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Reliability and Operation test of SF_6-free 170kV 50kA GIS with Fluoronitile (C_4F_7N) Mixtures

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SUMMARY

In 2016, the KEPCO (Korea Electric Power Corporation) announced a new policy of eco-friendly GIS adaptation using the alternative gas specified below than GWP 500 (100 years) for 170kV 50kA GIS. The mixture gas using C_4F_7N is the strongest candidate for the alternative gas and has been activated in Korea. Since 2016, the SF_6 free 170kV 50kA GIS development was started for the circuit breaker and other equipment. It was successfully completed in 2020.

After the first SF_6 free 170kV 50kA GIS development in 2020, the operation data is required to have proper management scheme before commercial application. For this purpose, new develped SF_6 free GIS has been installed and was operated for 8 months at a KEPCO's pilot substation and the operation data of SF_6 free 170kV 50kA GIS and new mixed gas was obtained. The pilot operation test has been launched since January 2021 at Wanggok substation and the test GIS was consisted of new development SF_6 free equipments which were a circuit breaker, disconnetors and earthig switches, a voltage transformer, and a surge arrester. During the pilot operation, various tests were conducted to to obtain operationg data of the SF_6 free GIS such as periodic operation, gas analysis, and PD monitoring. Also the installation, gas handling, and operation data obtained during pilot operation will be used for next commercial operation.

For the reliability of SF_6 free 170kV GIS using C_4F_7N mixed gas with O_2 which is included for the advantage on the dielectric performance and reducton of carbon monoxide and byproducts, the oxidation test and long-term reliabilty test was conducted. Especially, the oxidation test was conducted during 1,000 hours and it was founded that the color was changed and oxidation was happened at one of the specimens after test. So, the suface treatment was changed and the compatability was verified for the Oxygen. Since the high voltage transformer is one of the most important equipments, the long-term reliability test for the single and three phase voltage transfomer had been conducted to verify the 25-year lifetime.

KEYWORDS

Alternative gas, SF_6 free, Gas mixture, Fluoronitile, C_4F_7N, Pilot operation

1. INTRODUCTION

Since 2016, SF_6 free GIS developmen was started and among the SF_6 alternative gas, the mixture gas using C_4F_7N with O_2 is the good candidate for the SF_6 free GIS because of the high dielectric strength and breaking performance. The high dielctric strength made it possible to design SF_6 free 170kV GIS with almost similar size as SF_6 170kV GIS. The first development of SF_6 free 170kV 50kA GIS was completed sucessfully in 2020 including voltage transformers and surge arrester [1][2].
With introduceing new SF_6 alternative gas in GIS, it was necessary to establish new maufacturing process. The GIS maufacturing process such as assembly, testing, transportation, and installation need to be re-established to fit SF_6 free GIS. KEPCO must have to prepare for SF_6 free 170kV 50kA GIS using many kinds of new SF_6 alternative gas. Many GIS manufactures are developing or developed SF_6 free 170kV GIS using various SF_6 alternative gases which are dry air and different types of C_4F_7N mixture gas in Korea.
As KEPCO expects to use various SF_6 alternative gases in many GIS manufacturers, they must prepare the operaton manuals such as new gas handling and installation for each SF_6 alterantive gas and each GIS manufacture. So, KEPCO request the pilot operation test for the new developed SF_6 free GIS and want to check the initial stage problem. For the pilot operation test, KEPCO construct the new pilot substaion in Wanggkok substation. The test equipments are connected to actual high voltage transmission line via SF_6 circuit breaker that can separate the test equipments from transmission line if an accident occurs in test eqipments.

2. Pilot operation at test substation

2.1 Layout and installation

The test equipment for a pilot operating test of SF_6 free 170kV 50kA GIS (hereafter "SF_6 Free GIS) was composed of circuit breaker, disconnector, earthing switch, voltage transformer, and surge arrester. Figure 1 shows the single-line diagram and test layout of SF_6 free GIS for the pilot operation test. And it is designed to have three gas compartments: CB (circuit breaker and current transformer), DS #1 (No. 1 main bus and disconnector), and DS #2 (No. 2 main bus, disconnector, single voltage transformer, and surge arrester). After installation at the test substation, leakage and gas analysis etc. have been conducted with special test equipment for new C_4F_7N mixture gas. A monitoring system for test GIS is also installed to monitor partial discharge, CB operation, and gas pressure etc.

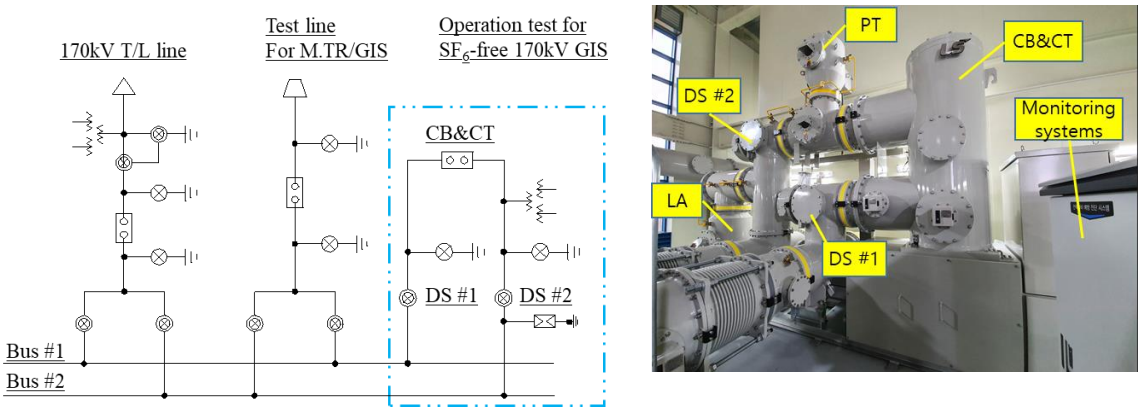


Figure 1. Single-line diagram for pilot opration test (left) and SF_6 free GIS installed at Wanggok substation (right)

2.2 Operation and Monitoring

The SF_6 free GIS was installed and had been operated in KEPCO's Wanggok substation for pilot operation for 8 months from January to September 2021. During pilot operation test, circuit breaker and disconnectors had been operated twice a week and gas analysis and PD monitoring had been done as shown in Table 1.

No.	Check & Monitoring	Remarks
1	Visual Inspection	A week
2	CB & DS Operation	2 times/week
3	Gas Analysis	1 time/ month
4	PD Monitoring	On-line
5	Gas Pressure	On-line

Table 1. Check and monitoring during pilot operation test

2.2.1 Gas analysis for mixed gas

SF_6 free GIS adopts the C_4F_7N mixed gas containing CO_2 and O_2. Especially, O_2 was included because it affects the breaking and dielectric performance circuit breaker [3]. The operating sequence at open operation was as follows; CB → DS #1 → DS #2, and at close operation, DS #1 → DS #2 → CB. The operation of circuit breaker and disconnectors made the small arc between the contacts and the ratio of C_4F_7N mixed gas could be changed. Especially, the carbon is the most important one of the by-products originated from the CO_2 because it could give sever effect on the long-term dielectric reliability. The gas analysis was carried out for the C_4F_7N, O_2, CO_2 and CO components as shown in Figure 2. According to the analysis, the ratio of the C_4F_7N, O_2, and CO_2 kept constant in CB , DS #1, and DS #2 during the pilot operation test.~~,~~ According to analysis results, the amount of CO is detected in DS #1 unit at 7_{th} analysis. Because DS #1 had been always connected to high voltage transmission line via SF_6 GIS and current switching is there. The amount of the CO kept constant and stable after 7_{th} analysis. By this the test GIS was inspected after the pilot operation test.
The gas analysis had been performed using FT-IR and GC-MS equipment until 5_{th} gas analysis but it was found that the FT-IR analysis could not detect CO content at low CO density. Since then, GC-TCD and GC-MS methods have been used for the gas analysis.

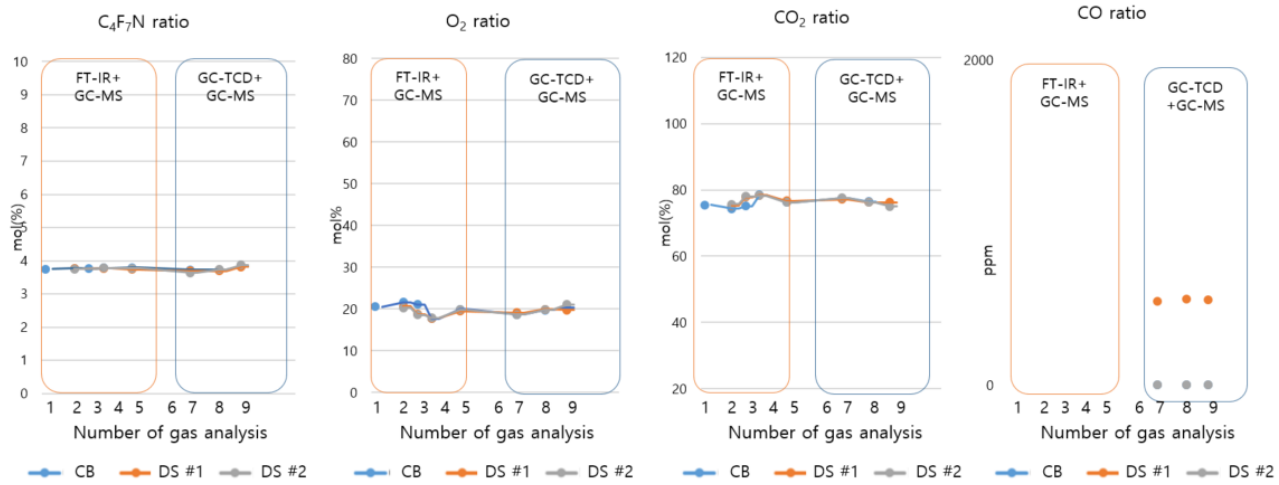
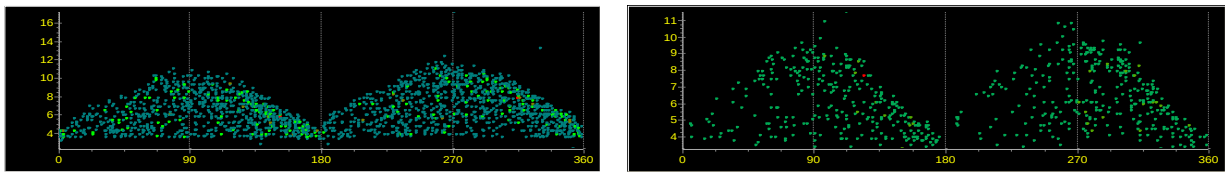


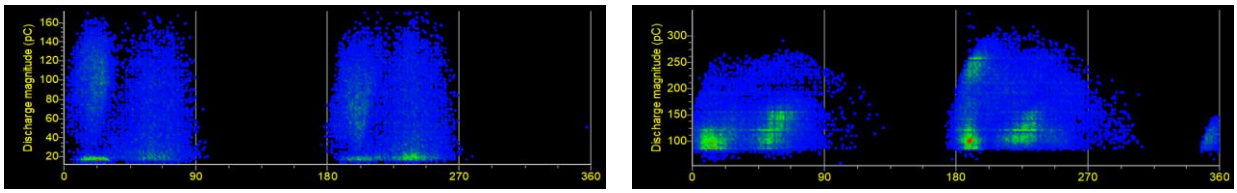
Figure 2. Gas analysis result of C_4F_7N (left), O_2 (middle), CO_2 (middle), CO (right)

2.2.2 PD and gas pressure monitoring

PD monitoring system was installed in SF_6 free GIS and PD pattern has been analyzed and compared in SF_6 and C_4F_7N mixed gas as shown in Figure 3. As a result of the comparative test for PD pattern, each of defects shows similar PD pattern to SF_6 and results could be implemented as a library to PD monitoring system for SF_6 free GIS.



(a) PD pattern for moving particle in SF6(left) and Mixed gas(right)



(b) PD pattern for void in SF_6 (left) and Mixed gas (right)

Figure 3. PD pattern comparison between SF_6 and C_4F_7N mixed gas

PD sensor is installed in circuit breaker and PD was detected and analyzed. During pilot operation test, PD has occurred at the instant of operation of circuit breaker and disconnector periodically. Figure 4 shows the records in PD monitoring systems.

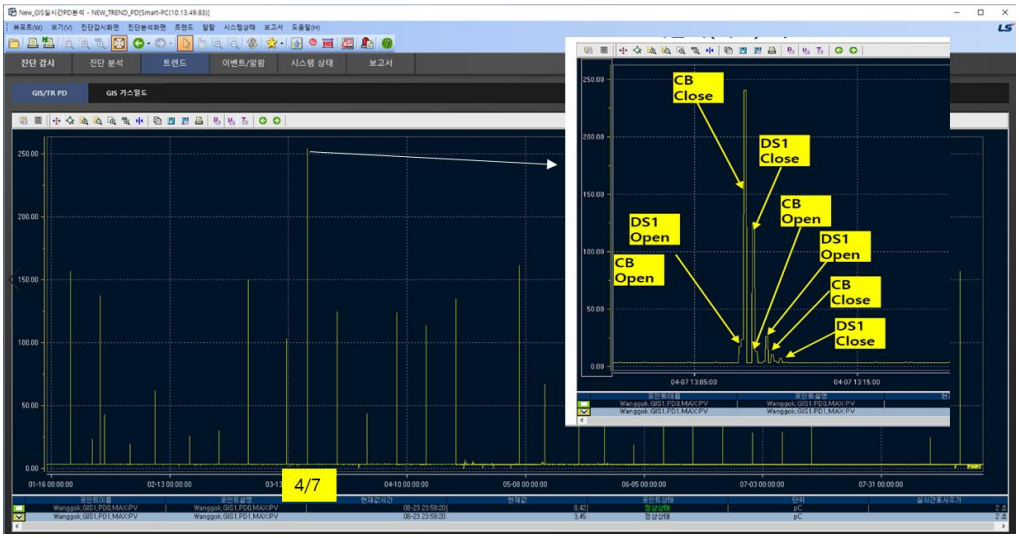


Figure 4. PD event record in monitoring system

Because SF_6 free GIS generally requires a higher gas pressure than SF_6 GIS and the molecular weight of C_4F_7N mixed gas is the smaller than SF_6, the gas leakage must be considered. As a result of checking the pressure change for each unit during the pilot operation test period of 8 months, it has maintained without change.

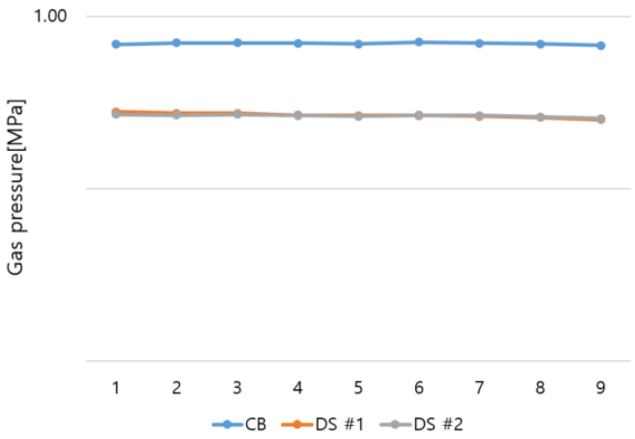


Figure 5. Gas pressure during pilot operation test

2.4. After pilot operation test

2.4.1 Inspection

After pilot operation test of SF_6 free GIS, a visual inspection has been done as it was without disassembly at Wanggok substation. And the GIS was transported to the factory and disassembled fully. The inspection was conducted in detail for contacts, nozzles, insulators etc. Especially, it was focused on DS #1 unit, because the CO ratio in DS #1 unit was detected during the pilot operation test. As shown in Figure 6, the small arc traces were founded on guide ring. However, it is normal phenomenon at disconnector after current switching.

Figure 6. Fixed contact of DS #1 (A phase (left), B phase (middle), C phase (right))

2.4.2 Dielectric test

The mixed gas which had been used in pilot operation test was collected for each unit and the breakdown voltage for dielectric characteristics was compared new and collected mixed gas at test chamber. The breakdown voltage was measured by changing the gap distance between the electrodes for AC and LI tests.

As a results of the dielectric test in Figure 7, it showed that the breakdown voltage of used gas were about 99% ~ 105% at AC test and about 97% ~ 108% at LI test of new gas. After pilot operation test, breakdown voltage did not decrease despite the change in CO density in mixed gas used.

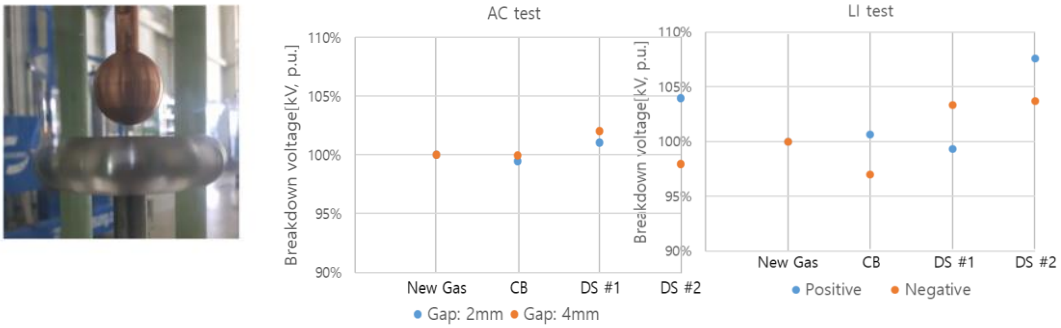


Figure 7. Dielectric test chamber (left) and breakdown voltage at AC test (middle), LI test (right)

3. Reliability test

3.1 Oxidation test

To improve the breaking and insulation performance, O_2 is used in SF_6 free GIS. However it is necessary to review the oxidation by O_2. The oxidation test was conducted with several specimens in SF_6 and C_4F_7N mixed gas with O_2 respectively for 1,000 hours. In Figure 8, test objects are compared before and after oxidation test. The corrosion layer was formed in the red circle area and it was solved by changing surface treatment.

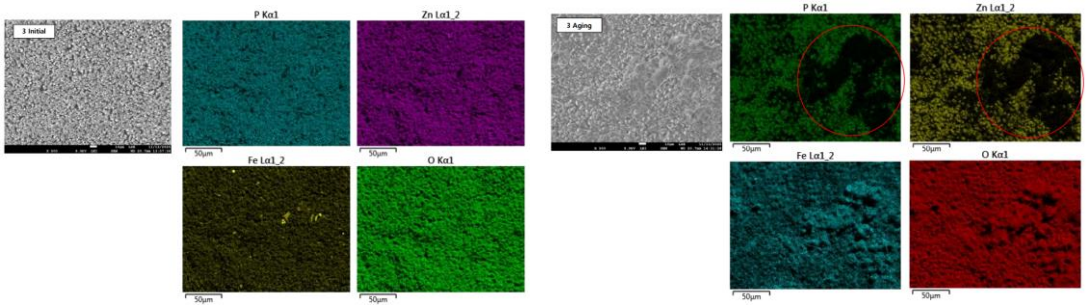


Figure 8. Oxidation test object before (left) and after test (right)

3.2 Long term reliability test for voltage transformer

The voltage transformer composing lots of insulating materials is a key component in SF_6 free GIS. So, the long-term reliability performance has been conducted for single phase and three phase voltage transformer, respectively. An Accelerating aging test has been done with increased voltage considering insulating paper characteristics to verify 25-year lifetime. After aging test, the routine test was conducted and visual inspection as well. Figure 9 shows the voltage transformer with C_4F_7N mixed gas under long-term reliability test.

Figure 9. Long term reliability test for single phase (left) and three phase (right) voltage transformer

4. Conclusion

The advantage of C_4F_7N mixture gas among the alternative gases is high dielectric performance. So, SF_6 free GIS using C_4F_7N mixture gas had been developed in similar dimension compared to SF_6 GIS and the pilot operation test was conducted successfully during 8 month in Wanggkok pilot substation. From this, the operating procedures are established for the next commercial operation.

O_2 is useful to improve breaking and insulation performance in the SF_6 free GIS with C_4F_7N mixture gas. However, some of material and surface treatments may cause the oxidation under O_2 condition. Hence, oxidation test is recommended.

Through pilot operation test, all units which are more than enough to implement SF6 free GIS to commercial market in Korea had been tested and verified successfully.

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