Development and optimization of breakdown strength measurements on polyethylene insulants

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Abstract

In order to study the ageing phenomena of polyethylene insulants in high voltage cables, we carried out electrical measurements, for example the short time dielectric breakdown field in polyethylene. The decrease of the intrinsic dielectric rigidity of polyethylene may be correlated with ageing. That is why we optimized the short time beakdown field measurements on polyethylene samples between plane surface electrodes immerged in a dielectric oil. First, we proceeded to the measurements of the dielectric breakdown voltages on polyethylene samples while increasing the voltage of 20 kV/mm/s. In a second step, the experimental results obtained from a population of 80 samples were treated by a Weibull statistic method : the two parameters model was used in order to deduce the value of the nominal breakdown field when the breakdown probability equals to 63.2 % and the threshold breakdown field equals to 0; when the threshold breakdown field wasn't nil, we applied the three order model. The study of experimental parameters, for example the nature and the surface of the electrodes, the viscosity of the immersion oil, the laboratory responsible for the experiments are presented, then discussed.

Introduction

The short term dielectric breakdown tests are widely used to compare new and aged polyethylene insulants in extruded cables. These tests could be directly applied to cables; therefore, the breakdown treatment by a statistic method needs so many results that it becomes rapidly expensive. That is why we appplied this method on polyethylene insulants obtained from extruded cables where the number of sample can be very important : each population contained a number of samples from 80 to 90. If it is not reasonable to consider the value of the dielectric breakdown field in polyethylene as the real intrinsic value of the extruded cables insulations, it is a convenient method to compare new and aged materials when we test them according to identical experimental conditions.

The short-time dielectric breakdown tests were performed using common parallel-plane electrode geometry with circular electrodes of equal diameters immersed in insulating oil, then the extensive data-sets were analysed by the Weibull statistics. The Weibull distribution has come to be preferred because it is widely used by insulation system designers. The polyethylene samples connected to the supply and tested between the electrodes were slices from 100 to 150 µm thick and 40 x 40 mm^2 in section cut from a power cable. In order to optimize the breakdown strength measurements on polyethylene insulants, the following parameters were investigated :

-voltage increase ramp;
-polyethylene samples thickness;
-electrodes profile;
-silicon oil viscosity;
-detection system;
-computation procedure.

Experimental procedure

The polyethylene samples were cut from the insulation of a power cable using a microtome, then degassed for 48 h at 65 °C in order to eliminate any volatile product without affecting the material. Their thickness was either 100 or 150 µm with a variation in the vicinity of 10 µm. The samples roughness was controled to prevent exceeding 5 % of their thickness.

The tests were performed either with LGET electrodes [1] made of stainless steel, 20 mm in diameter and with edges rounded to a 3 mm radius, or with Rogowski profile electrodes made of brass, 30 mm in diameter. The high voltage was applied to the upper electrode and the lower electrode was linked to the mass. In order to avoid any discharges around the electrodes edges, they were immersed in a bath of dielectric silicon oil of 50 cst or 500 cst.

After locating each sample between two electrodes, a 50 Hz ac linear ramp voltage with a slope of 2 kV/mm, 4 kV/s or 6 kV/s was applied until the material dielectric breakdown. As soon as the breakdown occured, the current circulating through the circuit disconnected simultaneously the high voltage and the voltmeter which displayed the maximum value reached.

Statistics on experimental results

Each population of typically 80 samples tested was analysed by the Weibull statistic. The cumulative probability of failure for the Weibull distribution can be written in its general form as :

$$P(E) = 1 - e^{\left[-\frac{E-Es}{Eo-Es}\right]^{\alpha}} \rightarrow Es < E < \infty$$
$$P(E) = 0 \rightarrow E < Es$$

with :

E=average electrical field;
Eo=nominal gradient;
Es=threshold gradient;
α=shape parameter.

This general case is the three parameters Weibull distribution : Eo, Es and α. A two parameters states a nil threshold gradient Es. Eo is the field corresponding to a 63.2 % breakdown cumulative probability.

The plot of data in a three parameters Weibull distribution can be obtained in the following coordinate system (see figure 1) :

$$X = \ln(E - Es)$$
$$Y = \ln\left[\ln\frac{1}{1-P}\right]$$

All the results are given with the two-sided tolerance bounds at a 90 % confidence level (see figure 1).

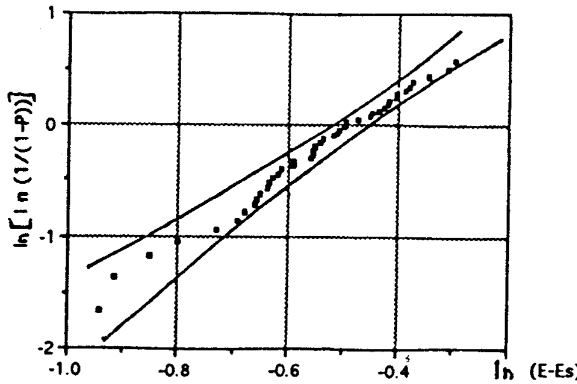

Figure 1 : Example of a Weibull distribution and 90 % confidence bounds

Influence of experimental parameters

Effect of voltage increase ramp

The effect of the voltage increase ramp was studied on polyethylene films, 100 µm thick; the tests were performed using LGET electrodes immerged in a bath of a 500 cst dielectric oil. The voltage increase ramps was of 2 kV/s, 4 kV/s and 6 kV/s (see table 1) :

Voltage ramp (kV/s)	2	4	6
Go (kV/mm)	180	182	190
Gs (kV/mm)	0	0	0

Table 1 : Effect of the voltage increase ramp

Go tends to increase with the voltage increase ramp of about 5-7 %. The voltage ramp of 2 kV/mm gives reproducible results in a convenient time. This value was then chosen for the following experiments.

Effect of the polyethylene samples thickness

The experiments were carried on with the LGET electrodes immerged in the 500 cst silicon oil; polyethylene films samples, 100 and 150 thick, were tested at 2 kV/mm, 4 kV/mm and 6 kV/mm (see table 2) :

Voltage ramp (kV/s)	2	4	6
Go, thick 100 µm (kV/mm)	180	182	190
Go, thick 150 µm (kV/mm)	159	171	176

Table 2 : Effect on samples thichness on Go

The nominal gradient for polyethylene samples, 150 µm thick, is about 10 % lower that the value obtained for the thickness of 100 µm. The voltage ramp of 2 kV/s and the polyethylene samples thickness of 150 µm were then retained for the next experiments.

Effect of the electrodes profile

The effect of the electrodes profile (LGET or Rogowski) immerged in a 500 cst silicon oil was studied at 2 kV/s with polyethylene samples, 150 µm thick (see table 3) :

Electrodes profile	LGET	Rogowski
Go (kV/mm)	162	144
Gs (kV/mm)	0	0
α	8.6	10.1

Table 3 : Effect of the electrodes profile

We note an effect of the electrodes profile on the nominal gradient : a difference of about 15 % are obtained comparing the LGET and Rogowski electrodes profile. We would prefer the Rogowski electrodes profile which surface contact with the electrodes is more important.

Effect of the silicon oil viscosity

The effect of the silicon oil viscosity (50 or 500 cst) was studied according to the following experimental conditions :

-voltage increase ramp : 2 kV/s;
-Samples thicknss : 150 µm;
-electrodes profile : Rogowski.

The results are presented table 4 :

Oil viscisity (cst)	50	500
Go (kV/mm)	143	142
Gs (kV/mm)	0	0
α	17.2	13.6

Table 4 : Effect of the silicon oil viscosity

According to the results in table 4, we can conclude that the silicon oil viscosity from 50 to 500 cst has no effect on the nominal and threshold gradients.

Effect of the detection system

The effect of the detection system, or in more details the effect of the electrical circuit including the series resistor and the current circuit breaker in order to limit the breakdown current to 5 mA maximum, and the effect of the precision of the peak voltmeter, was studied at 2 kV/s with LGET electrodes immerged in a 500 cst silicon oil and with polyethylene samples, thick 150 µm (see table 5). The detection system A is characterized by a short circuit current of 5 mA; it is only 1 mA in the system B.

Detection system	A	B
Go (kV/mm)	146	159
Gs (kV/mm)	0	0
α	11.5	9.6

Table 5 : Effect of the detection system

A difference of about 8-10 % on the nominal value is observed beteween the two detection systems. New and aged materials can be compared only if they are obtained with the same dtection system. Besides, in order to prevent any degradation of the electrodes, it is recommended to have a breakdown current as low as possible : 1 mA.

Effect of the computation procedure

In order to minimize the scatter between the experimental results and the theorical representation, the least squares (LS) and the maximum likehood (ML) methods were compared

[1]. The comparison between the two methods is given table 6 for three different populations :

Population	1	2	3
Go LS ML (kV/mm)	162 161	143 142	154 154
Gs LS ML (kV/mm)	0 0	0 0	0 0
α LS ML	8.6 9.5	17.2 20.4	13.4 15.2

Table 6 : Effect of the computation procedure

C. Chauvet and C. Laurent [1] observed that the nominal field was insensitive to the computation method, but the threshold taken together with the slope was different. We confirm that the nominal gradient is independant of the computation procedure. When the threshold is nil, it is not influenced by the Weibull distribution (in the case of the two parameter Weibull distribution).

Discussion

All the results presented in this paper have a two parameter distribution and a threshold equals to nil. We chose a 90 % confidence bounds where the Weibull distribution fit between the data and the straight line. C. Laurent, C. Chauvet and J. Berdala [2] have studied the significance of the Weibull threshold in short-term breakdown statistics. They concluded that the threshold value depends on test conditions and that the electrical ageing acts as a scattering factor.

Each studied parameter (the electrodes profile, the voltage increase ramp, the polyethylene sample thickness, the breakdown detection system) affects the nominal value Go. Only the oil viscosity used in order to prevent discharges from the metallic electrodes has no infuence on Go.

The short time dielectric breakdown measurements have been developed in the program of the optimization of physical and chemical procedures for the study of poyethylene ageing, insulation for power cables [3]. When the parameters (electrodes profile, samples thickness, oil viscosity, breakdown detection system) are fixed for the comparison of new and aged polyethylene insulations, we can note a decrease of the nominal value Go after an electrical ageing during 1000 hours at 25 kV/mm [4]. C. Laurent [2] also observed a difference of the Weibull plots between unaged and aged population. This method could be retained as a diagnosis method for the evaluation of on-line extruded cables.

Conclusion

The study of the effect of experimental parameters like the electrodes profile, the polyethylene samples thickness, the electrodes immersion oil viscosity, the breakdown detection system, the voltage incerase ramp was necessary in order to optimize the breakdown strengh measurements on polyethylene insulants. If the nominal gradient measured on polyethylene samples cannot be correlated with the maximum electrical field we apply to cables insulants without any damage, the short term breakdown measurements is an interesting method for comparing unaged and electrical aged polyethylene materials with a precision of about 1%.

References

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