PARATION AND TEST OF CRYOGENIC DIELECTRIC TEST FACILITIES FOR EXTRA HIGH VOLTAGE SUPERCONDUCTING ELECTRIC EQUIPMENT

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Abstract: Superconducting devices for transmission system were not available for commercial applications until now. One of the critical matters unsolved is high voltage insulation technologies in cryogenic environments. Furthermore, developers of superconducting electric equipment have difficulties in determining good choice of insulation materials and optimum high voltage insulation size due to the lack of information of high voltage cryogenic dielectrics. For these reasons, it is necessary to be equipped with extra high voltage cryogenic insulation test facilities in order to establish cryogenic dielectric technologies on the insulating design, insulation test methods for cryogenic systems. Recently 154 kV high voltage cryogenic dielectric test facilities have been built in Hanyang University in Korea. Major facilities are 2 m diameter and 3 m high FRP cryostat with 154 kV bushings, and 1.6 MVA lightening impulse generator, 400 kV 1 A AC overvoltage test system, and the electromagnetic shield room for cryogenic PD test. In this paper, the preparation of extra high voltage test facilities, fabrication and installation of big size cryostat, and the modification of extra high voltage bushings for cryogenic environment would be introduced in detail.

1 INTRODUCTION

Recently, high-temperature superconducting equipment including superconducting fault current limiters, superconducting transformers, and superconducting cables were under development by the funding of 21st century superconducting frontier project [1]. And their final target is to develop commercial products which could be installed at 154 kV transmission systems in Korea. Around the world, many research projects to develop commercial superconducting devices are undergoing and their final targets are also aims at the applications in extra high voltage markets [2]-[3].

The reason is that the manufacturing costs of superconducting electric devices are too high compared to the conventional devices at present. Therefore, considering economic efficiency and their utilities' needs, the main stage for superconducting electric equipment will be transmission electric networks.

But until now, superconducting devices for transmission line were not available for commercial applications. One of the critical matters must be solved is high voltage insulation technologies in cryogenic environments. And furthermore, utilities that develop superconducting equipment have difficulties in determining good choice of insulation materials and optimum high voltage insulation size due to the lack of information of high voltage cryogenic dielectrics.

And specialized test facilities for extra high voltage superconducting equipment were not available. In addition, determination of insulation level for extra high voltage systems could not be simulated from the obtained test results from the downsized test model [4]-[5].

For these reasons, it is necessary to be equipped with extra high voltage cryogenic insulation test facilities in order to establish the cryogenic dielectric technology on the insulating design, insulation test methods for cryogenic systems. Recently 154kV high voltage cryogenic dielectric test facilities have been built in Hanyang universities in Korea. Major facilities are 2 m diameter and 3 m high FRP cryostat with 154kV bushings, and 1.6MVA lightening impulse generator, 400kV 1A AC overvoltage test system, and the electromagnetic shield room for cryogenic PD test [4].

The most important task to construct high voltage cryogenic dielectric test system is the design and fabrication of big size cryostat with high credibility and also fabrication of the extra high voltage bushings for the test in cryogenic liquids.

So in this paper, these important matters including the preparation of extra high voltage test facilities, fabrication and installation of big size cryostat, and the modification of extra high voltage bushings for cryogenic environment were introduced.

And some test results of modified high voltage commercial bushings for liquid nitrogen cryostat in order to implement 154kV bushings were illustrated.

Until now, extra high voltage bushings for superconducting equipment were not available in the market. Thus, in order to apply extra high voltage to the prepared cryostat, modified commercial bushings by applying various kinds of insulating gases were fabricated and lightening impulse tests were performed to evaluate its insulation properties. And also, its possibilities as high voltage bushings for extra high voltage cryogenic systems were analysed.

2 CRYOGENIC DIELECTRIC TEST FACILITIES

Figure 1 shows the key facilities for cryogenic dielectric test facilities in Hanyang University and their major specifications were listed in Table I. And Table 1 shows possible test items for insulation characteristics of EHV HTS devices.

(a) 1600kVA Impulse generator

(b) 154kV Cryostat

(c) 400kV AC test transformer

(d) Shield room

Figure 1: Overview of cryogenic dielectric test facilities

Table 1: Specifications of the samples

No.	*Test Item*	*Major specifications*
1	1.6MVA Lightening impulse generator	Lightning Impulse Voltage : 1600 kV Switching Impulse Voltage: 1200 kV
2	400kV AC test transformer	Output Voltage: 400 kV Output current:1A PD Level: 2 pC
3	Cryostat	Diameter: 2600mm Height: 3300mm
4	Shield room	Frequency: 1 kHz-GHz Performance: 110dB
5	PD test set	PD free transformer : 100kV 1A PD measurement :0-999 pC/ nC

3 DESIGN AND FABRICATION OF 154KV CRYOSTAT

From IEC standards 60076-1, 60076-3 for power transformers, 154 kV electric equipment should be tested by 750 kV_{peak} lightening impulse voltage, and 350 kV_{rms} AC withstand voltage. Therefore in order to perform cryogenic dielectric tests for extra high voltage superconducting electric equipment, lightening impulse generator, chopping gap for lightening impulse test set, AC test transformers for withstand voltage test, cryostat with suitable bushing for extra high voltage tests should be prepared. Thus, all kinds of insulation tests for extra high voltage devices up to 170 kV was possible. But in order to test EHV superconducting equipment, big cryostat enough to endure up to 170 kVrms should be fabricated with suitable bushing.

After full consideration of the optimum size of cryostat for extra high voltage test, inner layer of cryostat was made of fiber reinforced plastic to reduce the total volume of the cryostat.

Figure 2 shows the structure of 154kV cryostat. Outer layer of cryostat was made of STS-316L and its diameter was 2600 mm and 3300 mm high. ISO 100 Pumping Port, ISO 100 Safety Port, and four lifting lug was installed on the top flange.

And also digital vacuum gauge was attached on the cryostat to check the degree of vacuum. Inner layer was made of FRP (fiber reinforced plastic) whose diameter was 2300 mm and height was 2900 mm.

This cryostat was designed to contain sub-cooled 65 K liquid nitrogen about 7000 Liters. And in order to reduce external radiant heat under 1W/m2, multi-layer insulation was adopted for super insulation.

4 INVESTIGATION OF HIGH VOLTAGE BUSHING FOR CRYOGENIC LIQUIDS

Until now, suitable bushings for superconducting HTS equipment were not developed due to the cryogenic insulation issues. Extra high voltage should be applied on the cryogenic temperature superconducting equipment by means of high voltage bushings which provides electrical insulation capabilities from room temperature to cryogenic temperature. Due to the steep temperature gradient, commercial bushings which insulated by oil or SF_6 gases could not directly apply to the cryonic equipment.

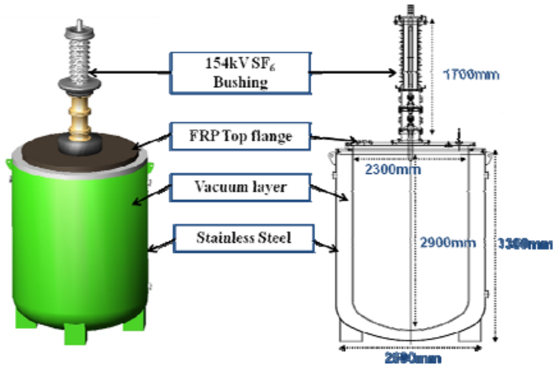


Figure 2: The structure of cryostat and bushings for 154 kV insulation tests

Therefore, suitable structure and insulation methods considering the steep temperature gradient should be developed. As a fundamental step to develop an optimum bushings for the cryostat, modification of conventional bushings were attempted. As a first step to develop 154kV bushing, 60 kV SF_6 bushings were reconstructed to acquire proper insulation performances. Figure 3 shows the modified structure of 60 kV SF_6 bushing. The modified bushing could be divided into three parts according to their insulation media. The upper parts of bushings were filled with 4 atm SF6 gas which has a excellent dielectric characteristics. And the middle part was filled with mixed insulation gas with 20 % SF6 and 80 % N2. Finally the lower parts which directly contact with cryogenic temperature were filled with different gases including pressurized N2, SF_6, CO2, and Helium gas in order to evaluate their insulation characteristics in cryogenic environments.

Liquid nitrogen was filled in the cryostat up to 30 cm high, and empty upper space in cryostat was injected with He, N2, CO2, and SF_6 gas pressure of 2 atm respectively to compare the insulation properties in cryogenic environments.

Basic lightening impulse voltage of 1.2 × 50 μs was applied to the bushing and their insulation performance was evaluated. Initial value of lightening impulse voltage was 80 kV and increased step by step by 10 kV intervals till the breakdown voltage.

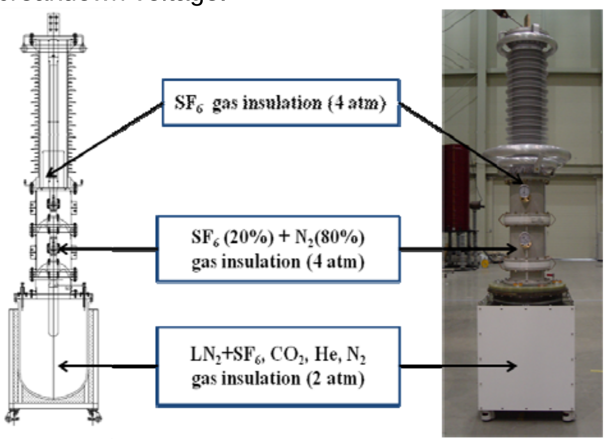
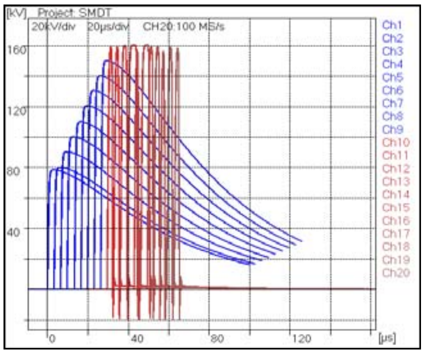
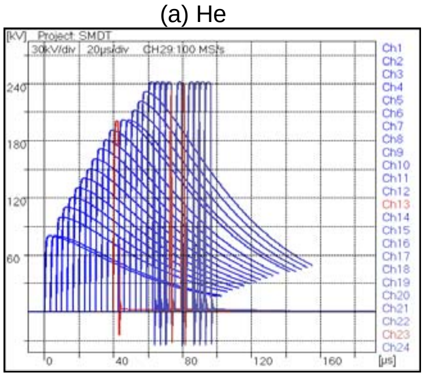


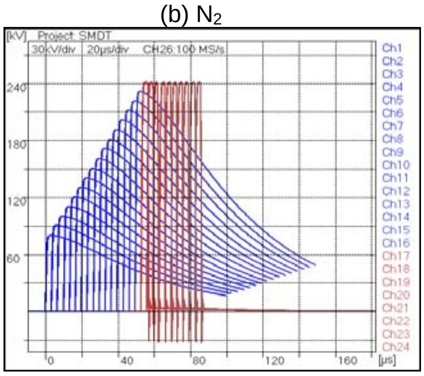
Figure 3: Modified 60kV bushings and its structure



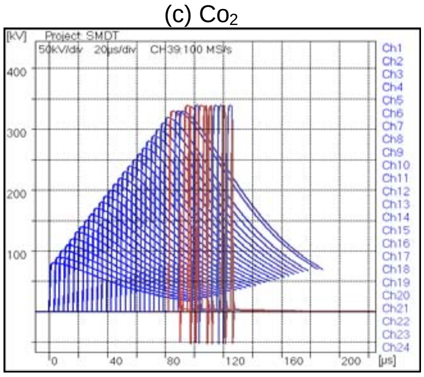
(a) He



(b) N_2



(c) Co_2



(d) SF_6

Figure 4: Lighting impulse test results of the bushing in cryogenic system

10 times of repetition breakdown tests were performed to determine its lightening impulse breakdown voltage.

From IEC 60071 standards, 60 kV bushings could pass the 280 kV lightening impulse voltage, so we'd like to determine whether these gases could fulfil this requirements.

Figure 5 shows the lightening impulse test results of the bushing filled with different gases in cryogenic system. In case of helium gas pressure of 2 atm, impulse breakdown voltage was 160kV and shows the lowest value among other gases. Impulse breakdown of N2 gas pressure of 2 atm was partly begun at 190kV and average measured breakdown voltage was 240 kV. In case of CO2 gas of 2 atm, breakdown was occurred at 240 kV but rather stable tendency compared to that of N2 gas.

Above all three gases of 2 atm could not meet the requirement of IEC60071 standards. But in case of SF_6 gas of 2 atm, impulse breakdown voltage was 340 kV, which could fulfil the standards. But the freezing point of SF_6 gas was about -50℃, thus as shown in figure 6, a layer of ice was occurred at the brim of liquid nitrogen surface.

Surely, existence of this ice layer could lower the pressure of SF_6 gas, and affect the dielectric properties of SF_6 gas. But its thickness and density was rather low than expected and did not significantly increased by elapsed time. From the literature sited, it was shown that SF_6 dielectric behaviour in a High Voltage Circuit Breaker at Low Temperature under Lightning Impulses was affected mainly by the gas pressure, not by its surrounding temperature [7]. Thus, in cryogenic environments, the usage of SF_6 gas should be considered by enhancing the pressure of gas and by mixing of suitable gas to lower the freezing points.

From the experimental results, it was known that SF_6 gas had a possibility to be used in cryogenic environments in spite of freezing phenomena. Therefore, further experiments will be proceed regarding the SF_6 gas insulation or mixed SF_6 gas insulation of 154 kV bushings and suitable methods to reduce the icing layer by application of separation membrane. If these experimental tests put together, the solution of extra high voltage bushings for cryogenic superconducting equipment could be obtained in the near future.

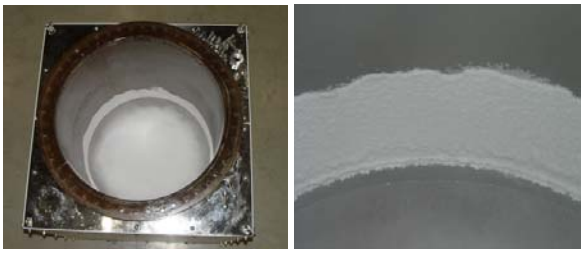


Figure 5: The picture of layer of SF_6 ice on the brim of inner cryostat : (a) SF_6 ice layer in the Dewar (b) Magnification of SF_6 ice layer

5 CONCLUSION

It is necessary to be equipped with extra high voltage cryogenic insulation test facilities in order to establish the cryogenic dielectric technology on the insulating design, insulation test methods for cryogenic systems. Thus, installation of high voltage cryogenic dielectric test system with a big size cryostat of 154 kV rated voltage would contribute the development and test of extra high voltage superconducting equipment. And the possibility of modification of conventional extra high voltage bushing in cryogenic environments was suggested by application of pressurized SF_6 gas. If planned other experiments were going well, the solution of extra high voltage bushings for cryogenic superconducting equipment could be available in the near future.

6 REFERENCES

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