TOSHIBA

Study Committee A2

BEYOND THE MINERAL OIL–IMMERSED TRANSFORMER AND REACTORS

Paper 10534_2022

Winding Insulation Characteristics of Gas Filled Transformers with SF_6 Alternative Gas

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1. Motivation

- Gas-filled transformers are non-flammable and have no risk of oil leakage, and use SF_6 gas as insulating & cooling medium.
- SF_6 gas has a high global warming potential, and alternating gas is needed and the candidates are dry air or N_2, however these insulation and cooling performance is extremely low compared to SF_6.
- Basic winding insulation characteristics (disk windings) is needed for realizing alternating gas-filled transformer.

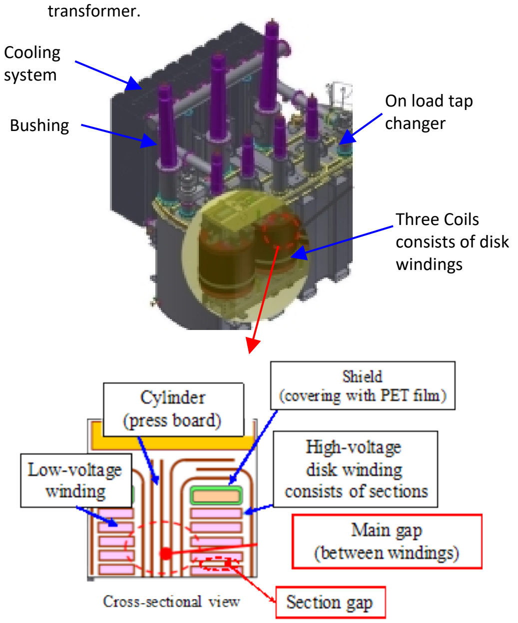

Fig.1 Configuration of gas-filled transformer disk winding

2. Examination Model

- Three basic disk winding insulation characteristics were investigated with negative lightning impulse voltage.
  - ➢ The winding section model simulating the inter-section insulation configuration with dry air, N_2 and SF_6.
  - ➢ The main gap model with actual scale with N_2.
  - ➢ The probability of discharge propagation survey model with dry air and N_2 (winding section model with 110% repeated voltage of PDIV)

2.1 Winding section gap model (between sections of disk-winding)

- The winding section model is installed in a test tank with filled with dry air, N_2 and SF_6 (gas pressure was 0.22MPa or 0.5MPa), and PDIV and BDV were measured.

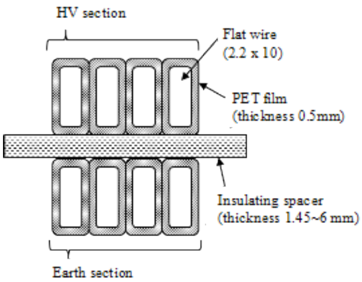

Fig.2 Winding section model (Cross-sectional View)

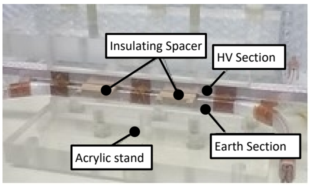

Fig.3 The appearance of the winding section model

2.2 Main gap model (between low and high voltage windings)

- The main gap model was installed in a test tank filled with 0.5 MPa N_2 gas and BDV was measured.

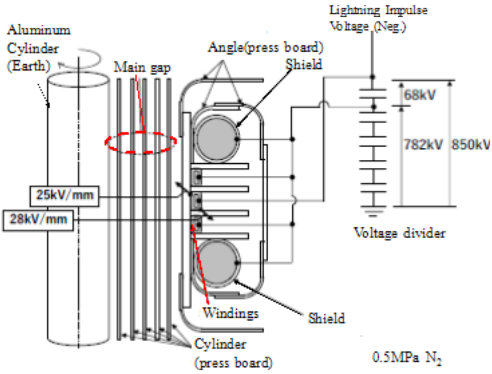

Fig.4 Main gap model (gap distance = 135mm)

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3. Result and Discussion

3.1 Winding section gap model

- The PDIV of N_2 and dry air is about 60 % of SF6 at 0.22 MPa and about 70 % of SF_6 at 0.5 MPa, and which is consistent with the theoretical solution of air from the streamer conditional expression

$$\int \alpha' dx = K$$

- BDV shows different aspects under the conditions of 0.22 MPa and 0.5 MPa.
  - At 0.22 MPa, because the partial discharge cannot penetrate the PET film, and BDV is constant value regardless of the gas type.
  - At 0.5 MPa, the discharge can easily penetrates the PET film because the voltage is enough high. BDV increases as the thickness of the insulating spacer increases.

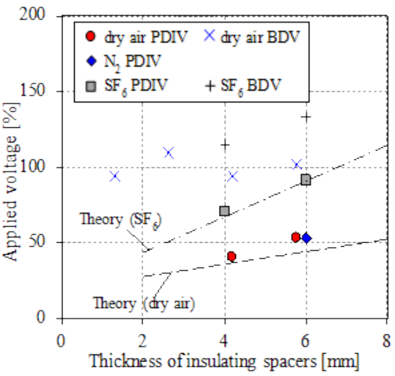

Fig.5 PDIV and BDV measurement results at 0.22 MPa

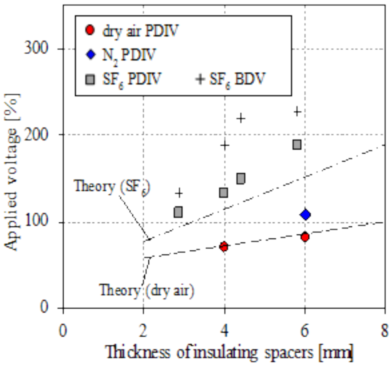

Fig.6 PDIV and BDV measurement results at 0.5 MPa

3.2 Main gap model

- The BDV was 900 kV, and the maximum electric field strength was 30 kV/mm, which greatly exceeds the theoretical dielectric breakdown electric field 10 kV/mm (N_2, 0.5 MPa) calculated from the effective ionization coefficient.
- Solid insulating materials with high insulation performance such as PET film and press board are effective in preventing the initial discharge propagation

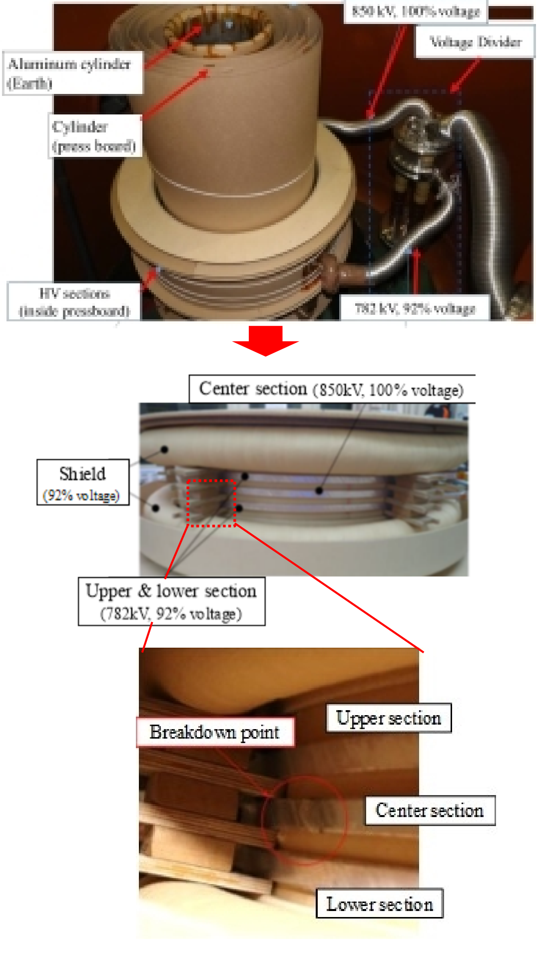

Fig.7 Main gap model and breakdown point

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3.3 Discharge propagation survey with winding section model

- Figure 8 shows an example of optical observation of partial discharge by applying repeated voltage with dry air and N_2. The applied voltage is 110% of PDIV, and the number of repetitions is 100 times.
- In dry air, uniform partial discharge emission was observed at triple junctions at all 100 times. On the other hand, in N_2, discharge emission was observed only 32 times out of 100 times, and the discharge emission itself was often not uniform because N_2 has no electron attachment. .
- Since the applied voltage exceeds PDIV, partial discharge occurs. However, discharge propagation that causes dielectric breakdown does not occur.

4. Conclusion

- Between the sections of the disk winding, a partial discharge occurs at the triple junction. The PDIV trends can be explained by theoretical value calculated from the streamer breakdown criterion.
- The BDV of winding section model at 0.5 MPa is determined by the insulation performance of the gas. However, the BDV at 0.22 MPa was determined by the penetration voltage of the PET film, and resulted in a constant value regardless of the section gap.
- From the test results of winding main gap model, the electric field strength of dielectric breakdown was 30 kV/mm, which exceeds the theoretical breakdown electric field of N_2 gas. The discharge propagation due to N_2 was prevented by the PET film and press board.
- In addition, the partial discharge in N_2, which has no electron attachment, is considered to have a large variation compared to dry air, which has electron adhesion. Nevertheless, at a voltage of about 1.1 times of PDIV, dielectric breakdown due to discharge propagation does not occur in both gases.

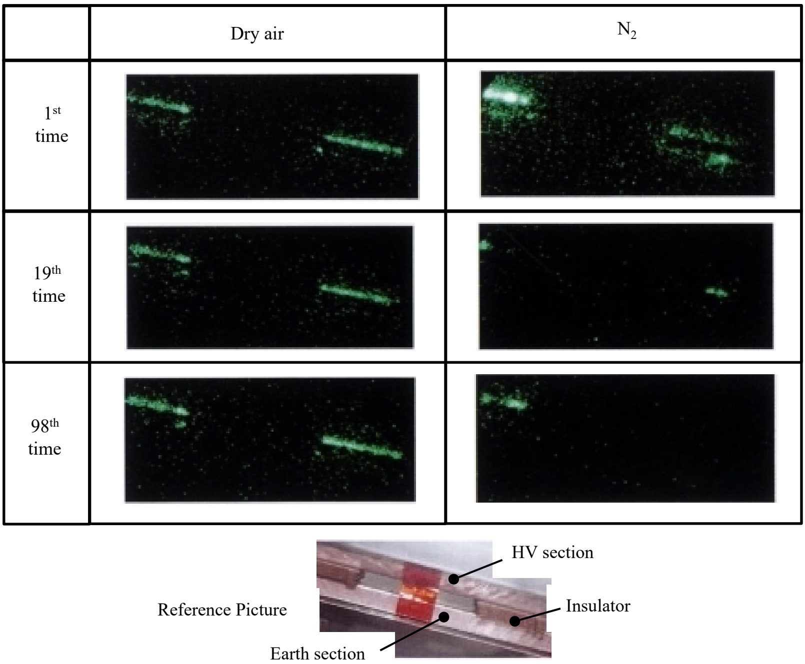

Fig.8 Comparison of partial discharge aspect of N2 and dry air