Cable Lore

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ANACONDA

Weibull Distribution Illustrates Weakest Link Theory

If a 2400-foot piece of power cable is cut into 24 one hundred-foot lengths, the voltage required to break down each of them will vary from piece to piece. To illustrate the variations in endurance, charts called histograms are frequently constructed.

An example involving the 24 cable samples might produce the histogram shown in **Figure 1.** Each bar here represents a 10 kV cell or range of voltage breakdowns. The dashed line is based on the number of samples in the cell and the cell midpoints.

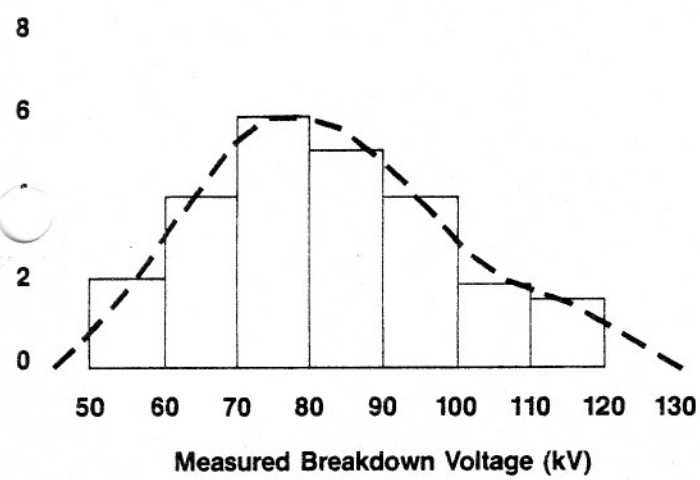

Fig. 1

This histogram shows that two of the cable samples failed in the 50-59 kV voltage range, four samples failed in the 60-69 kV range, six in the 70-79 kV range, and so on throughout the scale.

Histograms like Figure 1 are useful, but a little awkward. It would be much better if the data could be further condensed into an average and a dispersion of the results. One way would be to report the arithmetic average (the sum of all breakdown voltages divided by 24) with the minimum and maximum voltages; in this example, the results would be average 81, maximum [illegible], minimum 55.

If breakdown voltages formed a normal distribution, the histogram in Figure 1 would be symmetrical; the left half would be a mirror image of the right half. The average and standard deviation would then be all the information needed to summarize the data. But in Figure 1, and with dielectric strength results in general, the resulting curve is not symmetrical. Another distribution must be used.

Weakest Link Interpretation

Breakdown voltages and numerous other failure statistics follow a principle known as the Weibull distribution. This type of distribution is named after the Swedish statistician who first suggested it in 1939, and one statistical textbook sums it up as follows.

> "The experience of many investigators has shown that Weibull distributions provide good probability models for describing "length of life" and other endurance data. One explanation for the success of the Weibull distributions in describing such data is related to the following "weakest link" interpretation of endurance.
>
> "Suppose an object is put under stress. Think of the object as being composed of a large number of separate parts, each of which has its own statistically independent random endurance time (lifetime). If any one of these parts fails (or breaks) under stress, the whole object experiences failure (breakdown).
>
> "For example, the object could be a metal chain composed of a large number of links. If any link ("The weakest link") breaks, so does the chain. Thus, the lifetime of the object (the chain) is equal to the minimum lifetime of any of its parts (links). If the lifetimes of any class of objects (chain, rockets, transistors, and so on) have this property, then it can be shown that a Weibull distribution provides a close approximation to the distribution of these lifetimes."

(Continued)

Like the normal distribution, which can be described by an average and a standard deviation, the Weibull Distribution can be described by two constants: the scale and shape parameters. The scale parameter is similar to an average and is often called the "Characteristic Breakdown Stress". The shape parameter is similar to a standard deviation. The same breakdown data used to generate the histogram in Figure 1 produces the Weibull plot shown in **Figure 2.**

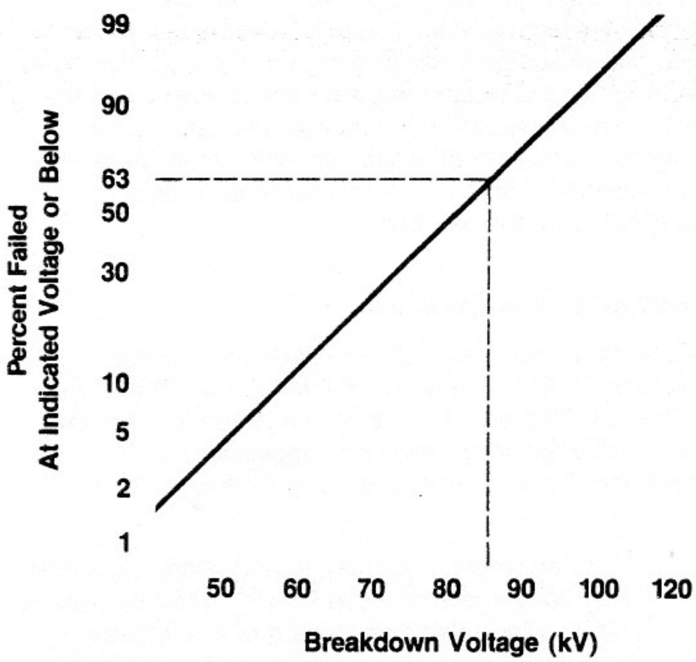

Fig. 2

Special Weibull plotting paper is used for this purpose, and the horizontal and vertical scales are constructed in a manner that produces a straight line, when data follow the Weibull distribution. (Data from a normal distribution would not produce a straight line.)

The steeper the slope, the larger the shape parameter and the greater the cable uniformity. Typical values for the shape parameter range from eight to twelve. The further the line is to the right, the higher the dielectric strength of the cable.

To determine the characteristic breakdown stress, the chart is entered on the left at the 63% point[1], as shown by the dashed line. The intersection of the dashed line with the line of experimental points then forms a point from which a vertical line is drawn to the horizontal scale where the characteristic breakdown is read directly. In the example, it is 86 kV.

Weibull plots of dielectric strength tests, combined with Weibull plots of time to failure tests, form the background of the latest technology in cable reliability prediction.

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[1] Defined as the Characteristic Breakdown Level.