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Life Line Characteristics of Solid Insulation under Electrical Stress

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Insulating materials subjected to electrical and thermal-electrical stresses exhibit life line characteristics which show a tendency to reach an electrical threshold. Their fit is investigated with reference to several sets of data derived from accelerated life tests performed on different insulating materials.

Life line models provide the estimates of failure time percentiles at selected probabilities and stresses so that life curves at fixed failure probabilities can be drawn. These characteristics should help in the choice of compatible thermal and electrical stresses for the design of insulation systems, apparatus and components.

The tests to be conducted to plot the characteristic curves involve Class B insulation (up to 8 specimens) under three active stress levels. Subsequently, using the data acquired, the Weibull probability distribution curves are plotted using STATISTICA software.

Keywords: *Scale parameter, Shape parameter, Endurance coefficient, Failure time probability, Weibull distribution.*

1.0 INTRODUCTION

The study of life line characteristics of solid insulating materials subjected to different kinds of stress is a topic very often dealt with in electrical engineering. Their knowledge supplies pair of stress-failure time values useful for insulation system design and/or material comparison. It constitutes a fundamental parameter for comparison of insulation materials. The General life line characteristics graph is shown in Figure 1[1].

- Shaded area-partial discharge development (treeing growth)
- E-electrical stress
- Es-initial electrical strength
- Et-electrical threshold

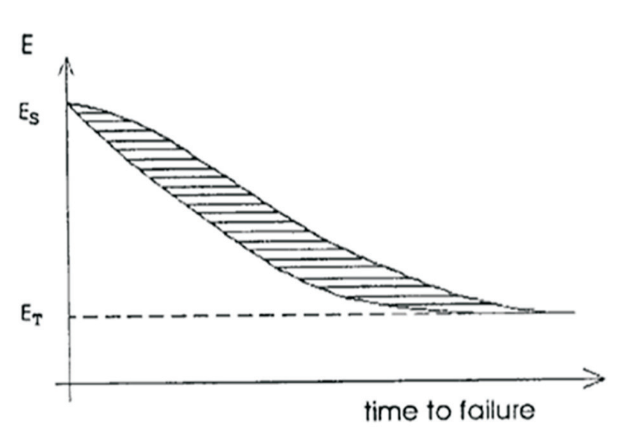

FIG. 1 GENERAL ELECTRICAL LIFE LINE CHARACTERISTICS

It is thought that the life lines of insulating materials should actually tend towards electrical threshold at low electrical field values, in appropriate ranges of temperature, characteristic

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of each material. However, existence of the electrical threshold can be revealed by life tests only when they are very much prolonged in time and/or the slope of life lines at stresses higher than the threshold is not too small. Under these premises, the linear models can be applied to describe only part of a life line, which can cover, for some materials, wide stress ranges, including design stresses.

2.0 LITERATURE SURVEY

A significant contribution to this field was made by a number of scientists, Gian Carlo Montanari, Mario Cacciari and I. Ghinello from Department of Electrical Engineering of University of Bologna and F. Peruzzoti, M. Albertini from University of Milano, Italy.These scientists conducted extensive research in this field and published their results over a series of papers in IEEE journals.

Mario Cacciari and G.C Montanari began their work by constructing a probabilistic life model for insulating materials. This model was based on a 2-parameter Weibull distribution of times to failure. The parameters of probabilistic life were explained as functions of stresses [1].

G.C Montanari established that life models of solid insulation subjected to electrical and thermal stresses tend to exhibit curvilinear life lines tending to an electrical threshold. In one of his earlier papers, he compared the various life models (3-parameter and 4-parameter models based on exponential and inverse power laws) while investigating treeing mechanisms. He found that the 4-parameter models yielded more accurate results than the 3-parameter models [2].

His work provided a complete characterization of combined stress endurance and thus, the electrical threshold at each selected temperature [4]. The theoretical data was cross checked with experimental data of tests conducted on different materials [3].

3.0 EXPERIMENTAL WORK

The arrangement of the electrodes and the insulation sheet (GARLAM G3) of thickness 7mil(0.1788 mm) is used in our experimental work and is shown in the Figure 2, the insulation is placed in between the two electrodes i.e. cylindrical rod electrode and circular plane electrode which forms a sandwich with the insulation as shown in Figure 2.

After setting up the components as indicated in Figure 2, high voltage is applied across the electrodes through High voltage testing Transformer. Voltage is gradually increased in steps till the breakdown of the medium takes place, and the breakdown value is noted down. This procedure is repeated for three trials and the average value is taken as breakdown value. The results are tabulated in Table 1.

FIG. 2 EXPERIMENTAL SETUP

TABLE 1	
BREAKDOWN VOLTAGE OF TRIPLEX SHEET	
Sl. No	**Breakdown value (kV)**
1	4.5
2	4.9
3	4.2
Average	**4.53**

$$\text{Breakdown stress} = \frac{\text{Breakdown voltage}}{\text{sheet thickness}}$$

$$\text{Breakdown stress} = \frac{4.53\ \text{kV}}{0.1788\ \text{mm}}$$

High voltages of less value compared to breakdown value of triplex sheet of thickness 7 mil i.e. 3.6 kV, 3.3 kV and 2.9 kV is applied across the electrodes. For each specified voltage the corresponding time (hours) to breakdown is noted down and the procedure is repeated for eight trials and the results are tabulated in Table 2.

TABLE 2			
TIME OF FAILURE FOR DIFFERENT STRESS LEVELS FOR 90% PROBABILITY			
Trial no	**Time to breakdown(hours)**		
	Stress level 1 20.24 kV/mm	**Stress level 2 18.56 kV/mm**	**Stress level 3 16.31 kV/mm**
1	0.02	0.442	0.123
2	0.024	0.201	1.382
3	0.269	0.016	0.441
4	0.246	0.364	0.268
5	0.007	0.587	0.567
6	0.262	1.126	0.404
7	0.004	0.804	0.708
8	0.231	0.011	0.608

4.0 RESULTS & DISCUSSIONS

The values of breakdown time were consolidated in an excel spreadsheet and then loaded into the software STATISTICA. The probability-probability Weibull plot was plotted and the values of scale (α) and shape (β) parameters were obtained for different stress levels and are tabulated in Table 3.

From Table 3 for different stress levelsand corresponding values of α and β, the failure time probability (t_{fp})is found by using the formulae shown in (1)

$$t_{fp} = \alpha\,(E, T)\,[-\ln(1-p)]^{1/\beta\,(E, T)} \quad ....(1)$$

Where t_{fp} is the failure time at probability P, E and T are electrical stress and temperature, α=α (E, T) and β = β (E, T) are scale and shape parameters of the probability function respectively.In our Present work temperature is not considered as the experiments were done at room temperature.

TABLE 3			
PARAMETERS OBTAINED FROM WEIBULL DISTRIBUTION CURVE			
Coefficients	**Stress level 1 20.24 kV/mm**	**Stress level 2 18.56 kV/mm**	**Stress level 3 16.31 kV/mm**
α:scale parameter	0.11652	0.425003	0.633151
β:shape parameter	0.771195	0.893351	1.68131

Assuming 90% probability, the tfp values are calculated for the three stress levels and tabulated in Table 4.

TABLE 4		
ASCENDING TFPVALUESWITH CORRESPONDING STRESS LEVELS		
Sr. No.	**tfp (hours)**	**Stress level (kV/mm)**
1	0.342	20.24
2	1.039	16.31
3	1.081	18.56

Subsequently, the values of tfp are plotted against stress in a scatter plot in MS Excel. From this plot, the value of initial endurance coefficient is obtained.

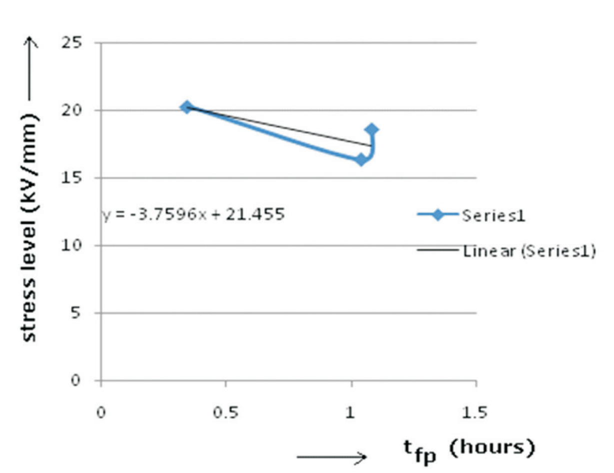

FIG. 3 T_{FP} V/S STRESS LEVELS FOR 90% PROBABILITY

From Figure 3 the endurance coefficient is obtained and is equal to n_i = 3.7596

$$L = t_s \left[\frac{E}{E_s}\right]^{-n(E)} --- (A)$$

$$n(E) = \frac{n_i}{[(E - E_t)/(E_s - E_t)]^{\beta}} --- (B)$$

L: life or time of failure

E_s: highest stress level in experiment i.e. 20.24 kV/mm

t_s:tfp corresponding to E_s i.e. 0.3436 hrs

E_t: Electrical threshold which is assumed to be 0

β: shape parameter whose value is corresponding to Es i.e. 0.771195

Substituting E_t =0 in equation (B)

$$n(E) = \frac{n_i}{[(E)/(E_s)]^{\beta}}$$

Varying E from 1kV/mm to 30 kV/mm in steps of 1kV/mm and substituting the values in the equation (A), Time of failure (L) is obtained and the values are tabulated in Table 5.

TABLE 5

TIME OF FAILURE FOR DIFFERENT STRESS LEVELS AT 90% PROBABILITY

Time of failure L (hours)	**Stress level E(kV/mm)**		**Time of failure L (hours)**	**Stress level E(kV/mm)**
3.879E+49	1		0.993	16
9.271E+22	2		0.728	17
1.419E+13	3		0.557	18
629700000	4		0.441	19
1824000	5		0.359	20
41403.7172	6		0.3	21
2990.8737	7		0.255	22
439.8515	8		0.222	23
103.08	9		0.194	24
33.3467	10		0.174	25
13.7384	11		0.157	26
6.54702	12		0.144	27
3.5909	13		0.132	28
2.17507	14		0.123	29
1.424	15		0.115	30

5.0 RESULTS& DISCUSSIONS

Plotting the values from "Time to Failure" table with time of failure (L) in hours on x-axis and Electrical stress (E) in kV/mm on y-axis, we get the life line characteristics of insulation sheet employed.

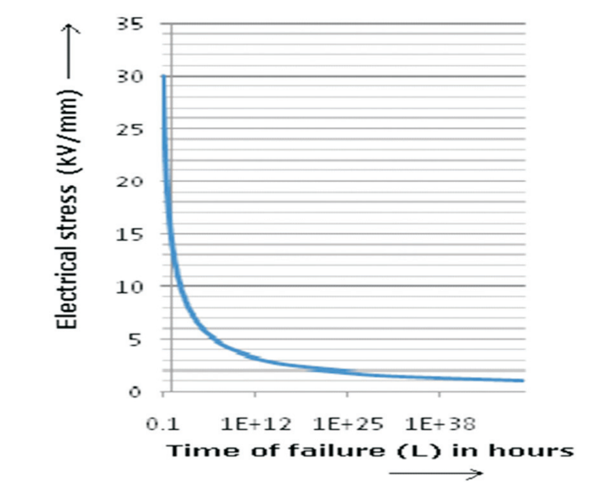

FIG. 4 LIFE LINE CHARACTERISTICS FOR 90% PROBABILITYFAILURE

Observations made from the Figure 4 :

- Time to failure for every stress level can be determined easily.
- From the stress one can calculate back the operating kV.
- Here for example an operating stress of 5kV/mm gives an operating life of 1824000 hours.
- In similar fashion we can determine the operating life of the insulation sheet at every stress level and hence determine the operating kV.

6.0 CONCLUSIONS

The LIFE LINE CURVE was successfully plotted, and the observation and results provided in the report can be effectively employed for choosing an insulation application which satisfies the obtained data. Furthermore, the data acquired in this project can be usedto specify optimum stress levels to maximize life of the insulation.

From the basis of this project one can instantly determine the operating life in hours of GARLAM Class B Insulation Sheets under various stress levels and hence under various operating voltages by simply observing the graph plotted in this paper.

Most of the operation failures in any electrical industry occurs due to the failure of insulation employed, this generally happens when the stress on the insulation is more than its optimum for a pro-longed time, if one can determine the appropriate operating stress and voltage for the given insulation, the failure can be reduced to an great extent.

It is concluded by signifying the importance of this project and also stressing on the importance of such experiments for the present day industry as it not only causes a failure of the machine employed but also is a time consuming process for a replacement where a significant output is lost from the industry point of view.

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REFERENCES

[1] G. C. Montanari "Electrical life threshold models for solid insulating materials subjected to electrical and multiple stresses, investigation and comparison of life models", IEEE Vol. 27, no. 5, pp. 974-986, Oct 1992.

[2] M. Cacciari, G. C. Montanari "Electrical life threshold models for solid insulating materials subjected to electrical stresses, probabilistic approach to generalized life models", IEEE Vol. 27, no. 5, pp. 987-999, Oct 1992.

[3] M. Cacciari, G. C. Montanari "A probabilistic life model for insulating materials showing electrical thresholds", IEEE Vol. 24, no. 1, pp.127-134, Feb 1989.

[4] F. Peruzzoti, I. Ghinello, M. Albertini, G.C Montanari "Endurance characteristics of XLPE compounds under DC voltage" IEEE international conference on conduction and breakdown in solid dielectrics, pp. 439-442, June 1998.

[5] International Electrotechnical Commission Standard 60085 Electrical Insulation-Thermal Evaluation and Designation, 3rd edition, 2004 ,page 11 Table 1

[6] Donald G. Fink and Wayne H. Beaty, Standard Handbook for Electrical Engineers, Eleventh Edition, McGraw Hill, 1978, ISBN 0-07-020974-X, page 7-12 "3.5.1 Electrical Breakdown and Failure". Tf.uni-kiel.de. Retrieved 2011-11-08.

[7] Christian H. Weiss "Commercial meets Open Source: Tuning STATISTICA with R" R-Project March 2008.