generator stator windings are shown in Tables 1-3. In all three phases of the stator windings, the PI measurements were below 2.0, indicating that the stator winding is contaminated or soaked with water [5]. As stated earlier, the ΔI and Δtanδ values in phases A, B, and C indicated that the insulation is in good condition, whereas the PD magnitude measurements suggested the bad condition. In addition, when the insulation was in fair condition, the point at which the dissipation factor in the tanδ-voltage curve increased was approximately 2.8 kV or 3 kV lower than the voltage at which P_{i1} appeared in the AC current-voltage characteristics. It was also similar to the DIV. Therefore, when insulation deterioration occurs in the generator stator windings, increasing point of dissipation factor, P_{i1} of AC current and DIV both decrease, and dielectric breakdown voltage also decreases.

After the diagnostic tests were completed, an AC overvoltage test was performed by gradually increasing the voltage applied to the stator windings until electrical insulation failure occurred, in order to determine the breakdown voltage. The breakdown voltage at all three phases (A, B and C) of generator stator windings occurred at 33.8kV, 31.9kV, and 28.3kV, respectively. The actual breakdown voltage of the generator stator winding was higher than the 2E+1kV test voltage and the dielectric strength of each individual winding is still higher. The breakdown voltage was higher than that expected for good-quality windings in a 13.8kV class generator [8, 9].

4 CONCLUSION

In this paper, a number of diagnostic and AC breakdown tests have been performed on the stator windings obtained from 13.8kV gas turbine generator in a thermal power plant. The conclusions drawn from the tests can be summarized as follows:

- The measurements of ΔI and Δtanδ in all three phases showed the generator stator windings to be in good condition, although the PD magnitude indicates bad condition. The overall analysis of the results suggested that the generator stator windings were in the careful condition and that the PD patterns in all three phases could be attributed to surface discharge. At 8kV and 10kV, when the PD magnitude measurements are high, the breakdown voltage in phases A, B, and C of generator were relatively high among 33.8kV, 31.9kV, and 29.3kV.

- The voltage at which dissipation factor shows an abrupt increase is almost the same as that of the DIV measurements. The point at which the dissipation factor in the tanδ-voltage curve increased was approximately 2.8 kV or 3 kV lower than the voltage at which P_{i1} appeared in the AC current-voltage characteristics.
- The results of the diagnostic tests performed on the generator stator windings showed that there was a strong positive correlation between the degradation in the insulation condition. The remaining service life of generator stator windings is predicted by comparing the results of the diagnostic tests. These results may be used as a guide to assess insulation conditions of generator.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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