Electrical Characteristic Assessment of Nomex Paper for Distribution Transformers

Il-Keun Song *, Jong-Wook Jung *, Byung-Sung Lee * and Hee-Ro Kwak**

Abstract - This paper describes the electrical characteristics of Nomex paper employed as an insulating material for distribution transformers.
The relative permittivities (dielectric constants) and tanδ (dielectric dissipation factors) were measured as dielectric characteristics and the partial discharge inception voltages (PDIVs) and breakdown voltages were also measured as electrical strength characteristics of Nomex paper.
As a result, the permittivity and tan δ of Nomex paper demonstrated both temperature and frequency dependency. Of particular note, the permittivity of 0.18 ㎜ Nomex paper was 2.4 according to the ASTM condition. The PDIVs and breakdown voltages were almost linearly increased with the thickness of Nomex paper. Furthermore, its electrical strength was superior to conventional Kraft paper.

Keywords: Nomex paper, permittivity, tan δ , partial discharge inception voltage, breakdown

1. Introduction

The transformers of today play a crucial role in power systems. When a transformer encounters failure, the effects to the power system can be severe and wide-ranging because economical loss and social confusion are unavoidable. Age related failures of transformers are generally due to the insulation deteriorating electrically or because "structural" weakness predisposes it to other failure mechanisms [1]. Insulation failure is caused by a reduction in electrical strength due to the electrical stress that continuously or transiently places tension on the insulating materials. In the case of conventional oil transformers, the insulating materials belonging to the cellulose class have been used for insulating the components such as conductor jackets, spacers and barriers due to the cost and the temperature rise limitations of the transformers. However, when the operating temperature is over 120℃, the ageing process is accelerated because thermal strength of the 105℃ class insulator is poor. Water is generated during the insulator ageing process, which triggers weakening of the electrical strength of transformers, ultimately causing a strength reduction in its ability to withstand short circuit force. Considering that the temperature at the hot spot during short-term overload is usually over 120℃, the ageing of the insulating materials is prevented by substituting aramid insulators for conventional cellulose insulators, which ultimately increases the transformer capacity. Nomex fiber is a kind of synthetic fiber of high thermal endurance, which was first researched successfully by the DuPont Company in the sixties [2]. Aromatic Polyamide (aramid: generic name: Nomex) is employed as an insulator for 220℃ class transformers since its ingredients are so stable. Nomex insulation does not create water or toxic gas during the process of its ageing in mineral oil. Nomex is produced by the condensation of *meta*- phenylenediamine (H2NC6H4NH2) and isophthaloyl chloride (ClCOC6H4COCl). It is composed of fibrid-combined molecular fine fiber in order to increase electrical strength and floc-single fiber in order to improve mechanical strength. Fig. 1 shows the structural formula of Nomex aramid fiber.

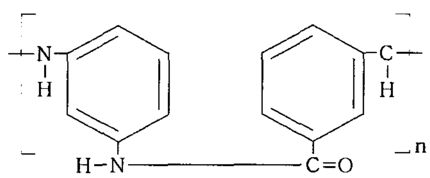

Fig. 1 Structural formula of Nomex aramid fibre (poly-*meta*-phenylenediamine-isophthalamide)

Since Nomex paper is individually selected by manufacturers according to the rating capacity and the application of the transformers, it is essential that various kinds of performance tests be carried out to ensure the reliability of the produced transformers.

Therefore, we measured Nomex paper's dielectric characteristics by means of temperature and frequency and electrical characteristics with its thickness in order to utilize the results as fundamental data in designing and manufacturing transformers.

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2. Experimental

2.1 Specimen

In the electrical strength characteristic test, three sheets of Nomex paper with different thicknesses were selected to determine the increasing trend of PDIV and breakdown voltage. The Nomex paper for each thickness is specified in Table 1.

Table 1 Specification of Nomex 410

thickness[㎜]	0.13	0.18	0.25
weight[g/㎡]	115.3	172.9	247.5

2.2 Dielectric Characteristic Test

WinDETA (Novocontrol Ltd.) was used to analyze the dielectric characteristics of the Nomex paper of three different thicknesses. Fig. 2 shows the schematic of the experimental apparatus.

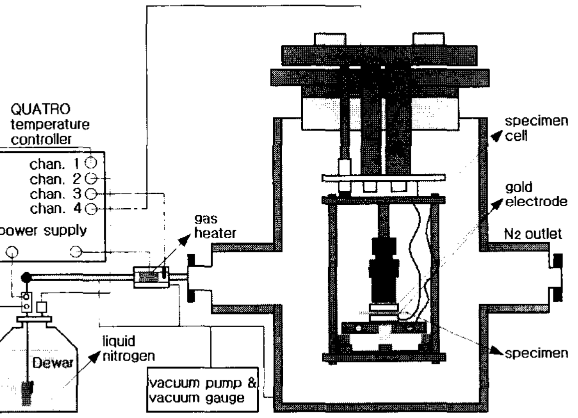


Fig. 2 Schematic of the experimental apparatus

As shown in Fig. 2, each specimen was placed between the upper circular plate electrode and the lower circular plate electrode in the specimen cell. The electrodes were 20 ㎜ in diameter.

Temperature and frequency were taken as the experimental variables of the specimen. Temperature was increased from -50℃ to 250℃ at incremental thermal steps of 2℃. The permittivity and tanδ of each frequency between 0.109 Hz and 3 ㎒ were measured at each temperature within an error boundary of ± 0.5℃ and only their typical values of interest were plotted on the graph.

2.3 Electrical Strength Characteristic Test

To measure the PDIVs and breakdown voltages for each thickness of Nomex paper, the experimental set-up shown in Fig. 3 was arranged.

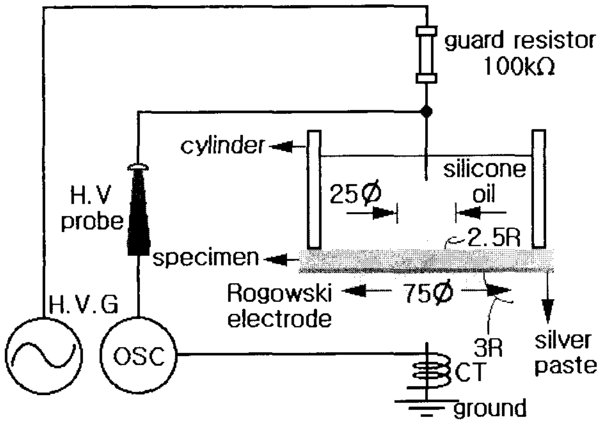


Fig. 3 Schematic of the experimental arrangement

As shown in Fig. 3, in order to measure electrical strength, each thickness of Nomex paper was sheared by 100 ㎜ in diameter and then affixed to the base of the transparent short cylinder. The bottom surface of the Nomex paper was painted with silver paste. This specimen set was arranged on a lower plain stainless Rogowski electrode of 75 ㎜ in diameter, with the edge-rounded 3 ㎜ in radius. The upper plain stainless Rogowski electrode (about 600g) of 25 ㎜ in diameter and edge-rounded 2.5 ㎜ in radius was placed on the Nomex paper. Next, the upper electrode was impregnated with silicone oil. The upper electrode was connected to a high voltage generator (H.V.G) through a guard resistor and the lower electrode was grounded. The 100 ㏀ guard resistor was inserted in sequence to the specimen in order to protect the H.V.G from impulse current and voltage at breakdown of the specimen. A high voltage probe (1,000:1) was installed in parallel to the specimen in order to measure the applied voltage, and a current transformer (CT: 1,000:1) was set up nearby the grounding conductor in order to detect the partial discharge. While increasing the applied voltage at the rate of 0.5 kV/s, we measured the PDIV and the breakdown voltage, repeated the measurement ten times and plotted maximum, minimum and average values on graphs [3]-[7].

3. Results and Discussion

3.1 Permittivity of Nomex by means of Temperature and Frequency

With increasing temperature and frequency, we measured the permittivity of Nomex paper. Fig. 4 shows the results.

As shown in Fig. 4, the permittivity of Nomex paper was increased with temperature and decreased with frequency. ASTM refers readers to the permittivity measured at 23℃ and 1 ㎒. The permittivity of 0.18 ㎜ Nomex paper was

2.4 to the standard. The Nomex paper was divided into the permittivities of temperature and frequency and Figs. 5(a) and 5(b) show each of them, respectively. Please refer to the Figures for a simplified understanding.

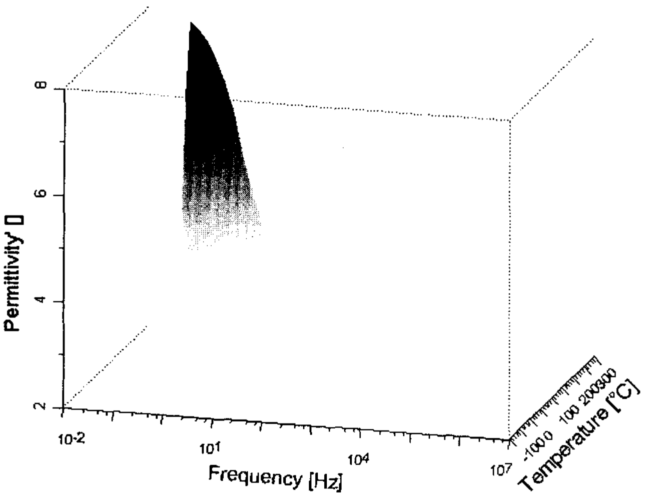
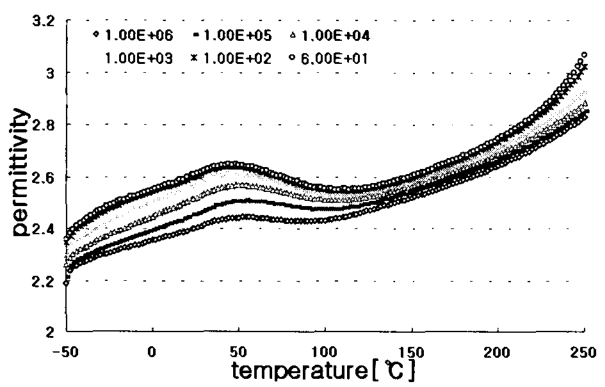
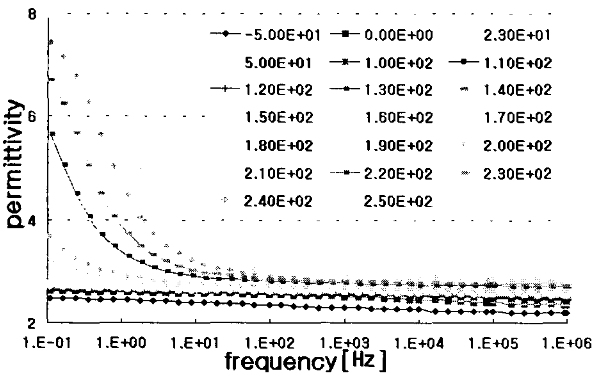


Fig. 4 Permittivity using temperature and frequency



(a) Temperature domain



(b) Frequency domain

Fig. 5 Permittivity with temperature and frequency

As shown in Figs. 5(a) and 5(b), the permittivity between -50℃ and 220℃ varied about 2.19 to 2.83 at all frequencies. Over 220℃, however, the permittivity was exponentially increased in low frequencies less than 100 Hz.

Furthermore, as shown in Fig. 5(b), the permittivity was decreased with frequency, and this is considered to occur because several kinds of dielectric polarization were superposed. In the same Fig., dielectric dispersion indicating that the permittivity outstandingly varies was observed in the range of high temperatures over 220℃ and low frequency below 100 Hz. In this case, the dispersion appeared by space charge polarization in the range of electrical frequency below 1012 Hz. This so called 'relaxant dispersion' is derived from molecular collision or the constraints imposed by the surrounding molecules [8]. In this case, the permittivity with frequency moves from the constant high value in low frequency domain to constant low value in high frequency domain and no peaks are shown on the permittivity curve. The dielectric loss factor in this case will be abruptly increased and decreased in the frequency range around 10 Hz at which the permittivity is dispersed. Thus it will show a peak on the dielectric absorption curve.

3.2 tanδ of Nomex with Temperature and Frequency

With increasing temperature and frequency, we measured the tanδ of Nomex paper. Fig. 6 shows the results.

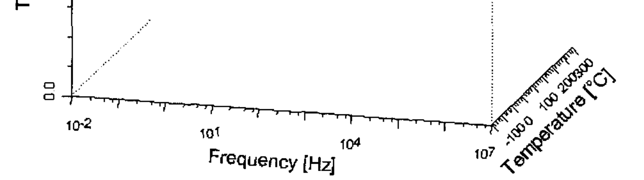


Fig. 6 tanδ with temperature and frequency

As shown in Fig. 6, the tanδ of Nomex paper was irregularly varied using temperature and frequency. Taking the depressing region out of interest, however, it generally tended to be increased with temperature and to be decreased with frequency. In Fig. 6, the tanδ for each frequency in the temperature domain is shown in Fig. 7.

As shown in Fig. 7, the tanδ of Nomex paper at low frequency tended to shift left with frequency in the temperature range below 180℃ and suddenly increased over 180℃. Particularly in this case, even tanδ at 1,000 Hz began to increase over 220℃. These phenomena show that the tanδ curve in the low frequency range is shifted to the lower temperature region.

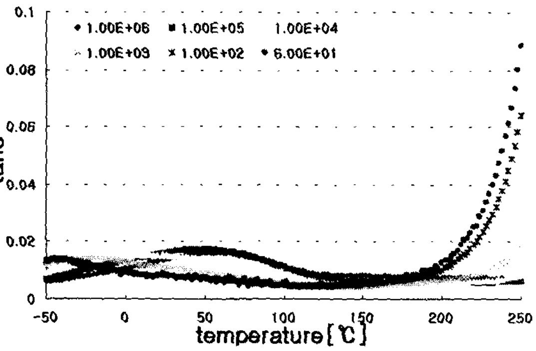


Fig. 7 tanδ for each frequency in the temperature domain

3.3 Electrical Strength Characteristics of Nomex

While increasing the applied voltage at the rate of 0.5 kV/s, we measured the PDIV of each thickness of Nomex paper. Fig. 8 shows the results.

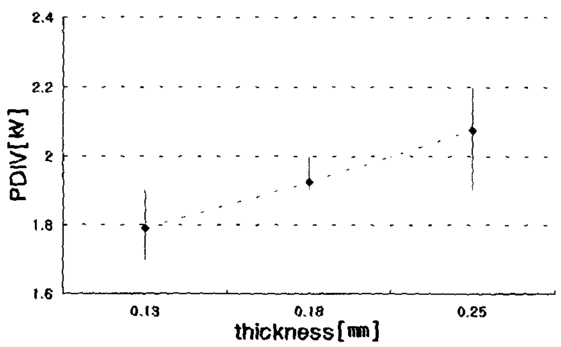


Fig. 8 PDIV with thickness

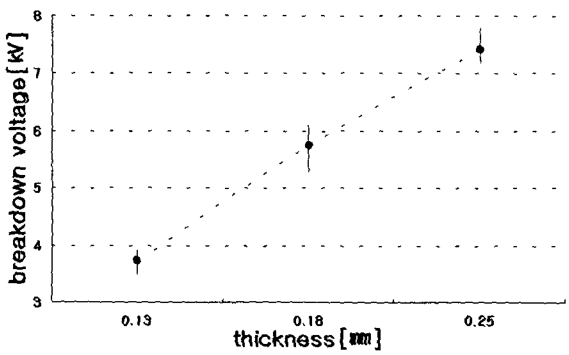


Fig. 9 Breakdown voltage with thickness

As shown in Fig. 8, the partial discharge of 0.13 mm thick Nomex paper was first observed at 1.79 kV $_{ave}$. and the increasing rate with thickness was about 2.375 kV/mm.

As shown in Fig. 9, the breakdown voltage of 0.13 mm thick Nomex paper was 3.725 kV $_{ave}$. and increased with thickness at the rate of about 30.83 kV/mm.

5. Conclusion

We measured the dielectric and electrical strength characteristics of Nomex paper. As a result, this paper concludes as follows:

(1) The permittivity of Nomex paper was increased with temperature and decreased with frequency. Of particular note, the permittivity of 0.18 mm Nomex paper was 2.4 according to the ASTM condition.

(2) Dielectric dispersion that varies greatly with the permittivity was observed in the range of high temperatures over 220℃ and low frequency below 100 Hz.

(3) Nomex paper's tanδ generally tended to be increased with temperature and to be decreased with frequency. Also, the tanδ curve in the low frequency range shifted to the lower temperature region.

(4) The partial discharge of 0.13 mm thick Nomex paper was first observed at 1.79 kV aver. and the increasing rate with thickness was about 2.375 kV/mm. In addition, the breakdown voltage of Nomex paper was 3.725 kV aver. and increased with thickness at the rate of about 30.83 kV/mm.

We measured the dielectric and electrical strength characteristics of Nomex paper in order to provide fundamental data that can be utilized in the design and manufacture of transformers. Obtaining aged Nomex paper was difficult because it has recently been introduced into transformers. Therefore, further studies on the aged specimen are required.

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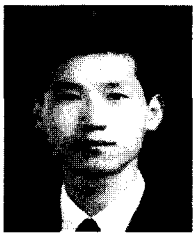

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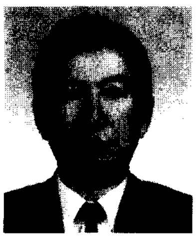

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