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Prediction of power cables failures using a software application

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This paper analyses the electrical performance of power supply cables in operation by investigating previous faults and forecasting faults using the Easyfit Professional 5.6 software program. The calculation of the maximum operating time until the first fault occurs is based on an algorithm for estimating the parameters entered in the application, respectively the intervals of good operation time between two successive faults. The case study presented in the paper analyses the probability of failure of a medium voltage power line, under the administration of a distribution operator, based on information collected during maintenance work on medium and low voltage installations in the analysed area.

Keywords: *prediction, cables, failure, software*

1. Introduction

During operation, an electrical system is subjected to a series of factors of a mechanical, electrical, thermal, atmospheric natural, etc., which can cause defects. The analysis of the causes of the defects, the determination of the solutions to reduce them, the estimation of the time until the next defect, respectively the improvement of the system performances, constitute the main objectives of the increase of the reliability [1], [2], [3].

Very often, the defects of the power supply cables determine the non-observance of the quality conditions regarding the supply of the consumers [4], [5].

In practice, the determination of reliability is based on the application of probability theory, considering both the history of defects prior to the monitoring period and that of the defects during the monitoring period.

This complex analysis is currently carried out on the basis of specific mathematical models [2], [3] which take into account the mechanical, electrical, thermal and environmental requirements to which electrical systems are subjected during operation.

In the case of electricity cables, mathematical models evaluate the electrical performance by monitoring the number of faults, information that is usually obtained from electricity suppliers.

In order to prevent reliability calculation errors and reduce the analysis time, which requires a large workload, the prediction of faults in the power cables is currently made by using software programs dedicated to forecasting [1], [2], [3]. These software programs have the advantage of processing a large number of input variables, speed and accuracy in calculation, along with a user-friendly interface, which makes it easy to use ed qualified personnel in the field.

2. Brief description of the EasyFit Profesional 5.6 software

EasyFit Professional 5.6 is a data analysis and simulation software program, used successfully in many fields of activity, including electrical engineering, in order to determine the probability of failure, and to ensure the safe operation of electrical systems [6], [7]. This simulation software is open-source and can be used in various applications. Based on the input data, which represents the period of the analysed defects, the software application allows framing the probability distributions in order to sample them, select the best model and use the results in order to find solutions to ensure prevention activities.

The software is designed by Mathware Technologies based on an algorithm meant for estimating the input variables entered in the calculation, starting from the experimental data and selecting the distribution that best suits them. The lesson is made from the 55 distributions of continuous and discrete functions in the library as its own [7].

Probability function histograms can be displayed simultaneously on a single chart for comparison. The main histograms displayed are [3]: the graph of the reliability function S (x); the graph of the cumulative (defective) distribution function F (x) - CDF; probability density graph f (x) - PDF; Graph of failure intensity h (x); the graph of the cumulative risk function H (x).

The use of the software program involves the following steps:

- entering the data in a table similar to the tables in Excel;
- selecting the button that chooses the appropriate distribution;
- reading and interpreting the results processed based on the algorithm.

The choice of a distribution law appropriate to each situation is based on the existence of a correlation between the mathematical model used and the experimental results obtained from the measurements performed on the monitored system, .in a certain time interval.

In the event of defects due to fatigue (degradation) over time, a situation often encountered in power supply cables, it is recommended to use Weibull’s law of distribution, also called cumulative distribution function, with mathematical expression:

$$F(t) = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \quad (0 \le t \le +\infty) \tag{1}$$

where α is the shape parameter by which the degradation level is indicated and β is the characteristic position or life parameter.

In the case of the three-parametric Weibull function, the parameter y is also introduced, which is a scale parameter, and the mathematical expression is:

$$F(t) = 1 - e^{-\left(\frac{t-y}{\beta}\right)^{\alpha}} \tag{2}$$

3. Case Study - Estimating the maximum operating time based on the operating times between two faults

The supply of electricity to domestic consumers is achieved through TP (transformation points) substations and UEL (underground power lines) or AEL (aerial power lines). Ensuring continuity in the supply of electricity to consumers is a quality condition that must be respected. Thus, special attention must be paid to the number of defects in consumer power cords. The number of faults is carefully monitored based on the history of events, in order to analyse the causes of failure and to establish their duration of operation between two faults [7], [8], [9]

The case study presented is performed on a 20 kV SLE, posed between two substations, noted in the paper TP 1 and TP PT 2, with an approximate length of 450 m. The electric cable is part of the medium voltage distribution network -one, administered by an electricity distribution operator [10].

Data on the number of events, causes of failure, as well as periods of malfunction between faults, were collected on the basis of test reports (BI), issued after defects were detected and remedied [10]. These test bubbles contain information about the measured values of the R_{iz} insulation resistances, the Ic conduction currents, as well as how to repair the defect. All this information formed the basis of the construction of the event data table (Table 1).

Table 1. Event at UEL 20kV (TP 1 →TP 2), cable type: NA2XS2Y, 3x1x150 mm2, l=~450 m

Date of defect occurrence acc.to BI	Cause of failure	Remarks
Report no. 182/ 20.07.2015	- T-phase defect (insulation breakthrough) at 247 m from PT 1	- High humidity in PT 1; -Phase T-sleeve was performed at the fault location and R, S, T phases were tested with increased voltage;

Date of defect occurrence acc.to BI	Cause of failure	Remarks
Report no. 235/ 07.10.2015	- Defective phase R (insulation breakthrough) at 200 m from PT 1 - Defective terminal heads in PT 1	- Defects were remedied by slewing the R phase at the fault site and replacing the end heads in cell MT-PT 1;
Report no. 97/ 19.06.2016	Defective phase T (insulation breakthrough) at 3 m from PT 1	- The value of R_{ins}, Ic asymmetry of the phases calculated after remediation of the defect did not fall within the allowed limits;
Report no. 99/ 22.06.2016	Defective phase T (pierced sleeve) at 250 m from PT 1	- The value of the R_{ins}, Ic asymmetry of the phases calculated after the defect was remedied did not fall within the allowed limits;
Report no. 154/ 09.08.2016	Phase R fault (insulation breakthrough) at 300 m from PT 1	- After mounting the sleeve, the tests were performed with increased voltage and the UEL was re-powered.;
Report no. 161/ 20.08.2016	T-phase defect (pierced sleeve) at 180 m from PT 1	- After replacing the sleeve and testing with increased, the UEL was re-energized;
Report no. 23/ 23.02.2017	- T-phase defect (insulation overflow on a 1 m section) at 230 m PT 1; - Defective terminal heads in PT1.	- The cable insulation was restored by mounting two sleeves and 2 m of cable -High degree of humidity in the 20 kV cell of PT 1;

The analysis of the data in Table 1 showed the following periods of good operation:

- 20.07.2015 ÷ 07.10.2015 = 79 days;
- 07.10.2015 ÷ 19.06.2016 = 256 days;
- 19.06.2016 ÷ 22.06.2016 = 3 days;
- 22.06.2016 ÷ 09.08.2016 = 48 days;
- 09.08.2016 ÷ 20.08.2016 = 11 days;
- 20.08.2016 ÷ 23.02.2017 = 187 days.

The time intervals, calculated in days, were entered in the data table of the "EasyFit" calculation software (Fig.1). After entering the data, the calculation software indicated the bi-parametric "Lognormal" and "Weibull" functions as the most appropriate distributions. (Fig.2).

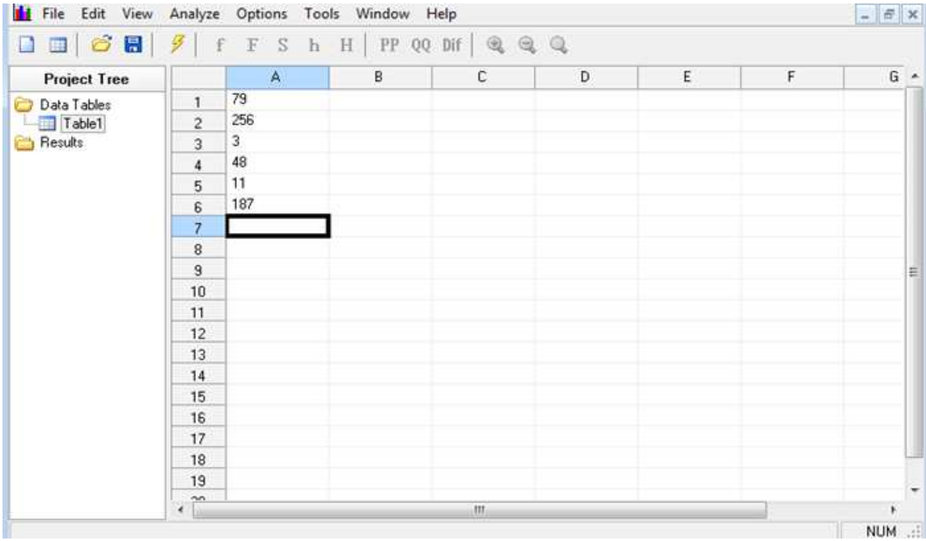

Figure 1. Operating times between two faults introduced in the program

By overlapping the graphs of the function f(x), small differences of the variation curves of the two distributions were observed and the "Weibull" distribution was chosen, which is the most appropriate in the estimates of the entities where effects of some phenomena of wear or aging, as in the case of power cables [3], [5], [6], [7].

The calculated percentage values (Fig.2) indicate for operating days of 100 days, a probability of failure of 70.1%, a relatively high value given the relatively short time interval. For longer time intervals, the probability of failure increases substantially, reaching 82.6% and 88.6% for operating times of 200 and 300 days, respectively.

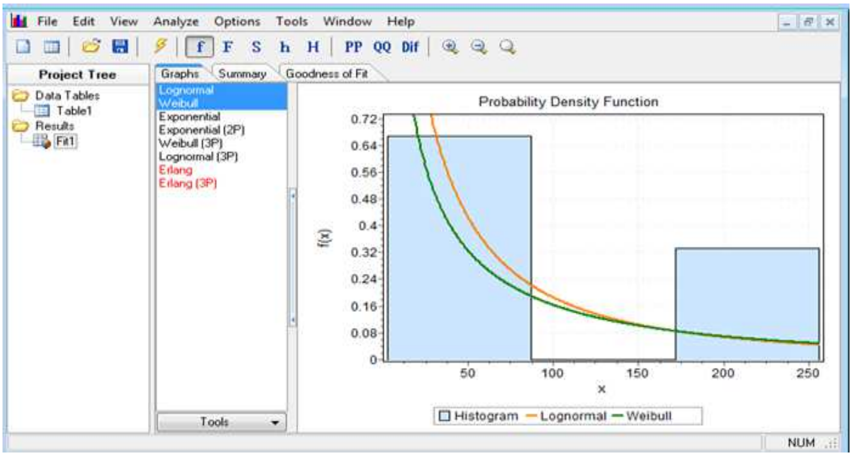

Figure 2. Automatic selection of the best distributions

The calculated percentage values (Fig. 3) indicate for operating days of 100 days, a probability of failure of 70.1%, a relatively high value given the relatively short time interval. For longer time intervals, the probability of failure increases substantially, reaching 82.6% and 88.6%, respectively, for operating times of 200 and 300 days (Fig. 4 and Fig. 5).

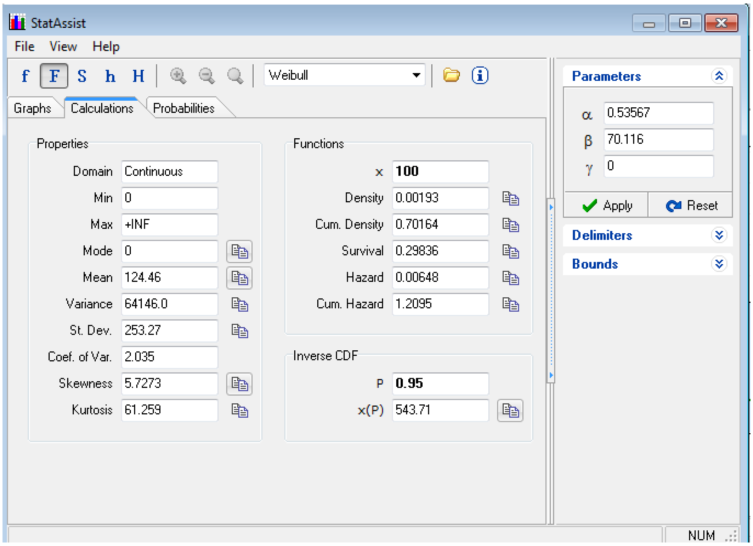

Figure 3. Calculation of the probability of failure and operation over a period of 100 days

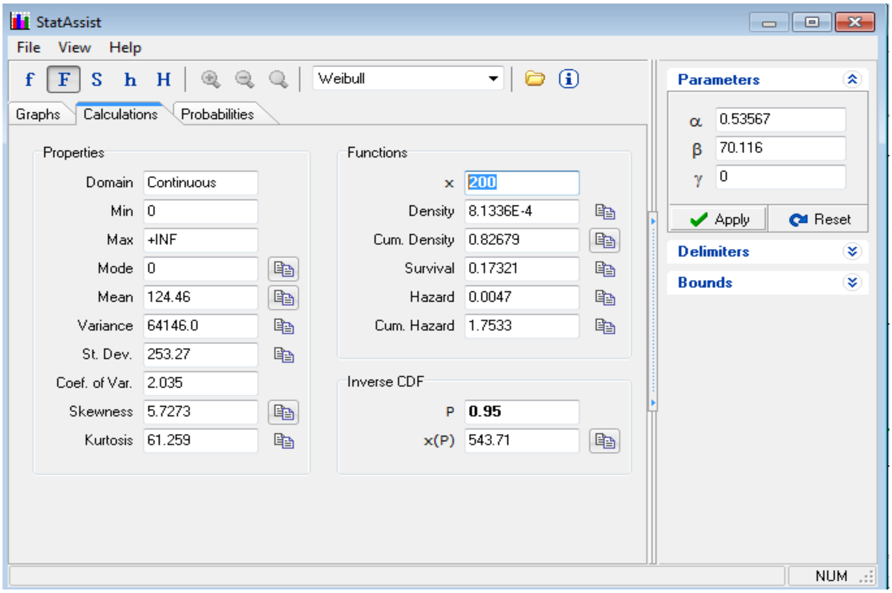

Figure 4. Calculation of the probability of failure and operation over a period of 200 days

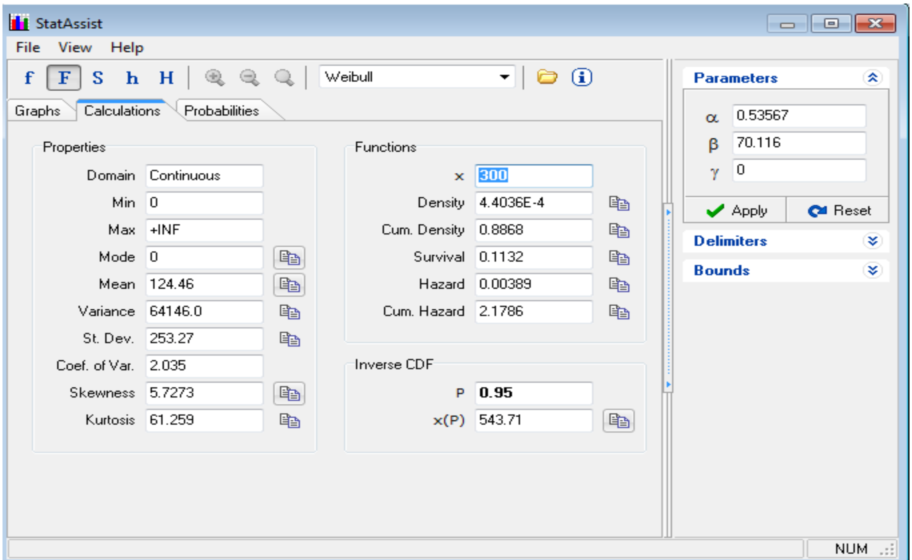

Figure 5. Calculation of the probability of failure and operation over a period of 300 days

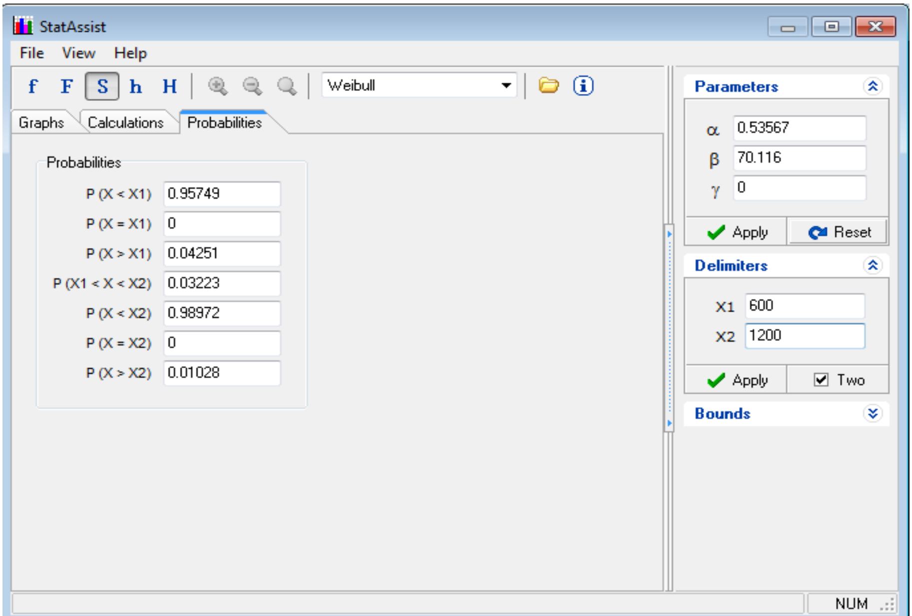

Figure 6. Calculation of the probability of failure and operation within 600 ÷ 1200 days

The probability of failure and that of operation were also calculated for longer time intervals: X1 = 600 days, and X2 = 1200 days, respectively. The probability of failure is for the range X1 of 95.74%, for X2 of 98.97% respectively. Thus it turns out that the probability of trouble-free operation for the X2 range is about 1%, which is very small. The obtained results are presented in Figs. 6.

3. Conclusions

The validation of the accuracy of the results obtained by simulation was made by comparing them with the real statistics of the failures [8], resulting from the incidents produced in the exploitation of the analysed SLE. The analysis concluded the following conclusions:

- The cable operated without interruption for 198 days, between 23.02.2017-09.09.2017 (BI no.231 / 09.09.2017), failing within 200 days, for which the probability of failure predicted by calculation was approximately 83%;
- The following incident took place after a period of 286 days (maximum duration of operation of the cable in operation from the moment of monitoring), on 22.06.2018 (BI no.130 /22.06.2018), so within the interval of 300 days, for which the calculated probability of failure was 89%;

- For all the analysed cases a value higher than 0.53 resulted for the coefficient α, which indicates that there is a serious degradation of the cable, and the coefficient β had a value higher than 70, which suggests that the moral wear of cable is quite accentuated;
- From the analysis of the events presented, one can remark that the real incidents took place after time intervals for which the calculated failure probability was higher than 80%, validating the correctness of the simulations.

It results that the use of EasyFit Professional 5.6. it is a useful method of estimating the service life of power cables between two faults and allows in operation, allowing to establish the opportune moment regarding the replacement of morally used cables. Thus, due to the low operational reliability of the LES 12 / 20kV cable, it has been completely replaced with a new cable, in order to avoid the high maintenance costs that would have resulted and the interruption of electrical consumers.

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