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Assessment of Dielectric Breakdown Characteristics of Nomex Paper under High Frequency Overvoltages for Superconducting Power Transformer Application

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Background

- Compared with conventional oil-filled transformer, one major advantage of superconducting transformer is reduced size and weight due to low resistive losses and enhanced dielectric strength of material under cryogenic environments. The power transformers are very significant component in a power system and their reliability depends on the insulation of the transformer.
- Dielectric strength of insulation is known to vary in cryogenic environments, but there are not reports on breakdown characteristics of paper insulation used as transformer insulation under lightning impulse voltages in liquid nitrogen (LN_2). In particular, high voltage power transformers were exposed to overvoltages of very high frequency components caused by external impulse voltages, which can lead to dielectric breakdown. Moreover, since there is not always consistent impulse waveform, it is necessary to ensure the dielectric strength against impulse voltages with different front time.
- Most studies have been conducted under standard impulse voltages in oil, and the application of non-standard impulse voltages in LN_2 environment is limited. Therefore, in this work, the lightning impulse breakdown test on paper insulation in LN_2 was conducted with adjusting front time.

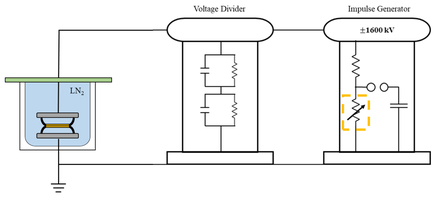
Objectives

- Assessment of breakdown characteristics of paper insulation under lightning impulse voltages in LN_2.
- Comparison of breakdown voltage change under lightning impulse waveform with different front time.

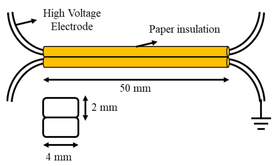
Experimental Set-up

- The impulse generator (High Volt, 1600 kV) was used to generate lightning impulse voltages. The cryostat chamber filled with liquid nitrogen (LN2) was used for the breakdown tests.
- In order to generate non-standard lightning impulse waveform, the front time was changed by adjusting resistors of the impulse generator. The standard front time (1.2 μs) and non-standard front time (1.0, 0.8 μs) were adopted as the voltage source
- We used a turn-to-turn insulation model to simulate the winding insulation configuration. The model was made by bending a pair of 2 mm × 4 mm rectangular copper wire with insulation paper. Each insulation paper was wound one, two and three times in the same direction.
- Kapton (Dupont polyimide, 130 μm), Kraft (125 μm) and Nomex (Dupont polyamide, 200 μm) were prepared for the breakdown test.
- The input voltage was increased by 1 kV until breakdown occurred at 60 % of the expected breakdown voltage. A total of 10 breakdown test results were applied to the Weibull function to estimate the dielectric strength of paper insulation.

Test set up for the lightning impulse breakdown test

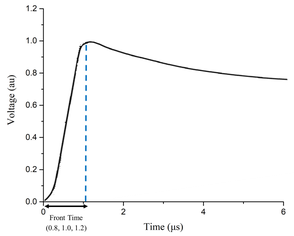


Schematic of the breakdown test with changing resistors



Turn-to-turn insulation model

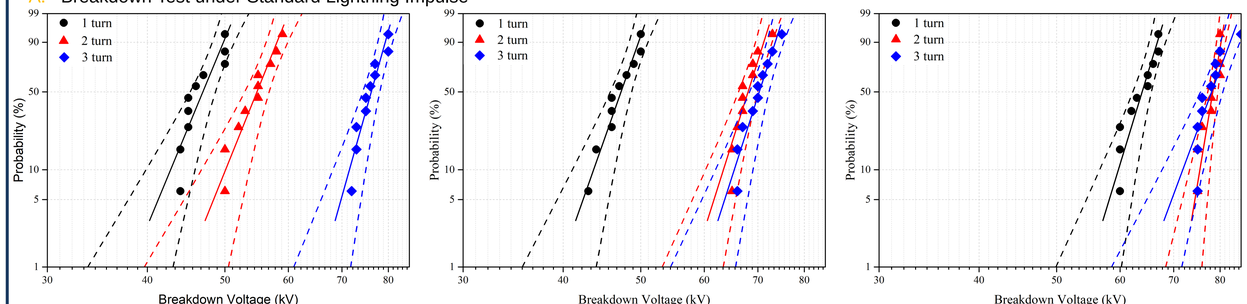
Resistors of the impulse generator



Lightning impulse waveform with different front time

Experimental Results and Discussions

A. Breakdown Test under Standard Lightning Impulse



(a) Kapton film **(b) Kraft paper** **(c) Nomex paper**

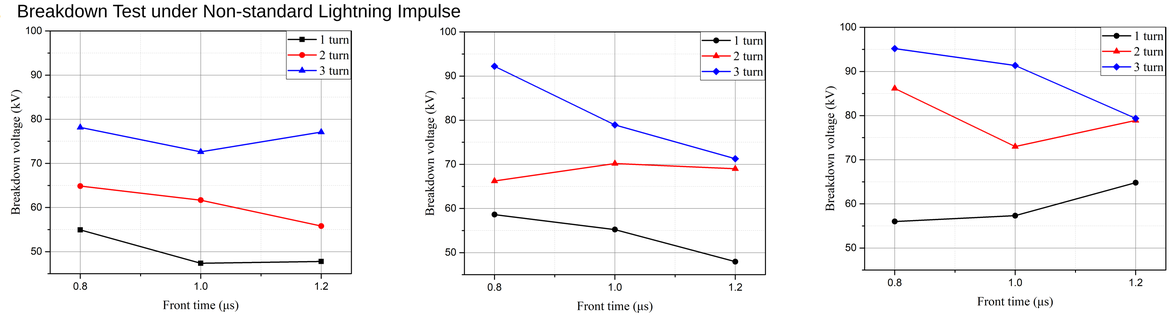
Weibull plots of the breakdown voltage under standard waveform

- For the relatively Kapton film, as the number of turns increased, breakdown voltage increased linearly from 47.77 kV to 77.10 kV.
- However, in the case of Kraft and Nomex paper, the breakdown voltage did not increase significantly over 2 turns.
- Due to the difference in molecular structure, impregnation process for Kapton film does not occur well in LN_2.
- However, Kraft and Nomex paper have the effect of improving the dielectric strength due to the LN2 impregnation. This effect is also assumed to be irregular depending on the thickness.

Shape parameters of Weibull plot under standard waveform

Number of turn	Kapton [kV]	Kraft [kV]	Nomex [kV]
1 turn	47.77	47.96	64.79
2 turn	55.80	69.01	78.91
3 turn	77.10	71.28	79.36

B. Breakdown Test under Non-standard Lightning Impulse



(a) Kapton film **(b) Kraft paper** **(c) Nomex paper**

Breakdown voltages under non-standard waveform

- Three types of paper insulation showed that the breakdown voltage generally increased when the front time was reduced. For the Kapton film, the increasing voltage degree was not significant. Kapton is known to have a small change in relative dielectric constant according to frequency band.
- According to the discharge theory, the formation probability of effective initial electrons is greatly influenced by the magnitude and duration time of the applied voltage. If the front time is shortened, there is not enough time to develop enough electrons for dielectric breakdown. In other words, in order to form electrons in a short time, a larger voltage should be applied to strengthen the electric field strength formed in the dielectric.

Conclusion

- The lightning impulse breakdown voltages of electrical insulating papers were evaluated in LN_2. Unlike other paper insulations, in the case of Kapton film, the breakdown voltage was observed to increase linearly with thickness.
- Breakdown voltages increase with the decrease of front time. This is because higher voltages are required for effective initial electrons to form in a short front time.
- The difference of breakdown characteristics was shown for each paper insulation. It is considered to be effect of electrical characteristics variation of each material with molecular structure, temperature and frequency component.