§14. Reliability Improvement of Cryogenic Refrigerant/Solid Insulator Composite Electrical Insulation System in LHD

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The world's largest class superconducting coil is used in the "Large-scale Helical Device" in NIFS. Its electrical insulation system, solid insulator/ liquid coolant insulation system, is exposed to considerably severe multiple stresses including cryogenic temperature, large mechanical stresses and strong magnetic fields. If a superconductor quenches, the liquid coolant vaporizes very easily and turns into high-density gas at cryogenic temperature. In these bubbles, partial discharge (PD) easily occurs and would lead to the electrical breakdown of solid insulator. It is therefore very important to study the electrical insulation performance under these severe conditions in order to establish the reliability of the cryogenic devices. However, the breakdown mechanism of insulating material such as polyimide or insulating paper, etc., is not yet clarified in detail. In this study, it is investigated the breakdown characteristics of the paper-liquid nitrogen (LN_2) composite insulating system with partial discharge.

DC breakdown test was performed by applying the DC ramp voltage with increasing rate of 500 V/s. Impulse breakdown test was performed by applying the lighting impulse of one shot and the breakdown occurred at the wave front. DC prestress test was effective to investigate the influence of the charge behavior on the breakdown strength (Fb). DC prestress was applied for 300 seconds. Then, the lighting impulse voltage of one shot was applied and the breakdown occurred at the wave front. In order to investigate the influence of the charge injection on impulse Fb of KP, the polarity of both DC prestress field and impulse field was changed.

As the results, the breakdown strength (Fb) under DC and impulse voltage application increased with increasing the air resistance of KP as shown in Fig.1. This is because that the discharge causing the breakdown is became difficult to inject into the insulating paper with increase of air resistance of insulating paper. In addition, the positive Fb became larger than the negative Fb when air resistance of the insulating paper is small, and this polarity effect of Fb was reversed with increase of air resistance of insulating paper. In general, it is reported that positive streamers easily progress in LN_2 and has the features such as high energy density and tip electric field. By these features of positive streamer, the positive Fb usually become smaller than the negative Fb at room temperature. Moreover, the negative discharge is developed along with the negative charge release while the negative charge need to be pulled out from the insulator in development of the positive discharge. From these consideration, we assumed that the negative discharge is easier to inject into the insulating paper as compared to the positive discharge. Consequently, in the insulating paper with small air resistance, it is considered that the negative Fb decreased due to effective thickness reduction with negative discharge injection into the insulating paper. Fig.2 shows DC prestress effect of insulating paper. From Fig.2, Fb of the insulating paper under homo condition was the same tendency as conventional DC prestress effect. On the other hand, the increase of Fb of the insulating paper with small air resistance under positive DC prestress with negative impulse voltage application is unique characteristics in spite of the hetero condition. This unique characteristics can be explained by the assumption of negative charge injection.

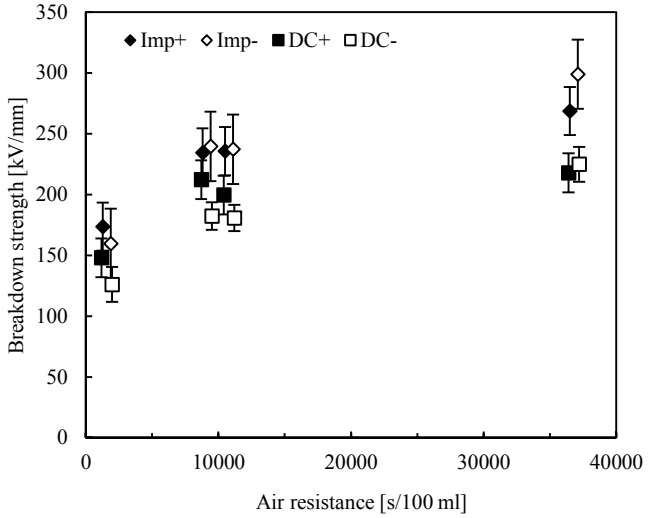

Fig.1. Air resistance dependence of DC and impulse breakdown strength of insulating paper

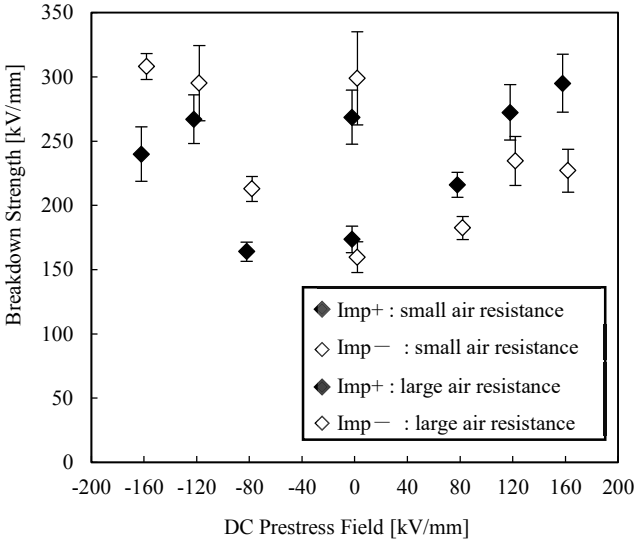

Fig.2. DC prestress effect of insulating paper with small and large air resistance