pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.17, No.1, (2015), pp.44~47
http://dx.doi.org/10.9714/psac.2015.17.1.044

A study on the barrier effect with respect to the condition of solid insulation materials in GN_2

Hongseok Lee[*, a], Young Kyu Mo[a], Onyou Lee[a], Junil Kim[a], Seungmin Bang[a], Jong O Kang[a], Seokho Nam[b], and Hyoungku Kang[a]

[a]*Department of Electrical Engineering, Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk, 380-720, Republic of Korea*
[b]*Department of Electrical & Electronic Engineering, Applied Superconductivity Lab., Yonsei University, Seoul, Republic of Korea*

(Received 23 February 2015; revised or reviewed 19 March 2015; accepted 20 March 2015)

Abstract

High voltage superconducting apparatuses have been developed presently around the world under AC and DC sources. In order to improve electrical reliability of superconducting apparatuses with AC and DC networks, a study on the DC as well as the AC electrical breakdown characteristics of cryogenic insulations should be conducted for developing a high voltage superconducting apparatus. Recently, a sub-cooled liquid nitrogen cooling system is known to be promising method for developing a high voltage superconducting apparatus. A sub-cooled liquid nitrogen cooling system uses gaseous nitrogen to control the pressure and enhance the dielectric characteristics. However, the dielectric characteristics of gaseous nitrogen are not enough to satisfy the grade of insulation for a high voltage superconducting apparatus. In this case, the application of solid insulating barriers is regarded as an effective method to reinforce the dielectric characteristics of a high voltage superconducting apparatus. In this paper, it is dealt with a barrier effect on the DC and AC dielectric characteristics of gaseous nitrogen with respect to the position and number of solid insulating barriers. As results, the DC and AC electrical breakdown characteristics by various barrier effects is verified.

Keywords: high voltage superconducting apparatus, barrier effect, gaseous nitrogen, dielectric characteristics, DC electrical breakdown

1. INTRODUCTION

Many researches on the dielectric characteristics of cryogenic insulation materials have been conducted for developing high voltage superconducting apparatuses such as a superconducting fault current limiter, a superconducting transformer and so on [1]. A high voltage superconducting apparatus with a sub-cooled liquid nitrogen cooling system uses gaseous nitrogen (GN_2) to control the pressure and enhance the dielectric characteristics. It is important that a study on the dielectric characteristics of GN_2 is conducted from ambient temperature to sub-cooled liquid nitrogen temperature because current lead as part of superconducting apparatus is classified into ambient temperature part and cryogenic part. Also, the application of solid insulating barrier is regarded as an effective method to reinforce the electrical breakdown voltage of a high voltage superconducting apparatus. In this paper, barrier effects on the DC as well as the AC electrical breakdown characteristics of GN_2 are conducted. All experiments for DC and AC electrical breakdown are conducted in GN_2 under atmospheric condition. Two kinds of solid insulation materials, such as glass fiber reinforced plastic (GFRP) and MC Nylon are used as a solid insulating barrier. To conduct the dielectric experiments, the solid insulation material is placed between a rod and plane electrode. The DC and AC electrical breakdown voltages and flashover path with respect to the position and number of solid insulating barriers are observed and analyzed. As results, the DC and AC electrical breakdown characteristics with respect to various barrier conditions are analyzed.

* Corresponding author: kang@ut.ac.kr

2. EXPERIMENT

2.1. Experimental Set-up

Dielectric experiments for DC and AC electrical breakdown characteristics of GN_2 with respect to various barrier conditions are conducted under atmospheric condition because dielectric characteristics under atmospheric condition are most severe in GN_2 part. An AC power supply has capacities of 100 kV with 60 Hz and DC power supply has capacities of 200 kV. Fig. 1 shows the overall schematic drawing of a dielectric experiment. The ramping up rate of AC and DC voltage is set to 1 kV/s. Also, the time interval between two successively applied voltages is set to 60 sec for AC electrical breakdown experiments and 10 min for DC electrical breakdown experiments to minimize the influences of surface and space charges [2]. The specifications of a rod to plane electrode system used in this study are shown in Table 1. High voltage is applied to a rod electrode with a diameter of 2 mm and a plane electrode is grounded. The gap between a rod electrode and plane electrode is fixed as 42 mm and a solid insulating barrier is placed between two electrodes. For the dielectric

TABLE I
SPECIFICATIONS OF AN ELECTRODE SYSTEM.

Material of solid insulation barrier	GFRP, MC Nylon
Electrode system type	rod to plane (stainless steel)
Gap (mm)	42
Diameter of a rod electrode (mm)	2
Plane electrode size (mm)	diameter: 120, thickness: 10, radius: 5

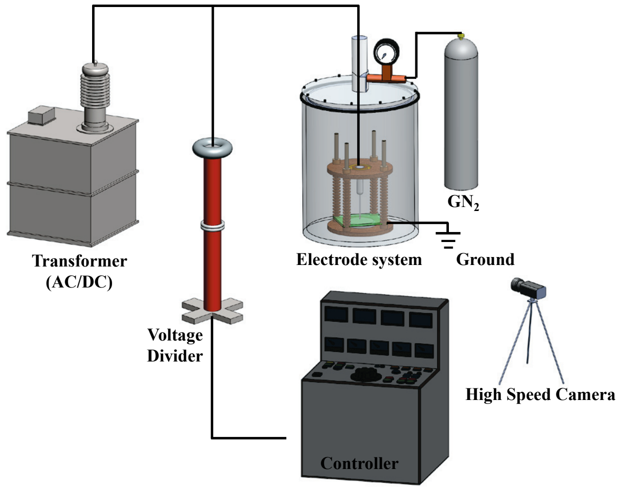


Fig. 1. Schematic drawing of experimental set-up.

experiments with various barrier conditions, the size of the solid insulating barrier is equipped as 250 × 230 mm and the thickness of the solid insulating barrier is set to 5 mm. The schematic drawing of a rod to plane electrode system with respect to the position of a solid insulating barrier is shown in Fig. 2. Fig. 2 (a) is called an 'upper barrier' system, where a barrier is located below a rod electrode with the interval of 1mm. Fig. 2 (b) is called a 'middle barrier' system, where a barrier is located below a rod electrode with the interval of 19 mm. Fig. 2 (c) is called a 'lower barrier' system, where a barrier is located above a plane electrode with the interval of 0 mm. Fig. 3 shows the schematic drawing of a rod to plane electrode system with respect to the number of solid insulating barriers. In addition, the surface creepage characteristics of GFRP and MC Nylon are examined to verify the intrinsic surface creepage characteristics of solid insulating barriers as shown in Fig. 4.

2.2. Experimental results

In this study, the DC and AC electrical breakdown characteristics of GN_2 with a solid insulating barrier are examined and experimental results are analyzed. Also, the geometrical flashover path according to the position and the number of barriers is observed by using a high speed camera.

Fig. 5 shows the surface creepage characteristics of solid materials in GN_2 with respect to the applied voltage and the material of a solid insulating barrier. Its electrode system is depicted in Fig. 4. It is found that the magnitude of surface creepage with MC nylon is larger than that with GFRP, as

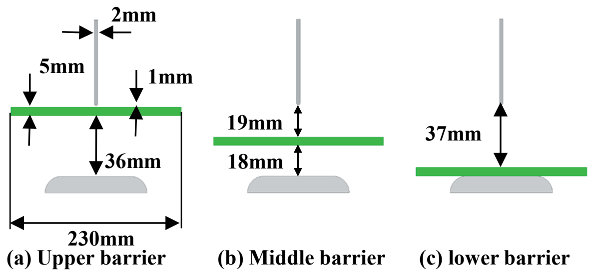


Fig. 2. Schematic drawing of a rod to plane electrode system with respect to the position of a solid insulating barrier.

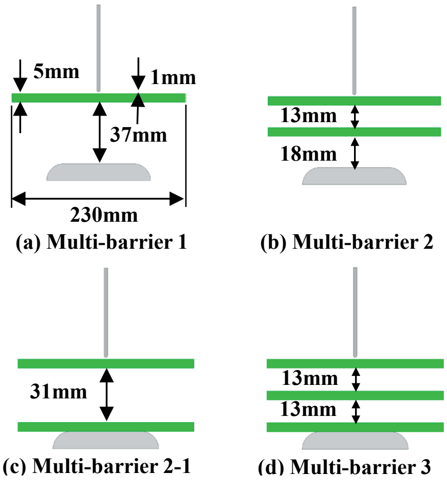


Fig. 3. Schematic drawing of a rod to plane electrode system with respect to the number of solid insulating barriers.

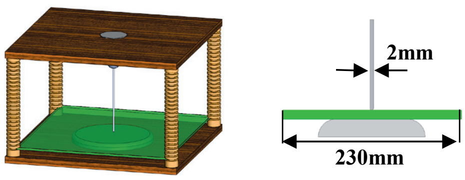


Fig. 4. Schematic drawing of a rod to plane electrode system for the surface flashover experiment of solid insulation.

shown in Fig. 5. Fig. 6 shows the flashover voltage of GN_2 with respect to the position of a solid insulating barrier. The flashover voltage of GN_2 increases as a barrier moves up to a rod electrode applying the high voltage. Fig. 7 shows the flashover voltage of GN_2 with respect to the number of solid insulating barriers. The axial x indicates the number of multi-barriers between two electrodes. The label of x-axis in Fig. 7 is depicted in Fig. 3. It is found that the flashover voltage of GN_2 increases as the number of barriers increases. The flashover voltage of MC Nylon in barrier conditions shows larger value than that of GFRP. This result is caused from the dielectric characteristics of intrinsic surface creepage of each material. It is found that the flashover voltage in case of '2-1' is similar to that in case of '3'. It is observed that the tendency of flashover

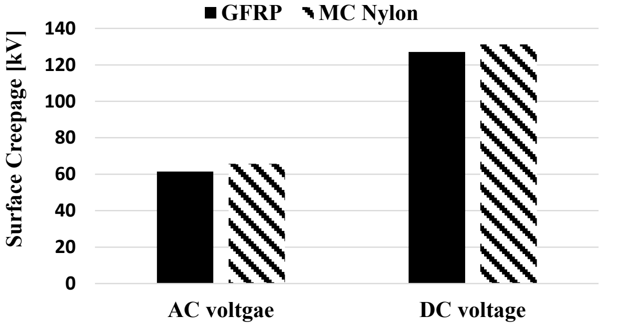
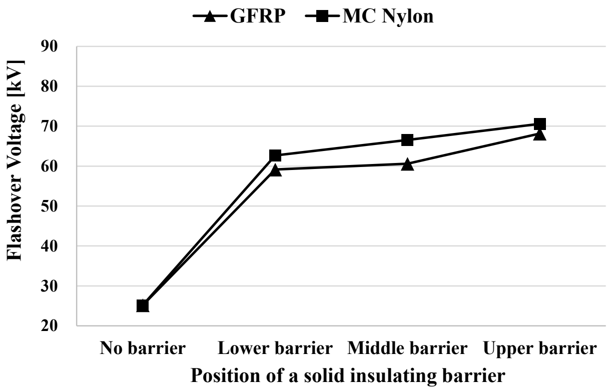
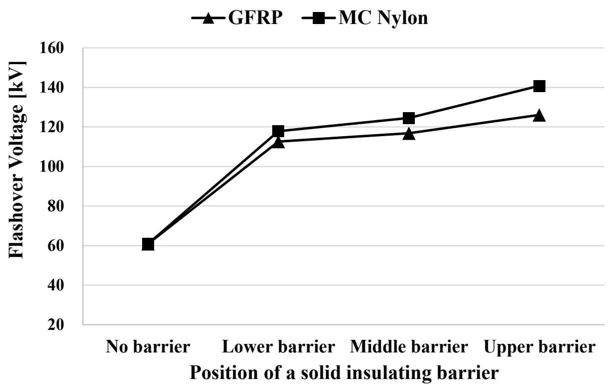


Fig. 5. Surface flashover voltage of a solid insulation in GN_2.



(a) AC



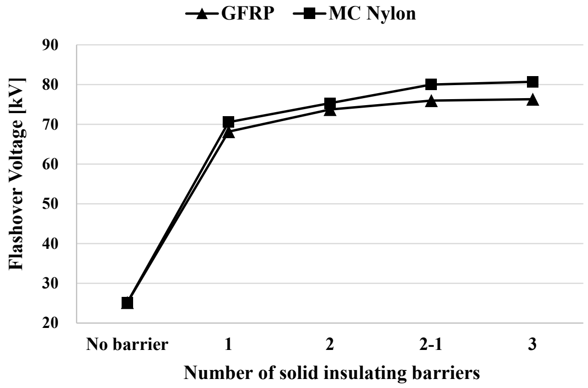
(b) DC

Fig. 6. Flashover voltage of GN_2 with respect to the position of a solid insulating barrier.

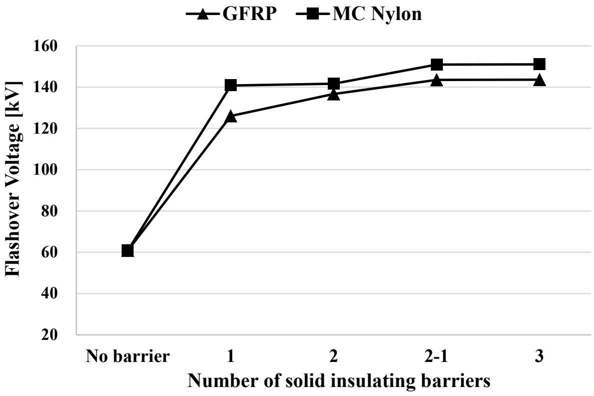
voltage according to the number of solid insulating barriers is similar with each other irregardless of the material of barriers and the applied voltage. Fig. 8 shows the flashover path with respect to various barrier conditions observed by a high speed camera.

3. DISCUSSION

In this paper, it is dealt with the AC and DC electrical breakdown characteristics of GN_2 with respect to various barrier conditions. A barrier effect on the dielectric characteristics of GN_2 can be verified by geometrical flashover path and surface creepage characteristics of a



(a) AC



(b) DC

Fig. 7. Flashover voltage of GN_2 with respect to the number of solid insulating barriers.

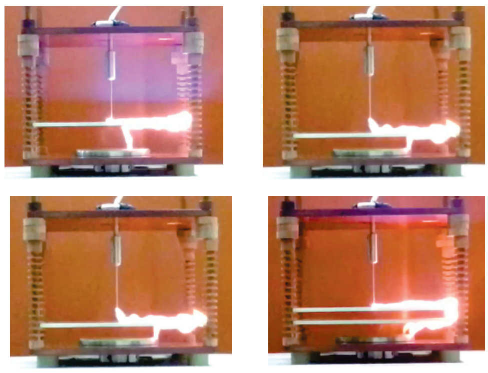


Fig. 8. Flashover path with respect to various barrier conditions observed by a high speed camera.

solid insulation material. It is observed that DC and AC electrical breakdown voltages of the electrode system with a barrier of MC nylon show larger value than those of GFRP. It is inferred that dielectric characteristics of GN_2 with a solid insulating barrier conform to the intrinsic surface creepage of each solid material. Also, it is observed that the DC and AC electrical breakdown voltages increase as the position of a barrier between two electrodes moves up to a rod electrode and the number of multi-barriers increases. Fig. 9 and Fig. 10 show the geometrical flashover paths of a rod to plane electrode system with the various barrier conditions. Fig. 11 shows the distribution of electric field intensity in case of upper and lower barrier system made with MC Nylon. It is found that the flashover voltage of GN_2 with a barrier system do not conform to electric field intensity as shown in Fig. 11. The dielectric constant of GFRP and MC Nylon is 4.3 and 3.7, respectively. The resistivity of GFRP and MC Nylon is 1.5E+16 Ω·cm and 4.2E+13 Ω·cm, respectively. It was generally known that the electric field intensity is affected by the dielectric constant (ε) of a material in case AC source and by the resistivity (Ω·cm) of a material in case DC source. Eq. 1 and Eq. 2 show governing equation for AC electric field and DC electric field, respectively.

$$(\quad)\left(— \quad — \quad —\right) \tag{1}$$

$$(\sigma)\cdot\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}+\frac{\partial^2 V}{\partial z^2}\right)=0 \tag{2}$$

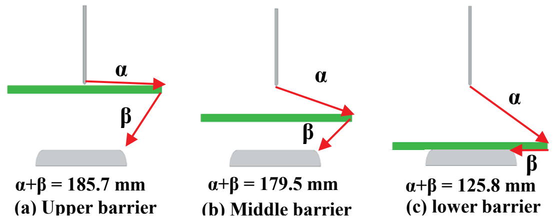


Fig. 9. Geometrical flashover path of a rod to plane electrode system with respect to the position of a solid insulating barrier.

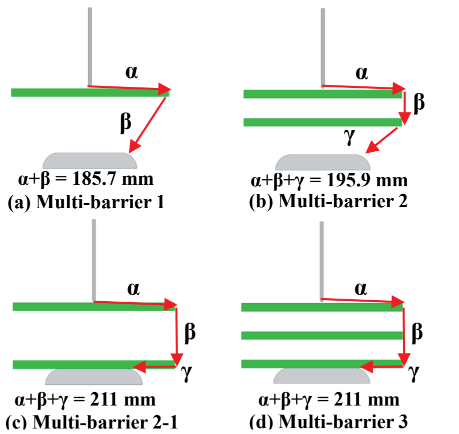


Fig. 10. Geometrical flashover path of a rod to plane electrode system with respect to the number of solid insulating barriers.

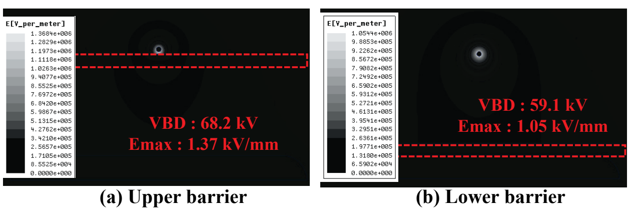


Fig. 11. Distribution of electric field intensity in case of upper and middle barrier systems.

Consequently, the DC and AC electrical breakdown characteristics of GN_2 with the solid insulating barriers can be explained by the geometrical flashover path between two electrodes. In case of AC source, the electrical flashover voltage of GN_2 can be lowered when the dielectric constant of a solid insulating barrier increases. In case of DC source, the electrical flashover voltage of GN_2 can be lowered when the resistivity of a solid insulating barrier increases. It is concluded that the electrical flashover voltage of GN_2 with a barrier system can be affected by the geometrical flashover and electrical properties of a material but is mainly affected by the geometrical flashover path between two electrodes.

4. CONCLUSIONS

In this paper, it is dealt with a barrier effect on the DC and AC dielectric characteristics of GN_2 with respect to the position and the number of solid insulating barriers. A barrier effect on dielectric characteristics of GN_2 can be explained by the geometrical flashover path and electrical properties of a material. It is verified that the barrier effect is enhanced as the geometrical flashover path increases irregardless of the number of solid insulating barriers. Also, it is concluded that the dielectric characteristics of GN_2 with barrier system conform to the permittivity of a material under AC source and resistivity of a material under DC source.

ACKNOWLEDGMENT

This work was supported by the Human Resources Development program (No. 20124030200040) of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry and Energy.

REFERENCES

[1] H. Kang, C. Lee, K. Nam, Y. S. Yoon, H.-M. Chang, T. K. Ko, and B.-Y. Seok, "Development of a 13.2 kV/630 A (8.3 MVA) high temperature superconducting fault current limiter," *IEEE Trans. Appl. Supercond.*, vol. 18, no. 2, pp. 628-631, 2008.

[2] W. J. Kim, S. H. Kim, H. J. Kim, J. W. Cho, J. S. Lee, and H. G. Lee, "The Fundamental Characteristics of PPLP as Insulating Material for HTS DC Cable," *IEEE Trans. Appl. Supercond.*, vol. 23, no. 3, 2013.