The Analysis of Discharge Distribution due to the Inner Void of Extra High Voltage Cable

Tag-Yong Kim† and Jin-Woong Hong*

Abstract - This paper addresses the discharge characteristics of cross-linked polyethylene according to void by the Weibull function. It analyzes discharge number and amount of discharge using Weibull distribution to identify the inter-relationship between partial discharge and defect. We detected a 10 second discharge. The applied voltage increased by 1 [kV] at discharge inception voltage. As a result, in a no-void specimen, the shape parameter was consistent according to the increase of voltage, whereas, in a void specimen, it increased according to the increase of voltage. As the result, the shape parameter expressed a fixed value at no-void specimen. However, in void specimen, according to increasing voltage shape parameter rapidly increases.

Keywords: extra high voltage cable, inception voltage, partial discharge, Weibull function

1. Introduction

Recently, with the increase in the demand for electricity, electric cables or electric power transmission machines are rapidly being developed, which can cover the extra high voltage and massive capacity. The dangers of electrical accidents related to insulators are on the rise due to the electric stress, insulation degradation and insulation breakdown in insulators[1]. Simultaneously, interruption of service due to electricity failure, which was considered insignificant in past times, is becoming an important matter. Thus, interests in insulation degradation and dielectric strength are increasing because estimation of the life of high voltage machines is essential to reduce economical losses and to secure reliability[2, 3]. There are many other reasons for the insulation degradation and insulation breakdown phenomenon of electrical insulating material. Among those, leakage current due to a partial discharge (PD) occurs in insulators used for high voltage, which results in a very small electrical road known as a tree at the insulation layer. This is well known as the treeing phenomenon, which is decisive when determining the life of an insulator[1, 4]. When there is a defect in the inner insulator, treeing phenomenon speeds up rapidly, reducing the life of the insulator, which often results in the occurrence of an unpredictable accident. These days, the estimation of the insulator lifespan is determined through the neural network because the distribution of discharge is very irregular. In general, probability distribution, which is used to manage irregular statistics, is analyzed through Weibull distribution, regular distribution, exponential distribution, and gamma distribution. To investigate degradation statistics and defect diagnostics of high voltage machines, Weibull distribution is widely used[5, 6]. Therefore, in this paper, discharge amount and discharge number according to the inner void of extra high voltage cable insulator, cross-linked polyethylene (XLPE), was analyzed using the Weibull function[7]. The changes of life characteristics were also investigated.

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2. Specimens and Experiment

2.1 Specimens

For specimens, two extra high voltage cable layer XLPEs were inserted between two of the electrodes. Specimens were cut into 800[㎛] thickness and size of 100×100 [㎜].

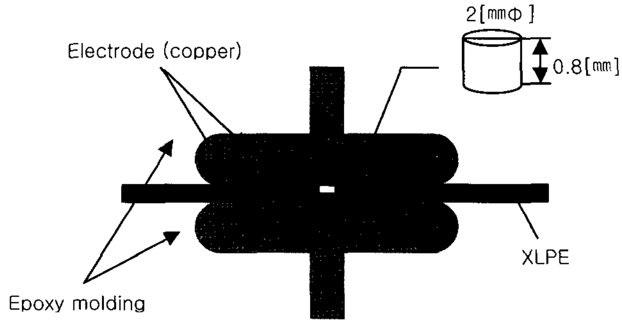


Fig. 1 Electrode and specimens

For electrodes, plate to plate type was employed, and each electrode was molded with epoxy to suppress creeping discharge. The inner-void was treated into a cylinder-shape 2[㎜] in diameter on an upper specimen. Fig. 1 indicates the shape of electrodes and the structure of specimens.

2.2 Experiment

This experiment utilized PD measurement equipment, which is product of AVO. CO., and calibration of discharge was set to 50[pC] (slope=8.333). The 60Hz AC power applied to the electrode was increased by 1[kV] from 3[kV] to trip voltage.

Table 1 Classification of Specimens

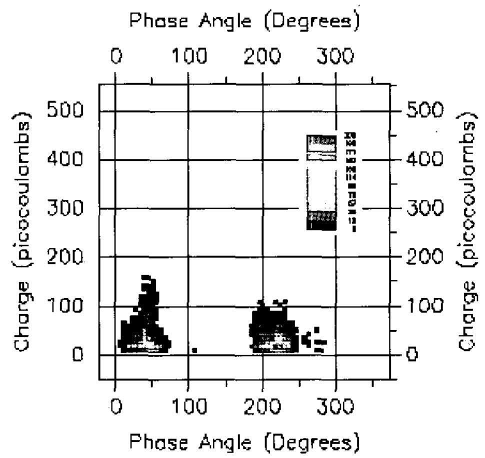
Specimen		Voltage [kV]
N series	N1	6
	N2	8
	N3	10
A series	A1	4
	A2	5
	A3	6
	A4	7
N series: XLPE layer-XLPE layer A series: air layer-XLPE layer		

After the voltage was applied for 10 [sec] (600 [cycle]), occurring discharge and number were detected. Electrodes and specimens were immersed in silicone oil (1000[cSt]) during the experiment to suppress creeping discharge of specimens according to the increase of applied voltage. Using the same conditions, the experiment was performed more than 10 times. Shape parameter was determined through the Weibull distribution function with the data excluding highest and lowest values. Table 1 indicates applied voltage and specimens.

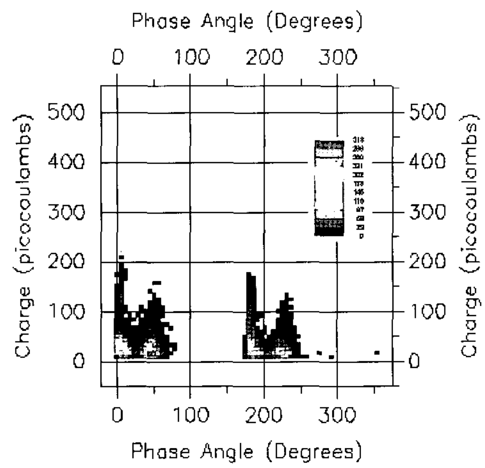
3. Result and Discussion

3.1 Partial discharge distribution

Fig. 2 illustrates the $\phi - q - n$ distribution of no-void specimens. Fig. 2(a) presents partial discharge at inception voltage. For positive phase, discharge occurs mostly in 0° ~75° sections. The highest count number of 133 and amount of discharge of 161 [pC] occurred in the 50° area. For negative phase, discharge occurs mostly in 180°~250° sections and the highest count number of 209 and the highest charge of 116 [pC] occurred at 225°, with some in the 260~290° area. When the voltage was increased to 10 [kV], discharge increased 0~80° in the positive phase, and especially in the 5° and 50° area, amount of discharge became 210 and 180 [pC] respectively, and the highest count number was 318 at 50°. For the negative phase, discharge usually occurred in the area of 180~260°, but unlike 6 [kV], in the area of 190° and 225°, the discharge number of 190 and 150 occurred, respectively. That is, with the increase of voltage, larger discharge occurrence areas appeared in two locations. Fig. 3 shows **Φ**-q-n distribution of void specimens. In Fig. 3(a), 5 [kV] was applied, and discharge occurred in 5°~115°, and 180°~300°.



(a) 6 [kV]



(b) 10 [kV]

Fig. 2 $\phi - q - n$ distribution at no-void

For the positive phase, at the phase angle of 50° the highest amount of discharge showing 400 [pC] and highest discharge number 198 occurred. For the negative phase, the highest amount of discharge 183 [pC] occurred in 221°, and the highest discharge number was 90. Thus, the early discharge characteristic of showing lower value than the positive phase was confirmed. But with the increase of voltage, in the case of the positive phase, the early discharge area was similar as with 0~115°, but in locations (0~10° and 180~190°) where the voltage reversed, large discharge was shown. Discharge frequency of 242 occurred at positive phase 20°, 182 at 50°. And at negative phase 183°, it showed 333, and in 234~251°, it showed 308~333. Amount of discharge occurred about 500[pC] at the positive phase of 10°, and amount of discharge occurred about 500[pC] at the negative phase of 183°, until it reached 250°.

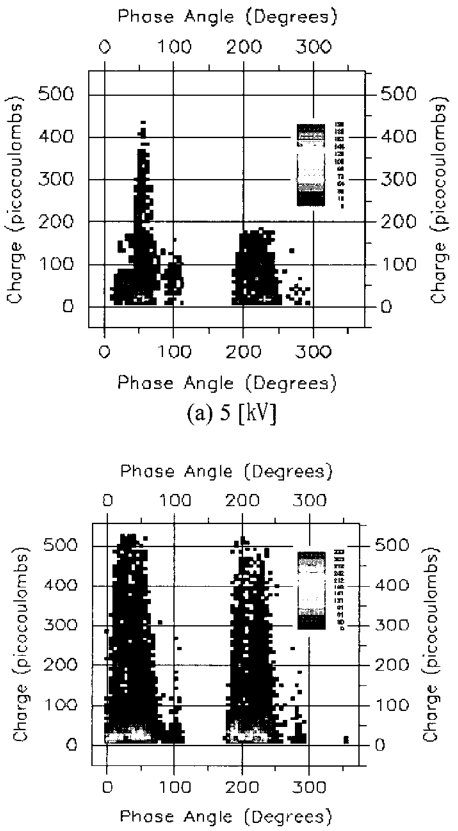


Fig. 3 $\phi - q - n$ distribution at air void

However, in the case of such Φ-q-n distribution, various values occurred even with the same conditions, so there were difficulties involved in applying them to assessment. For quantitative analysis of this pattern, Weibull analysis on discharge number and amount of discharge was performed.

3.2 Weibull distribution

To examine detected 10 data, the 2 parameter Weibull function is employed.

$$F(n) = 1 - \exp\left[-\left(\frac{n}{n_s}\right)\right]^m \quad (1)$$

where, n_s and m are scale parameter and shape parameter by step method

To obtain scale parameter n_s, axis x has been set for discharge number and amount of discharge, and axis y has been set for accumulation probability distribution. Then the variation factor of each has been calculated. Scale parameter indicates when the accumulation probability is 63.2%, so when it is calculated, it can be shown as in Tables 2 and 3. In the table, one can see that the leakage current of the inner insulator is increasing according to the increase of voltage. It is also confirmed that discharge number and amount of discharge are increasing. At the same time, in the void specimen, discharge number was 57 times and amount of discharge 8 times than those of specimens without void. It is considered that the concentration of electric field occurs because void insulation characteristics are lower than that of XLPE, which results in the increase of leakage current.

Table 2 Scale parameter (n_s) of discharge number

	Voltage [kV]	PN	NN	TN
N series	6	2,628.59	2,976.65	5,603.67
	8	2,627.56	3,048.24	5,678.39
	10	2,658.68	3,393.52	6,018.65
A series	4	513.68	184.82	605.42
	5	2,530.41	1,855.78	4,241.39
	6	6,279.85	7,395.83	13,651.09
	7	9,844.44	9,740.83	19,501.47

where, PN : positive discharge number
NN: negative discharge number
TN: total discharge number

Table 3 Scale parameter (n_s) of discharge

	Voltage [kV]	PC [pC]	NC [pC]	TC [pC]
N series	6	122,257	94,861	213,941
	8	227,948	196,845	424,119
	10	262,761	238,826	501,065
A series	4	50,903	9,259	53,197
	5	232,354	118,087	338,433
	6	653,240	457,101	1,103,520
	7	1,032,719	640,079	1,667,461

where, PC: positive discharge
NC: negative discharge
TC: total discharge

When equation (1) is transformed, one can get

$$\ln\ln\left[\frac{1}{1-F(n)}\right]=m\ln\left[\frac{n}{n_s}\right] \tag{2}$$

Further simplification yields the following equation

$$y=mx \tag{3}$$

where, $x=\ln\left[\frac{n}{n_s}\right]$, $y=\ln\ln\left[\frac{1}{1-F(n)}\right]$

In equation (3), gradient of the linear function indicates shape parameter. To obtain shape parameter, equations (4) and (5) need to be set as axis X and axis Y[8, 9], and one can obtain Fig. 4~7 using those equations.

$$X=\ln\left[\left(\frac{n}{n_s}\right)\right] \tag{4}$$

$$Y=\ln\ln\left[\frac{1}{1-F(n)}\right] \tag{5}$$

Fig. 4 presents the Weibull distribution of discharge number in no-void specimen (N series). The figure has confirmed that gradient is 1.3067 at the inception voltage of 6[kV] and it shows 1.7849 as the voltage increases to 10[kV]. That is confirmed according to the variation of voltage, as they show less than 2.

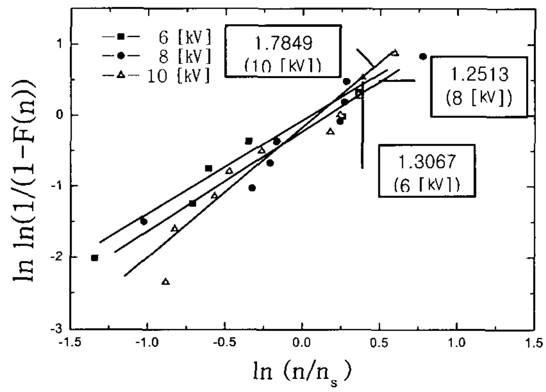


Fig. 4 Weibull plot of X versus Y of number (N series)

Fig. 5 shows the Weibull distribution of amount of discharge of no-void specimen. In the figure, when the voltage applied is 6[kV], gradient becomes 1.8625, and when the voltage is increased to 10[kV], it becomes 2.4198.

According to the increase of voltage, the Weibull distribution of discharge number and amount of discharge are gradually increasing although its change is very small, so as for the discharge number, they have less than 2, and the amount of discharge shows a factor similar to 2. In the

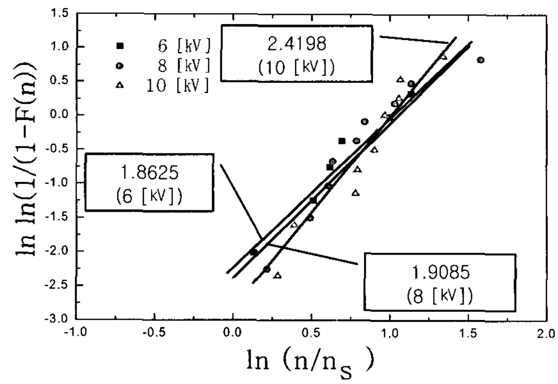


Fig. 5 Weibull plot of X versus Y of discharge (N series)

Weibull distribution, probability density function of X varies according to the shape parameter. In general, when m=2, it is called Ralyleigh distribution, and with this standard, when m becomes smaller, it indicates an exponent distribution function, and when m becomes bigger, it indicates a regular distribution function. Especially, when m is 1, it shows the perfect probability density function, so when there is no-void, discharge number forms the exponent distribution. It was also indicated that the amount of charge primarily indicated the form of exponent distribution, which gradually changed to the form similar to regular distribution. It is considered that dielectric strength at inception voltage is so strong that discharge distribution forms exponential distribution. However, the discharge occurs in the place where dielectric strength is weak according to the increase of voltage, and the discharge distribution changes into the form of regular distribution.

Fig. 6 shows the discharge number when there is a void, and one can know that the shape parameter at 5 [kV] is 5.3375, and it has a very big gradient of 6.9913 before trip voltage. Fig. 7 indicates the amount of discharge in the void specimen; shape parameter of 4.3803 in 5 [kV], which is increased to 7.8843 in 7 [kV] before trip voltage. In the void specimen, with the increase of voltage, the discharge number of shape parameter and the amount of discharge are increased from 5 to 7 and from 4 to 13, altogether m>2, respectively.

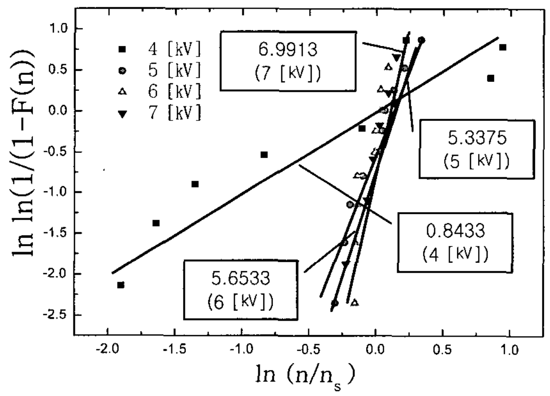


Fig. 6 Weibull plot of X versus Y of number (A series)

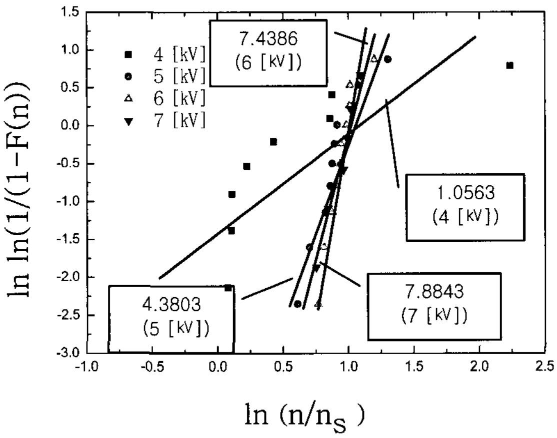


Fig. 7 Weibull plot of X versus Y of discharge (A series)

For the case of void specimen, one can define that it shows a probability density function of regular distribution with the increase of voltage. This phenomenon causes concentration of electrical field at void, and indicates growth characteristics of a frictional tree[2]. The form of discharge is not accidental but rather continuous and regular.

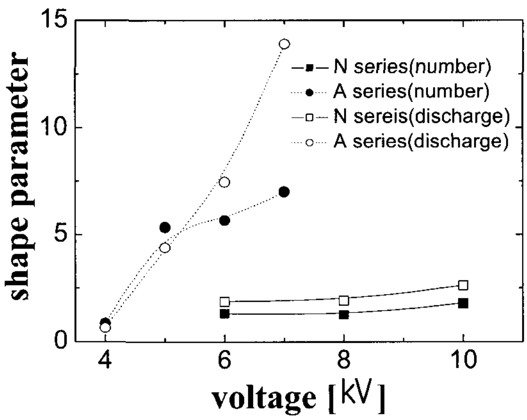


Fig. 8 Shape parameter (m) due to voltage variation

Fig. 8 presents the change of shape parameter according to the change of voltage. In the no-void specimen, the change of shape parameter is displayed as a solid line, whereas it is shown as a wave line in the void specimen. In the figure, with the case of wave line (void specimen), the change of shape parameter is rapidly increasing according to the increase of voltage, and in the case of solid line (no-void specimen), there is no outstanding change according to the change of voltage. It was also confirmed that the change of discharge distribution was much bigger than that of the discharge number. This phenomenon seems to occur when the higher discharge is mainly acting in the void specimen.

Finally, time function on the defect ratio is shown in Fig. 9. Defect ratio exponentially increases at void specimen, and no-void specimen linear increases. Therefore, existence of void occupies significant gravity in the assessment of the life of an insulator.

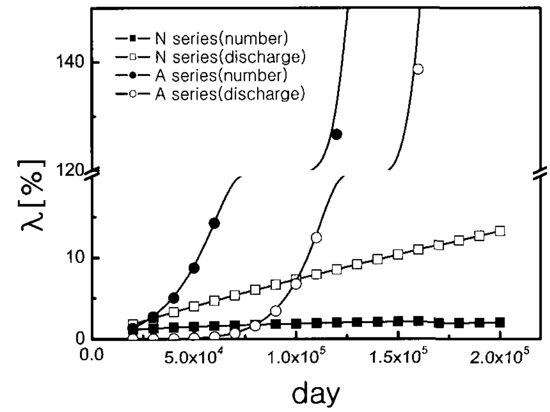


Fig. 9 Defect ratio according to Weibull distribution at 6[kV]

4. Conclusion

The analysis results of discharge distribution due to inner void of extra high voltage cable are as follows:

(1) In no-void specimen with the increase of voltage, the discharge position has two peak-appearances in positive and negative phase.

(2) In void specimen along with the increase of voltage, it was confirmed that the high amount of discharge is occurred in the early phase region at 10° and 183°.

(3) Shape parameter of discharge number in no-void specimen indicated values under 2, with the size of void specimen 5~7. It was confirmed that the discharge occurs in regular distribution.

(4) The shape parameter of discharge amount is similar to that of discharge number distribution in no-void specimen. But in void specimen, when it reaches trip voltage, shape parameter increases to 13.

(5) In void specimen, with the increase of time, defect ratio increases exponentially while its life decreases rapidly.

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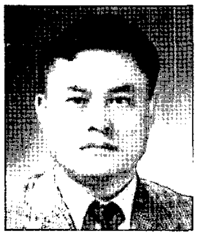

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