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# Application of Pearson Type III Statistics to High Voltage Breakdown Realizations.

Fathi Yousef
*Associate Professor of Electrical Power Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.*

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# APPLICATION OF PEARSON TYPE III STATISTICS TO HIGH VOLTAGE BREAKDOWN REALIZATIONS

# تطبيق احصائيات بيرسون من النوع الثالث على نتائج معملية للانهيارات فى الجهد العالى

**Fathi M. H. Youssef**
Elect. Eng. Dept., Faculty of Eng., Mansoura University, Egypt.

الخلاصة : يقدم البحث النوع الثالث من احصائيات بيرسون كأداة قوية وجديدة للاستخدام فى التطبيق الاحصائى فى مجال الجهد العالى • تم أختبار التوزيع على عينات نتائج عملية لمراحل ماقبل الانهيار والانهيار فى ثغرات زيت ذات مجال كهربى متزايد نتيجة وجود جزئيات معدنية ثابته ومتحركة وأوضحت النتائج مدى تطابق هذا التوزيع مع التوزيع الحقيقى للعينات المعملية فى الوقت الذى تباعدت فيه التوزيعات الاخرى الشائعة الاستعمال عن التوزيع الفعلى • تم تطبيق هذا التوزيع أيضا على عينات لمسافات الانهيار السطحى لعازل البكالايت فأتضح أن توزيع بيرسون المقدم فى هذا البحث لا يتغلب فقط على الاخطاء خاصة التوزيعات الاخرى الشائعة الاستعمال كتوزيع الوايبول بل أيضا أن هذا التوزيع قادر على تمثيل النتائج المعملية فى الجهد العالى لحالات الاختبار المختلفة ذات الجهد المتزايد وذات الجهد الثابت •

## ABSTRACT

In the high voltage engineering, the mathematical statistics play a dominant rôle for choosing test procedures as well as for the analysis and interpretation of measurements. However, the currently used normal, double exponential and Weibull distribution types are not powerful enough to describe many insulation electrical strength behaviours. Some dangers have been found by the approximations of concrete high voltage breakdown realizations through the Weibull distribution. To avoid these dangers, the paper introduces a powerful distribution type as a new tool for the statistical analysis of high voltage breakdown realizations. This is the Pearson type III distribution. This three parametric distribution has been applied to different high voltage breakdown realizations. The results show the better fitting features of the distribution compared with the other currently used distribut types.

## 1. INTRODUCTION

By the design of high voltage insulating systems, the calculated electric field values must be compared with the dielectric strength of the system. Thereby, it should be noted that the dielectric strength can not be described by means of a single concrete numerical value. The dielectric strength has more or less a random nature. This random nature can be described by a distribution function depending on the stochastic variations caused by the building of the electron avalanches of the breakdown process [1-4]. This distribution function must be taken into consideration to meet realizable declaration about the rigid breakdown voltage values. So, the distribution type should not only be able to adopt the measured values to a theoretical distribution function, but also it is recommended to modulate the process theoritically or experimentally [5].

The uncertainty by the modelling of the stochastic breakdown process does not allow a direct practical employment of the distribution types assigned by the theoretical considerations. They rather serve to realize the approximation of the empirical distribution functions through theoretical distribution functions in a significant physical manner [6]. The kind of distribution type to be perfomed is consequently decided through the experiments. Thereby, it should be clear that through measurements and interpretations probable random errors of the investigated breakdown voltage values may be superimposed. These errors can already exist through the action of many random influences such as the random appearance of high electric field strenghts caused by a particle, the random disposition of an initial electron and/ or the random building of breakdown [7].

If all conceivable random influences contribute to the whole process, and if these influences can be described through random variables, which are independant of each other, thus the distribution of the sum of these random variables will converge to the normal distribution [6]. The normal distribution is of great importance for most statistical estimations in the high voltage engineering, specially for describing of air breakdowns and flashovers of insulators [5]. It is also successfully used by other insulation tests because of its simplicity.

It lies by the stochastic nature of the breakdown process itself, that the electrical strength is neither identical distributed for all arbitrary electrode systems nor for all kinds of stresses. For example, by electrodes having large areas with constant electric field strength, like those of gas compressed insulating systems, an elevation of the electric field strength through particles at different elementary regions is possible. In this case the avalanche building will be the measure which determines the breakdown process and an extreme distribution value is expected for the electrical strength [2]. The double exponential distribution has been successfully used for describing the stochastic processes and breakdown behaviours in such compressed gas insulated systems [6].

The normal and double exponential distributions have been found to be insufficient for describing more complicated breakdown phenomena as those in liquid insulations. To this extent, the Weibull distribution has been introduced to model such stochastic processes [8]. This two parameters Weibull distribution converges for large Weibull exponents to the double exponential distribution.

The three mentioned statistical distribution types are the currently used distributions in the high voltage engineering. They have the advantage of being simple by employment and interpretation. However, they are not powerful enough to describe many of the behaviours of the insulation electrical strenght. So, some dangers have been found by the approximations of concrete high voltage breakdown realizations through the weibull distribution [9-10].

Nowadays, and with the ever growing facilities by the use of digital computers, it has been a main demand to employ more powerful distribution functions for modelling and analyzing of electrical strengths. To this extent, the paper introduces a powerful distribution namely; the Pearson type III distribution, as a new tool for the statiscal analysis in high voltage engineering. This distribution has been originally introduced by the author together with other researchers for use in statistical analysis of wind data [11,12]. The excellent results achieved encouraged the author to apply this distribution on different random samples of the electrical strength under technical limitations. The fine results achieved prove its necessity to introduce this distribution type to the high voltage area.

## 2. PEARSON TYPE III DISTRIBUTION

The Pearson type III distribution is a three-parameter distribution. If, for example, the breakdown voltage v is the random variable to be anali-ed, the three parameters used are the mean breakdown voltage, $\mu$, the standard deviation, $\sigma$, and the skewness, $\beta$. The skewness is a function of both the third moment of the breakdown voltage data about the mean breakdown voltage and the standard deviation and it is defined as follows [13]:

$$\beta = \frac{\sum_{i=1}^{N} ( v_i - \mu )^3}{\sigma^3} \qquad (1)$$

where $v_i$ is the i th breakdown voltage value and N is the number of breakdown voltage values.

The Pearson probability distribution function f(v) has the following form for positive skewness [13]:

$$f(v) = \frac{A.(A^2+A(v-\mu)/\sigma)^{(A\ -1)^2}}{\sigma\ .\ \Gamma(A^2)} .\exp\ (-(A^2+A(v-\mu)/\sigma)) \qquad (2)$$

For negative skewness the distribution function is expressed as:

$$f(v) = \frac{A.(A^2+A(v+\mu)/\sigma)^{(A-1)^2}}{\sigma \,.\, \Gamma(A^2)} .\exp\left(-(A^2+A(v+\mu)/\sigma)\right) \quad ..(3)$$

where $A = 2/\beta$ (4)

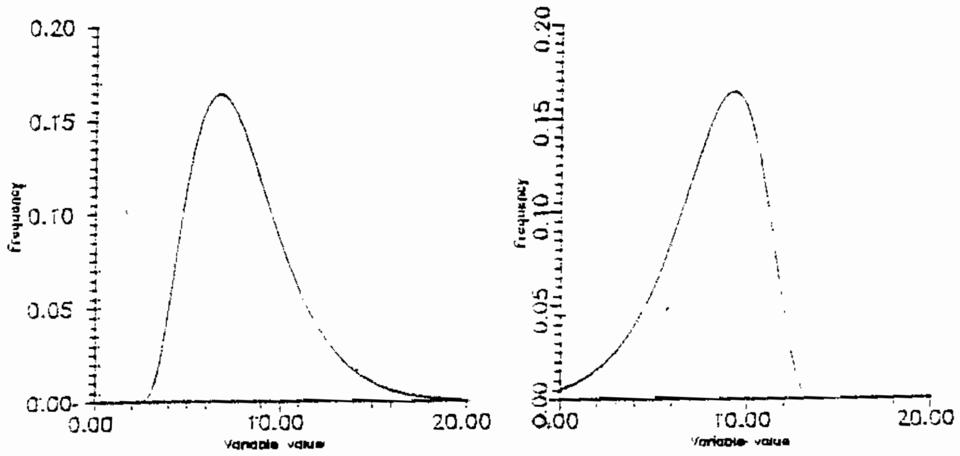
One important characteristic of the pearson type III distribution is that its distribution function does not exist for all breakdown voltages from 0 to ∞ as in the Weibull distribution. It has a maximum breakdown voltage beyond which the frequency is zero in the case of negative skewness. This maximum breakdown voltage is:

$$V_{MAX} = \mu + A \,.\, \sigma \quad (5)$$

And in the case of positive skewness, it has a minimum breakdown voltage below which the distribution function is zero. This minimum breakdown voltage equals:

$$V_{MIN} = \mu - A \,.\, \sigma \quad (6)$$

This characteristic is shown in Fig. 1.



(A) : Positive Skewness

(B) : Negative Skewness

Fig. 1 Pearson type III disribution

Really, the Pearson distribution function has a more complicated form than the Weibull distribution. However, the construction or fitting of this function to the actual data is more simple than the Weibull distribution. This is due to the fact that the Pearson distribution parameters are the mean, standard deviation and the skewness which are estimated directly from the actual data; whereas the Weibull parameters are related to these statistical parameters by complicated relations which has no straightforward method to solve it.

## 3. APPLICATIONS

As mentioned in the above introduction, the breakdown phenomena in liquid insulations is the most complicated phenomena to be described, specially when the electric field strength is elevated through randomly existing particles. Therefore, inception (prebreakdown) and breakdown voltage samples of oil gaps influenced by the existance of fixed and free moving conducting particles have been investigated. The random voltage samples were examined for the best fitting distribution type. After being sure that the random samples are not accepted for the normal distribution test at the 95% confidence level, the Weibull distribution, the Pearson type III distribution and the Rayleigh distribution [13] have been applicated to the data. It should be mentioned here that, as illustrated in all applications, the Rayleigh distribution is found to be of no interrest for this area of application.

The experimental set up used is a 60 kV semi-automatic test set with BSS/IES test vessel. This small volume transformer oil tester has a motorized variable transformer to raise the voltage at 2 kV/second. This means that the test stress is a voltage rising test method (VRT). Details of experimental set up is published in reference [14].

Using two sphere electrodes of 1.3 cm diameters and a horizontal oil gap of .55 cm, 100 inception and 100 breakdown voltage values of the oil gap have been recorded. For this case, without existing conducting particles, whereby the electric field can be considered a weak non uniform one. The breakdown voltage values have been accepted for the normal distribution test at the 95% confidence level. Thereby, the average breakdown voltage of the data sample was 46.576 kV with a standard deviation of 7.9 kV.

However, the analysis of the inception voltage values showed a rejection to the hypothesis of a normal distribution at the 95% confidence level. This, in turn, confirms that the breakdown mechanisms in oil may include different stages of different electric field dependency. The inception voltage data (without particle) having a mean value of 23.535 kV, a standard deviation of 1.4 kV and a skewness of .3388 has been tested for the best fitting distribution type. Fig. 2 shows the distribution fittness test. It is clearly seen that the Pearson type III distribution is the most fitting one.

A conducting particle of 1 mm diameter has been fixed on a sphere electrode at the symmetry axis level. The oil gap is then adjusted to be also of .55 cm width from particle tip to the other sphere electrode. Inception and breakdown voltage values for this oil gap, having an elevated nonuniform field through the particle, have been recorded. For this testing case, both inception and breakdown voltage data samples were rejected for the normal distribution test at the 95% confidence level. Accordingly, they have been tested for the best fitting distribution type.

Fig. 3. illustrates the distribution fitness test for the inception voltage in presence of fixed particle. The data sample composed of 55 values of a mean value of 10.08 kV, standard deviation of 1.528 kV and a skewness of .07895.

Fig. 4. illustrates also the distribution fitness test for the breakdown voltage in presence of the same fixed particle. The data sample composed of 55 values of a mean value of 30 kV, standard deviation of 1.7 kV and a skewness of 1.276.

Both figures 3 and 4 illustrates not only that the Pearson type III distribution is the best fitting distribution, but also that the Weibull distribution is far away from an acceptable fittness to the data. The acceptance of the Weibull distribution for such breakdown mechanisms may lead to far consequences regarding errors by the insulation dimensioning.

To investigate the influence of free conducting particle existence on the breakdown behaviour, a conducting particle of 1 mm diameter has been suspended through a thin hair, 30 cm long, in the middle of the original sphere gap arrangement. Also, in this case the oil gap (between both spheres) was of .55 cm. In this case no definite inception voltage was recognized and thus only breakdown voltage values have been recorded. Also in this case of elevated field strength in insulating oil liquid, the breakdown voltage values showed a rejection to the hypothesis of a normal distribution at the 95% confidence level. Then, the data sample composed of 55 values having a mean breakdown voltage of 26.72 kV, standard deviation of .8256 kV and a skewness of .12648 has been tested for the best fitting distribution.

Fig. 5. illustrates the distribution fitness test for the breakdown voltage in presence of that free moving conducting particle in the oil sphere gap. Again, it is very clear that the currently used Weibu' distribution is very far from the actual distribution. The Pearson ty III distribution is the best fitting one for this kind of breakdo phenomena.

Another kind of application on electrical strength investigations has been undertaken to examine the distribution type of creepage distance of the bakelite insulating material. This creepage distance is an important factor by designing insulating systems in coastal and marine electrical equipment.

The experimental set up is thereby a standard electrode system configuration. With a constant voltage stress and with a wetted insulation surface through drops of ionic solution at intervals of 35 s, the creepage distance at which the material withstands 50 drops without tracking will be evaluated. The used ionic solution in this experiment is .1 ± 0.002% by mass amonium chloride ($NH_4CH$) in distilled water prepared solution. For the details of test procedure as well as the electrode arrangement and investigation techniques, refer to [15].

Fig. 6 illustrates the distribution fittness test for the creepage distance of the insulating bakelite material under 440 V AC stress and with a wetted surface by the ionic solution as described above. It is clearly seen from the figure that the Pearson type III distribution is also, for this kind of stress and by this complicated creepage mechanisms, the best fitting distribution type. The actual data analyzed in this figure is composed of 35 creepage distance values having a mean value of 3.4348 mm, standard deviation of 1.5273 mm and skewness of .5629.

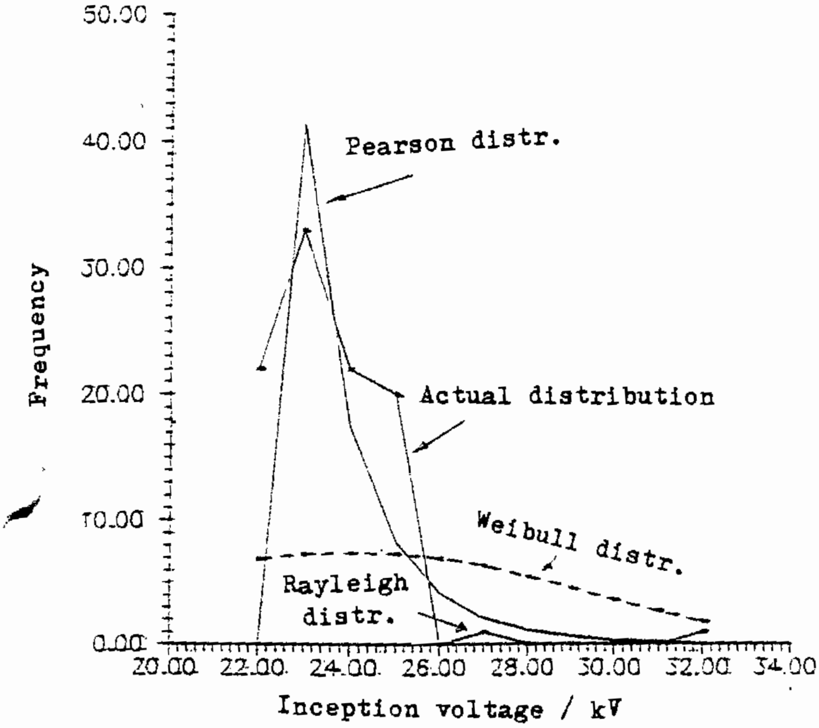


Fig. 2. Distribution fitness test for inception voltage values in a sphere oil gap without particle.

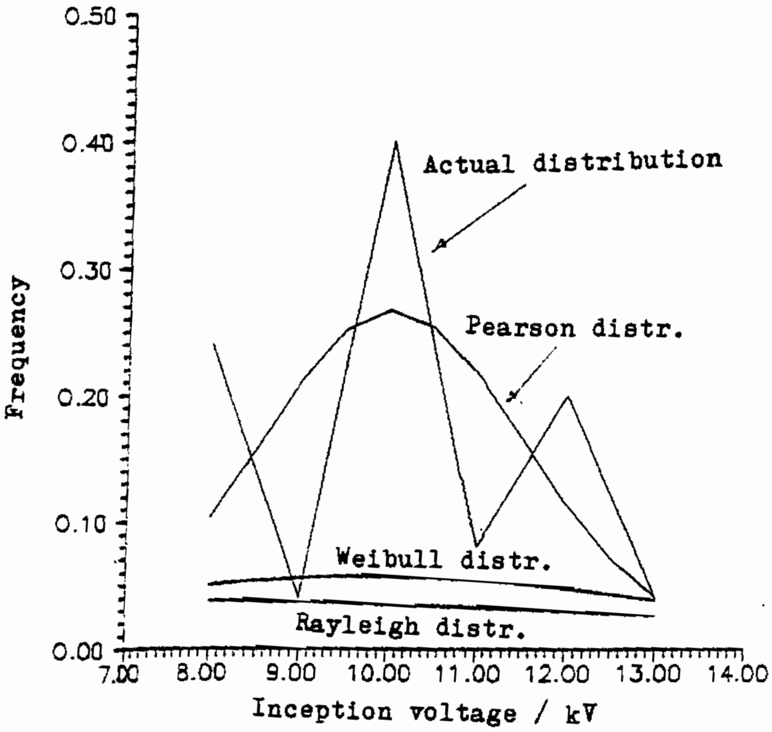


Fig. 3. Distribution fitness test for inception voltage values in a sphere oil gap in presence of fixed particle on the sphere at the symmetry axis level.

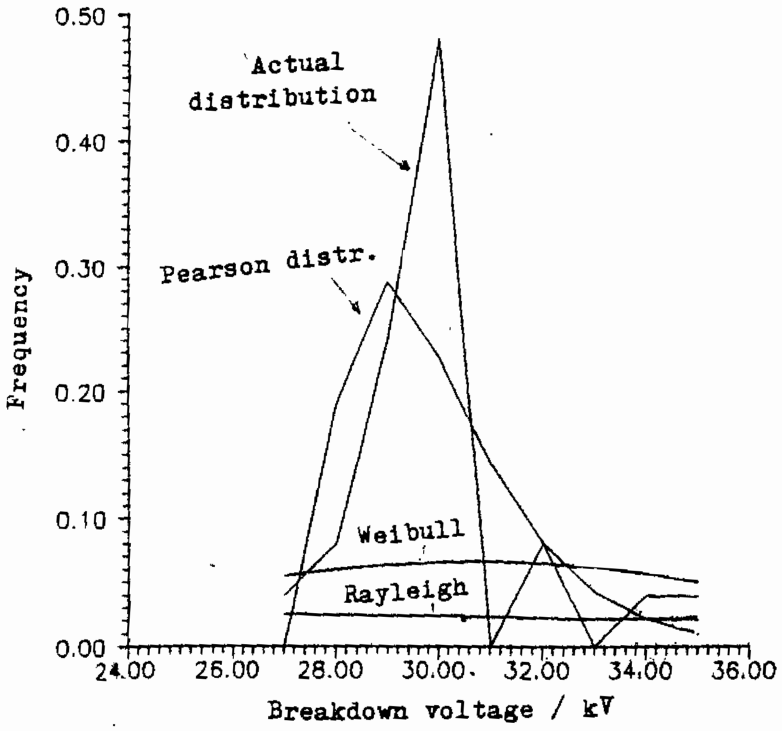


Fig. 4. Distribution fitness test for breakdown voltage values in a sphere oil gap in presence of fixed particle as discussed in text.

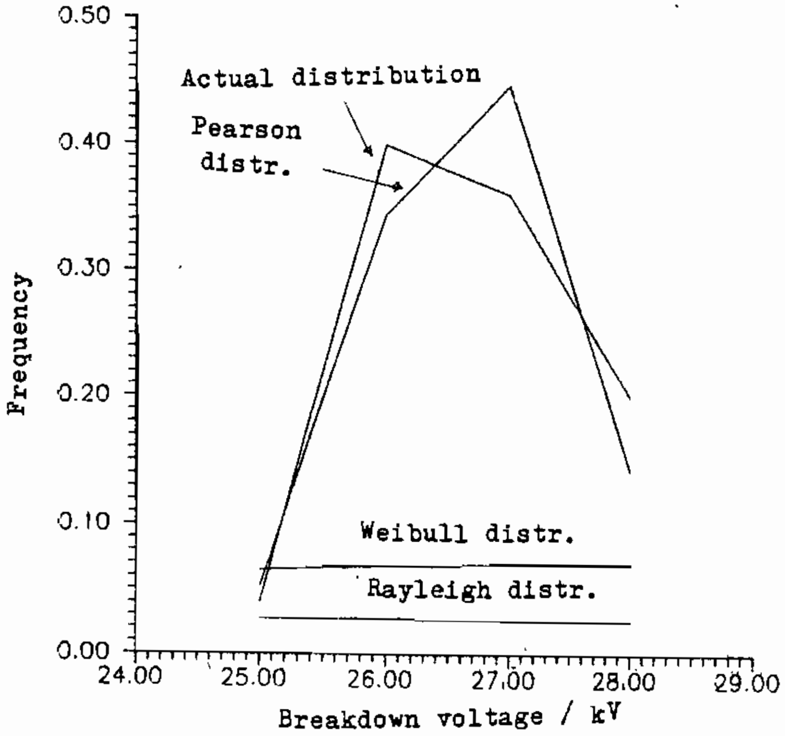


Fig. 5. Distribution fitness test for breakdown voltage values in a sphere oil gap in presence of suspended free conducting particle as discussed in text.

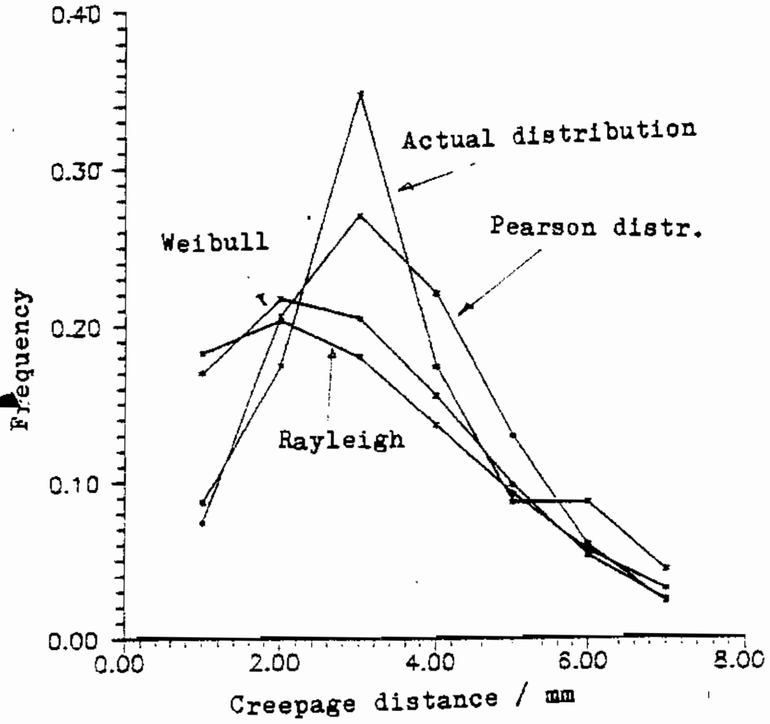


Fig. 6. Distribution fitness test of the creepage distance of a bakelite insulating material under 440 AC volt and solution conditions as discussed in text.

## 4. CONCLUSIONS

The paper introduces the Pearson type III distribution as a powerful new tool for the high voltage statistical applications. Although this distribution has a more complicated form than the Weibull distribution, the construction or fitting of this distribution function to the actual data is more simpl than the Weibull distribution.

The introduced distribution has been applied on high voltage data samples for prebreakdown and breakdown phenomena in highly elevated electric field oil gaps, which are known to be complicated to be described. The results show not only that this introduced distribution is better fitting type compared with other currently used distributions, but also how the Weibull distribution can be far away from the real one.

The Pearson type III distribution has also been applied with great success for fitting creepage distance realizations of bakelite insulation. This indicates the capability of this distribution by dealing with high voltage random samples of the voltage rising test method as well as of the constant voltage method.

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