# Statistical Analysis of Impulsive Flashover Voltages Across Solid-Air Interfaces

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**Paper ID - 467**

**Introduction:** Within the pulsed power industry, a key factor determining the achievable output voltage of a HV system is the flashover voltage of the insulating parts. Statistical analysis of the breakdown voltages associated with solid-gas interfaces can reveal useful information to aid system designers in the selection of solid materials. However, it is important to test the applicability of the distribution being applied, to ensure that the fitting parameters obtained are truly representative of the distribution of the data. Normal, lognormal, 2-parameter Weibull and 3-parameter Weibull cumulative distribution functions (CDF) were plotted, to enable extraction of the specific fitting parameters associated with each distribution. The CDF for each statistical method has been plotted alongside the empirical cumulative distribution function (ECDF), found from the flashover voltages recorded during experimental testing. The distribution of best fit was then analysed by using the Kolmogorov-Smirnov (K-S) test, in order to determine the CDF that best represented the ECDF. Maximum values have been compared to the α = 0.05, K-S critical value, in order to reject or accept the null hypothesis based on how the data fits the specified distributions. This will facilitate a comparison between different statistical distributions, applied to experimental data on breakdown/flashover voltages of gas-solid interfaces, generated at a fixed pressure, and different levels of RH.

## Results

From the K-S statistics conducted for each system setup. The K-S test statistic value and the rank orders have been published below for each CDF.

**RESULTS FOR HDPE, ULTEM AND DELRIN AT –0.5 BAR GAUGE AND AT <10% RH**

| | Delrin | | HDPE | | Ultem | |
|---|---|---|---|---|---|---|
| | K-S critical value | Rank | K-S critical value | Rank | K-S critical value | Rank |
| Nor | 0.1036 | 3 | 0.1228 | 3 | 0.1404 | 3 |
| Log | 0.0944 | 2 | 0.1074 | 2 | 0.1323 | 2 |
| 2- P | 0.1423 | 4 | 0.1557 | 4 | 0.1599 | 4 |
| 3- P | 0.0665 | 1 | 0.0760 | 1 | 0.0833 | 1 |

**RESULTS FOR HDPE, ULTEM AND DELRIN AT –0.5 BAR GAUGE AND AT ~50% RH**

| | Delrin | | HDPE | | Ultem | |
|---|---|---|---|---|---|---|
| | K-S critical value | Rank | K-S critical value | Rank | K-S critical value | Rank |
| Nor | 0.1368 | 3 | 0.1594 | 3 | 0.1910 | 2 |
| Log | 0.1301 | 2 | 0.1613 | 4 | 0.1754 | 1 |
| 2- P | 0.1401 | 4 | 0.1333 | 2 | 0.2542 | 4 |
| 3- P | 0.1055 | 1 | 0.1207 | 1 | 0.2095 | 3 |

**RESULTS FOR HDPE, ULTEM AND DELRIN AT –0.5 BAR GAUGE AND AT >90% RH * refers to R value was maximum at 0, so 3-P Weibull not applicable**

| | Delrin | | HDPE | | Ultem | |
|---|---|---|---|---|---|---|
| | K-S critical value | Rank | K-S critical value | Rank | K-S critical value | Rank |
| Nor | 0.1294 | 3 | 0.0566 | 1 | 0.2146 | 2 |
| Log | 0.1355 | 4 | 0.0574 | 2 | 0.2199 | 3 |
| 2- P | 0.1178 | 2 | 0.1084 | 4 | 0.1612 | 1 |
| 3- P | 0.1121 | 1 | 0.0773 | 3 | 0.1612 | -* |

The critical value used in this paper, at a significance level of 0.05, is 0.2941, which refers to the 95% confidence interval.

## Cumulative distribution functions

**Normal**

$$CDF(V;\ \mu,\sigma) = \frac{1}{2}\left[1 + erf\left(\frac{V-\mu}{\sigma\sqrt{2}}\right)\right]$$

**Lognormal**

$$CDF(V;\ \mu,\sigma) = \frac{1}{2}\left[1 + erf\left(\frac{\ln V-\mu}{\sigma\sqrt{2}}\right)\right]$$

**2-P Weibull**

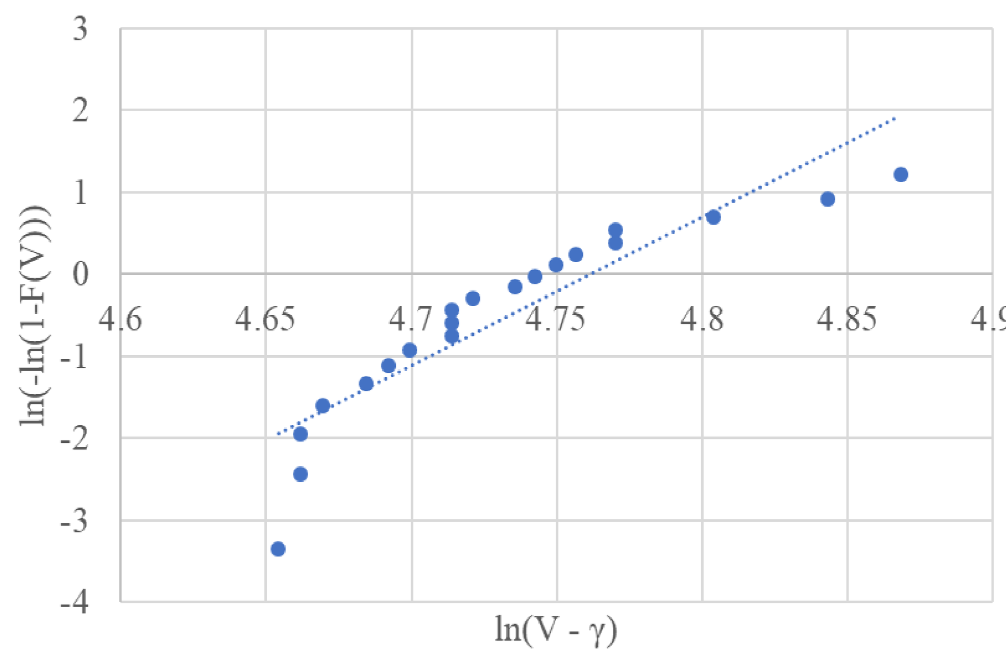
$$CDF(V;\ \alpha,\beta) = 1 - e^{\left(\frac{V}{\alpha}\right)^{\beta}}$$

**3-P Weibull**

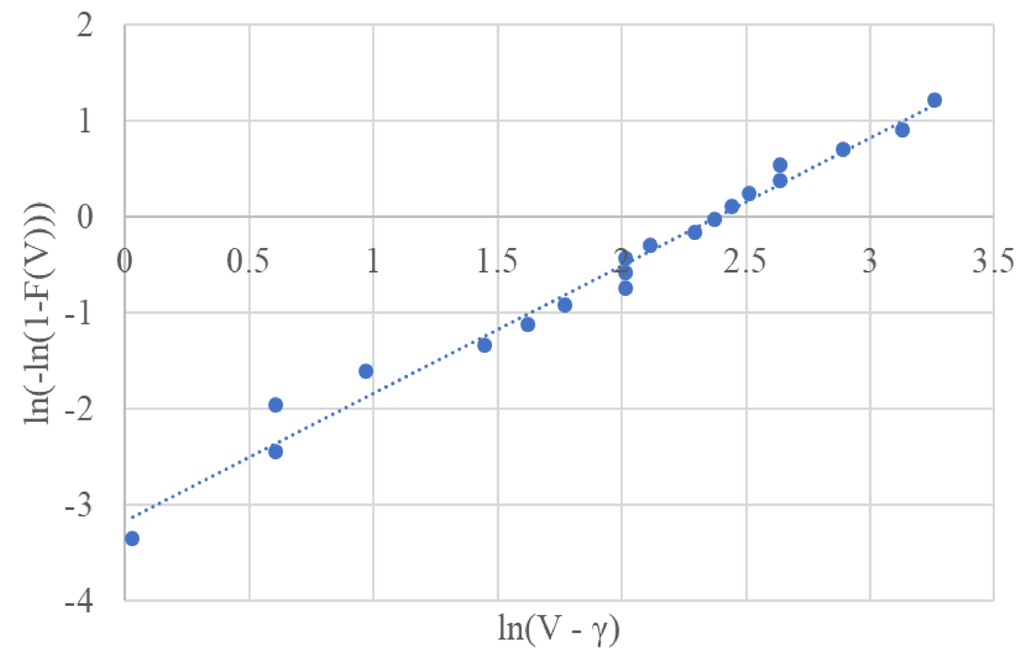
$$CDF(V;\ \alpha,\beta,\gamma) = 1 - e^{\left(\frac{V-\gamma}{\alpha}\right)^{\beta}}$$

## Using linear regression to approximate γ value for 3-P Weibull

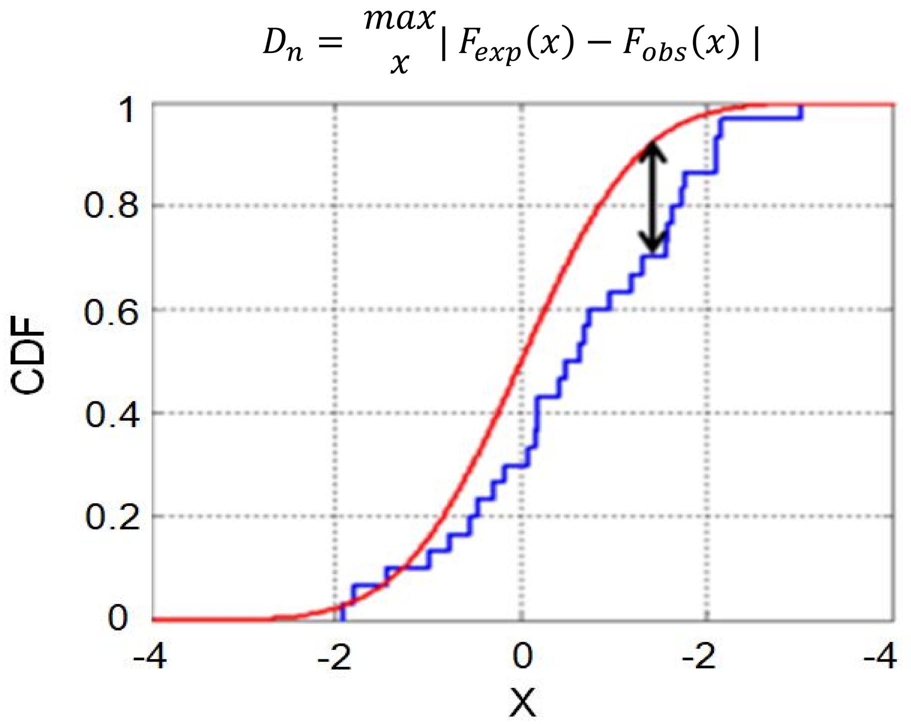
γ = 0, R = 91.21%

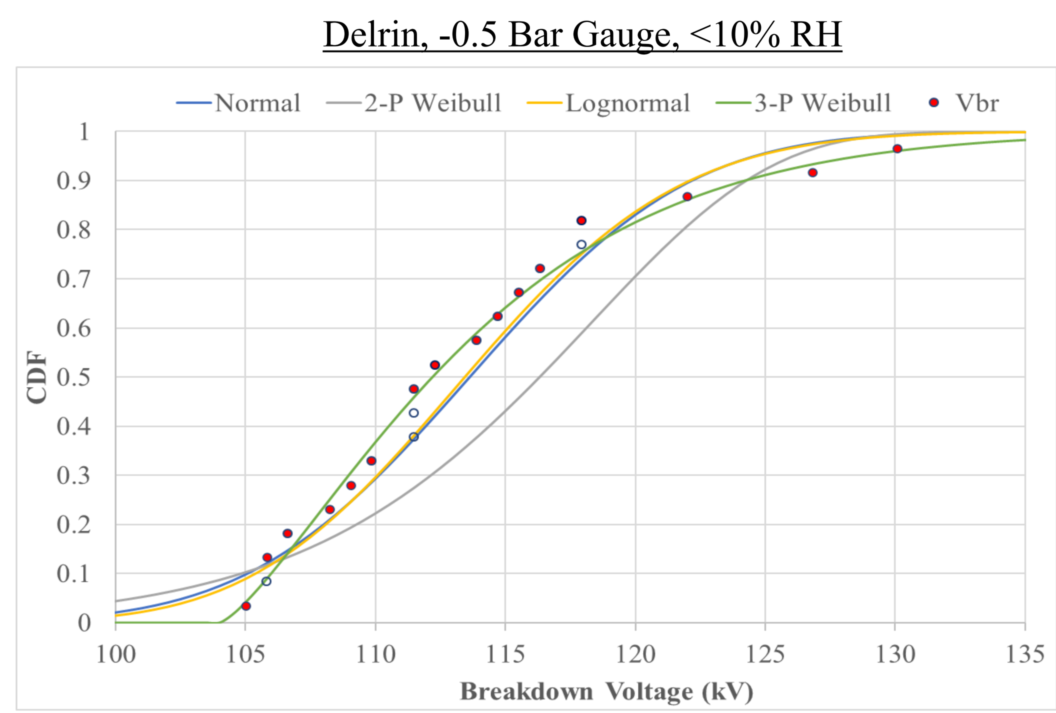


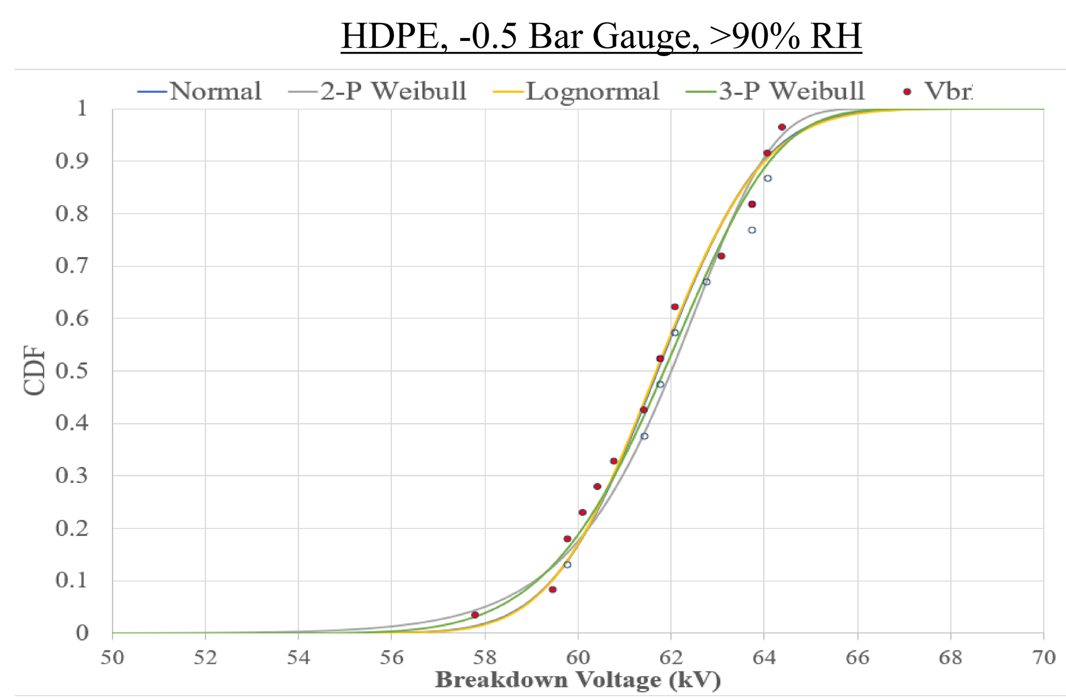

γ = 104, R = 99.09%




## Using K-S statistics in order to compare practical data, $F_{exp}$ (x), to normal, lognormal, 2-P Weibull and 3-P Weibull distributions, $F_{obs}$ (x)




**Discussion:** In each table generated, the maximum K-S point ($D_n$) is listed for each of the four distributions plotted. Overall, from the rankings, the best fit to the tested data is generally the 3-parameter Weibull fit. For dry air (<10% RH), the ranking order remains consistent for each material. However, as the humidity increases, the distribution of best fit changes, where the ranking order becomes more erratic, when comparing materials at high levels of relative humidity. Yet, from the 9 tests conducted, 6 of these resulted in a 3-parameter Weibull best fit. The K-S critical value is equal to 0.2941 for $\alpha$ = 0.05, and the values in Tables show that the $D_n$ value was always lower than this critical value, for all tests. Therefore, for all tests, the null hypothesis is not rejected, meaning that each CDF could statistically be used to represent the ECDF. However, the smallest critical value on average is offered by the 3-parameter Weibull distribution, which is therefore concluded as the distribution of best fit overall.