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Review Article:

Weibull Distribution Applications in Engineering,

(Review, Critiques and Research Directions/Methods)

Submitted to the Department of Electrical Engineering at Salahadin University-Erbil

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List of Contents

Table of Figures

List of Tables:

1- Abstract

Weibull models are employed to explain numerous kinds of observed failures of parts and phenomena. The Weibull distribution is a broadly used statistical model for investigating weakness and durability in engineering machines and materials. In this review article, some knowledge of this distribution method is presented by showing up the essential background then presenting some applications from the literature on this topic. The fan bearing reliability, analysis of PCB boards, estimating the life of P.V. modules, and a lifetime of switching devices are some application examples that have been reviewed in this paper.

Keywords: Weibull probability distribution, reliability.

2-Introduction and Basic Background

Throughout the 1940s and early 1950's Wallodi Weibull (1887-1979), a Swedish material expert, issued a set of papers employing the distribution that now carries his name. Weibull models are employed to explain numerous kinds of observed failures of parts and phenomena. They are extensively applied in reliability and endurance investigation. In addition to the common two-parameter and three-parameter Weibull distributions in the reliability of statistics literature, several distinct Weibull-related distributions are possible. The Weibull distribution is a broadly used statistical model for investigating weakness and durability in engineering machines and materials. Several examples can be found among the aerospace, electronics, materials, and automotive manufacturers.

Advanced computing technology has caused many of these methods obtainable over the engineering spectrum (Luko, 1999).

In (Jianwei *et al.*, 2009), the principles and essential background on Weibull distribution were presented. They stated that this distribution has several advantages that make it suitable for several applications. For example, for the impulse response of RLC circuits, this method has flexibility, unimodal, and positively skewed properties that adequately match the impulse response of RLC circuits. Besides, it is easy to find the Median in the Weibull distribution and adjust the parameter to match the moments.

The (PDF) probability distribution function and cumulative distribution function (CDF) in Weibull can be expressed as:

$$f(t) = \frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1} \exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right] \qquad (1)$$

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right] \qquad (2)$$

Mentioning that variable β is the scale parameter, and α is the shape parameter. The following formula expresses the variance and means of Weibull distribution:

$$\mu = \beta\Gamma\left(1 + \frac{1}{\alpha}\right) \qquad (3)$$

$$\sigma^2 = \beta^2\left(\Gamma\left(1 + \frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right)\right) \qquad (4)$$

The two-parameter formula for Weibull probability density is:

$$f(t) = \frac{\beta t^{\beta-1}}{\theta^{\beta}} e^{-\left(\frac{t}{\theta}\right)^{\beta}}, \quad t > 0 \qquad (5)$$

The variable (t) represents the number of cycles, actual time, or generally, it can be considered time. Beta and theta parameters are shape and scale, respectively. In general, the parameter (β) is named the "Weibull slope."

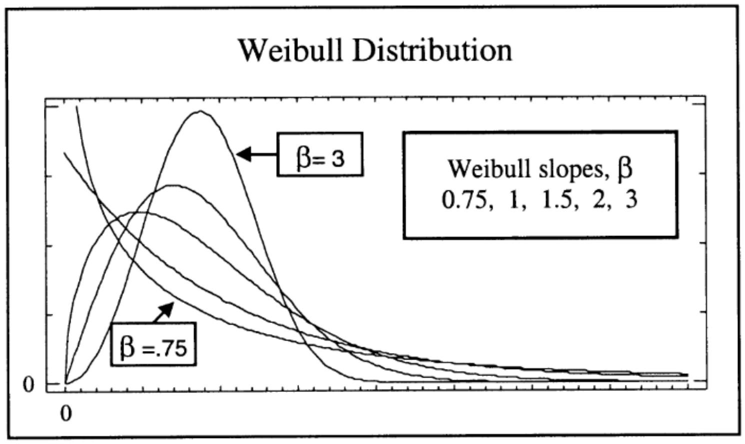


Figure 1: Varying Weibull slope parameter (beta) and the Weibull distribution.

It is clear from **Figure** 1 that by adjusting the slope parameter, different shapes of the distribution can be constructed, and this shows the flexibility and versatility of this distribution.

The angle parameter does not affect the shape of the distribution in any way. It's known as characteristic life, and it can be thought of as the Median or mean of the Weibull distribution. Integrating the formula of Weibull probability density function from time zero to time (t) will obtain the Weibull distribution function:

$$\int_0^t f(u)du \quad = \quad F(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}}, \text{ for } t > 0 \qquad (6)$$

Moreover, the reliability function will be obtained from taking the complement of the function F(t).

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}}, \text{ for } t > 0 \qquad (7)$$

Furthermore, the hazard function can be expressed as:

$$h(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1}, \text{ for } t > 0 \qquad (8)$$

From the equation of Weibull variance and Weibull mean, we can observe that the two functions are dependent on two parameters (β, α, or θ), so it is evident that Weibull distribution characteristics will be based on these two parameters. Furthermore, from the variance equation, when the variance increases, the Weibull curve slope will decrease. More statistical equations and definitions of Weibull distribution can be found in reference (Luko, 1999) and (Ali, Lee and Jang, 2018).

3- Application of Weibull distribution in Electrical Engineering:

In this section, some applications of Weibull probability distribution will be presented and reviewed. Each section will be ended by an individual conclusion specific to the reviewed application.

3-1 The Fan Bearing Reliability of the Weibull Distribution

The fan is an electrical component composed of bearing, blades and motor, and circuit board. With the modern industry and technological developments nowadays, fans have higher proportions in industrial facilities and wide applications in modern devices. The life span of fans depends on the mechanical parts' life cycle and the circuit board's reliability. The bearing is the most wearing part of the electric fan. According to the statistics, 90 % of fan failures are caused by bearing damages. Also, 40% of fan motors will fail because of bearing damage. The bearing state of work is directly proportional to the electric fan's performance (Jin *et al.*, 2012).

(Yudong *et al.*, 2016) investigated and experimented with the bearing reliability by constructing the fan-bearing test-bed. By using the correlation coefficient optimization method, the three-parameter of the Weibull distribution was calculated. To analyze the bearing's reliability, they constructed a model for bearing life reliability based on the aforementioned parameters.

It is imperative to estimate the fan bearing's life to ensure the device's safety and durability. Besides, the periodic maintenance of the bearing will lead to lengthening the life of the fan device. The tracking of the bearing state of life is crucial and meaningful.

In this work, the fan test-bed bench was created to test and assess the fans' reliability in real-time. This bench is beneficial to test the bearings' lives because, truthfully speaking, the life of bearings can be estimated by tens of thousands of hours. Waiting this much time is not a possible and wise idea for research. For this reason, the accelerated life test method was used.

The environmental stresses can be applied to the rolling bearings (Temperature, contact stress, and lubrication condition) to accelerate the electric fans' failure. In this work, applied external loads were chosen for this accelerated life test by inserting the unbalancing loads on the fan blade, as shown in the **Figure** below:

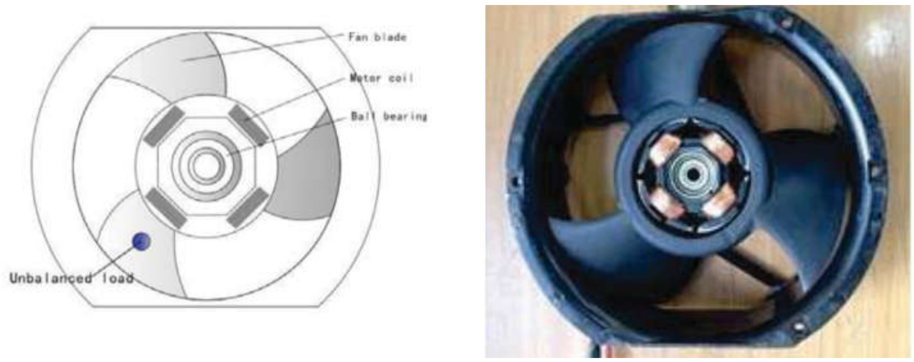


Figure 2: The fan physical and bearing Figures.

The test-bed used in this work is shown below. This test uses thirty-six fans arranged, as shown below. The fans bearing type is ball bearing, and the fans data will be recorded by the computer database in real-time.

Figure 3: The arrangement of test-bed for testing the fans

Taking the statistical data from thirty-six fans and ruling out the damage of the circuit fault or other reasons, 29 adequate data were extracted from the test, as shown below:

Fan number	Life quantitative values (h)	Fan number	Life quantitative values (h)
01	1474.74	16	1994.06
02	1396.17	17	2914.6
03	3181.35	18	1917.17
04	1857.83	19	2015.63
05	3031.84	20	2010.07
06	1778.45	21	1956.28
07	2663.24	22	2341.23
08	3084.36	23	2919.43
09	2026.83	24	2730.62
10	3156.72	25	1353.27
11	1512.99	26	1941.18
12	2937.59	27	1453.79
13	1452.01	28	2075.59
14	2831.23	29	2746.67
15	2642.45		

Table 1: the lifetime value for the electric fans obtained from the test.

The columnar distribution for the 29 fans lifetime is shown below:

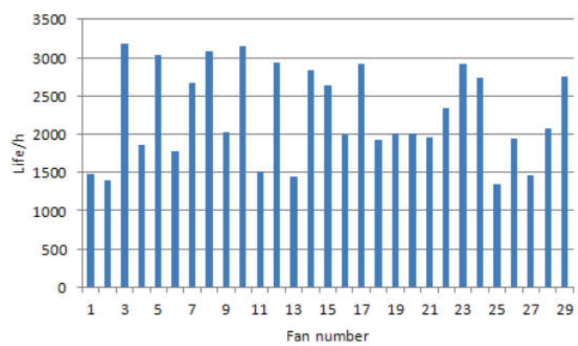


Figure 4: the columnar distribution of the test lifetime data

From the columnar **Figure**, it is clear that the exhaustion life of the bearings is mainly different. The lifetime of the same fan with the same environmental situations has a longer lifetime. These lifetime variations for the same fan properties decide the need to calculate the maximum lifetime and minimum lifetime using statistical mathematics to analyze the situation above.

Using the weakest link theory, the Weibull model can be expressed as follows:

$$f(x) = 1 - exp\left[-\left(\frac{x-\mu}{\sigma}\right)^{m}\right] \quad (9)$$

After taking twice the logarithmic transformation, the type 2 equation will become a linear equation.

$$y = mx - B \quad (10)$$

The position parameter represents the minimum lifetime of the equipment that the fault will not occur. Sorting the data from the experiment from minimum to maximum shows that the minimum lifetime is smaller than the lifetime data. The computer program is used to perform successful iteration and calculations. The flowchart is shown below.

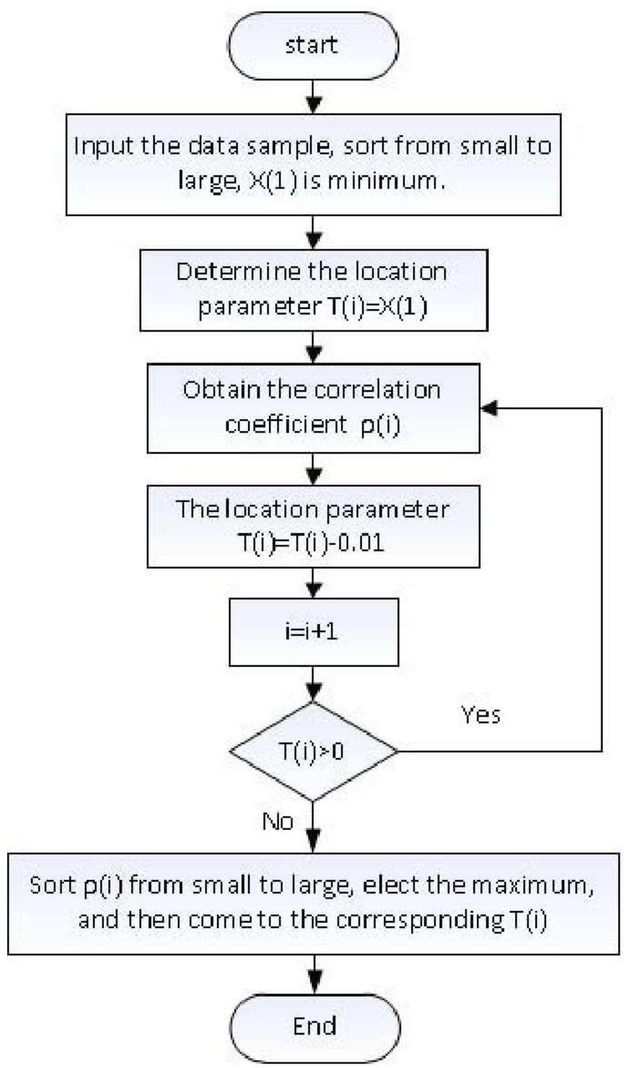


Figure 5: the flowchart of the proposed model.

Finally, the estimation of scale and shape parameters were calculated using the least square method. For calculating the whole lifetime of fan bearings, the accelerated factor (k) should be calculated. The relationship between dynamic load rating and longevity was extracted from the bearing exhaustion life **Table**, and It calculated to be (k=55.78). Therefore, the expected life of the bearing can be listed as shown below:

Fan number	Life quantitative values (h)	Fan number	Life quantitative values (h)
01	82261	16	111228.7
02	77878.36	17	162576.4
03	177455.7	18	106939.7
04	103629.8	19	112431.8
05	169116	20	112121.7
06	99201.94	21	109121.3
07	148555.5	22	130593.8
08	172045.6	23	162845.8
09	113056.6	24	152314
10	176081.8	25	75485.4
11	84394.58	26	108279
12	163858.8	27	81092.41
13	80993.12	28	115776.4
14	157926	29	153209.3
15	147395.9		

Table 2: the whole lifetime of fan bearings.

According to the data listed in **Table** 1, the position parameter, the scale, and the shape parameter were 1277.95, 1118.24, and 1.2659.

The Weibull cumulative distribution function and reliability function curve are shown in the **Figure** below:

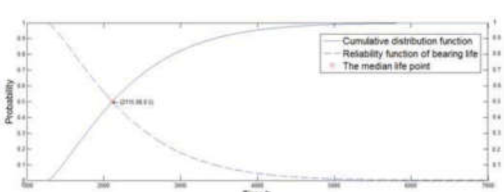


Figure 6: CDF and reliability function curve from **Table** 1

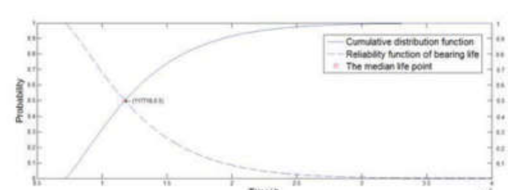


Figure 7: CDF and reliability curve from **Table** 2

The same scheme was performed to calculate the three parameters from **Table** 2, and the result is shown in **Figure** 7. The results show that both calculated quantities for the three parameters from both **Tables** have only a deviation of 2.5%.

3-2 Analyse PCBs breakdown using Weibull Distribution.

In (Xiong *et al.*, 2017) work, the study of the breakdown voltage of printed circuit boards under different abnormal situations performed. The printed circuit boards are used everywhere and in every electric device. The safety and stability of the board are paramount, especially in spacecraft. The printed circuit board is facing more problems and the abnormal situation in the case of spacecraft. Due to the advancing of technology and the fast development of electric devices, the boards will be minimized in size. Thus miniaturization will cause decreasing the insulation between the printed circuit board's interconnections. The decrease in insulation distance between the interconnections will decrease the printed circuit board's ability to stand with the breakdown voltages. The abnormal situations that will be cover for testing the stability and safety of the printed circuit board in this work are temperature, the distance between the interconnections, pressure, and the pulse width.

The insulation condition has a direct impact on the PCB's lifetime, accuracy, and quality. The spacecraft's PCB will face several abnormal situations such as high temperature, electromagnetic irradiation, and other unknown disturbances that will cause charging and discharging of dielectric materials. Afterward, the insulation quality of the PCB will decrease with the continuation of the mentioned disturbances, and it causes the breakdown.

As a result of the above problems, the PCB's reliability will decrease, and the impact will be on the spacecraft's operation.

In this work, an experimental platform was built to test the PCB breakdown characteristics. The schematic diagram of the test platform built for the study is shown below:

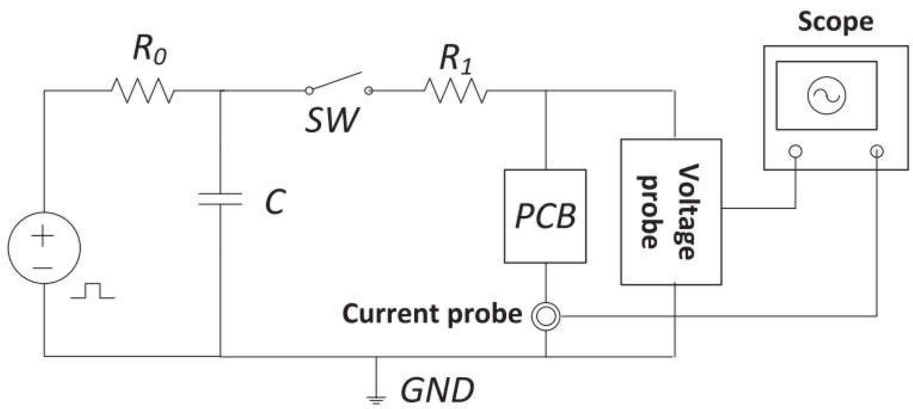


Figure 8: The test platform to test the breakdown characteristic of the PCB boards.

The power supply can produce a **stable** and adequate pulse for the test sample. The minimum width for the pulse is 20 nanoseconds. The scope block is used to monitor the two plates, voltage changes in the PCB, and record the Breakdown voltages.

The following is the test tank for testing the PCB sample.

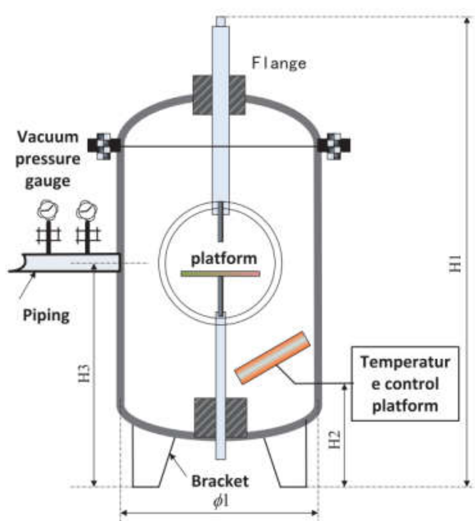


Figure 9: Test tank

The tank is made of stained steel material, and it can alter the value of temperature from room temperature up to 250 C°. It can also control the pressure inside the tank.

The PCB electrode structure is shown below.

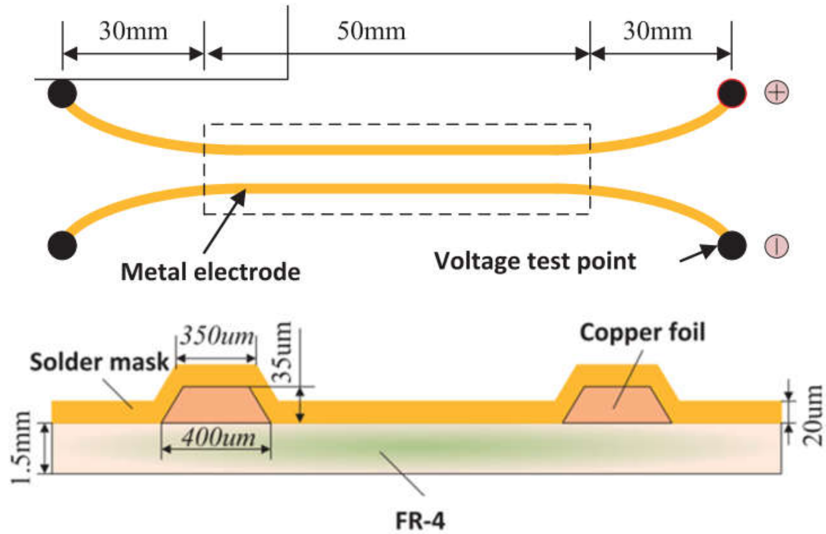


Figure 10: PCB Electrode

The interconnection of the PCB can be expressed as a row capacitor. **Figure** 10: to avoid the edge effect of the electrodes and ensure that the PCB breakdown field is uniformly distributed and the breakdown will occur only in the parallel part only, the PCB electrodes' footnote is designed as a circular arc shape.

The experimental method is based on a step-stress test. The step-up rate of the test voltage is 2kV to ensure the breakdown in one minute. The PCB plate breakdown is the Median of six groups of PCB breakdowns.

To test the influence of the distance between the two plates on the breakdown voltage, the distance altered from 0.2 mm to 0.8mm. The square pulse wave applied to the PCB electrodes has a 1khz frequency and 60% duty ratio. The breakdown process of the PCB is the breakdown of the solid-gas combined medium. In this way, we can apply the Weibull distribution because this breakdown process is following the Weibull distribution.

The experimental data are drawn using the Weibull distribution, as shown in the **Figure** below:

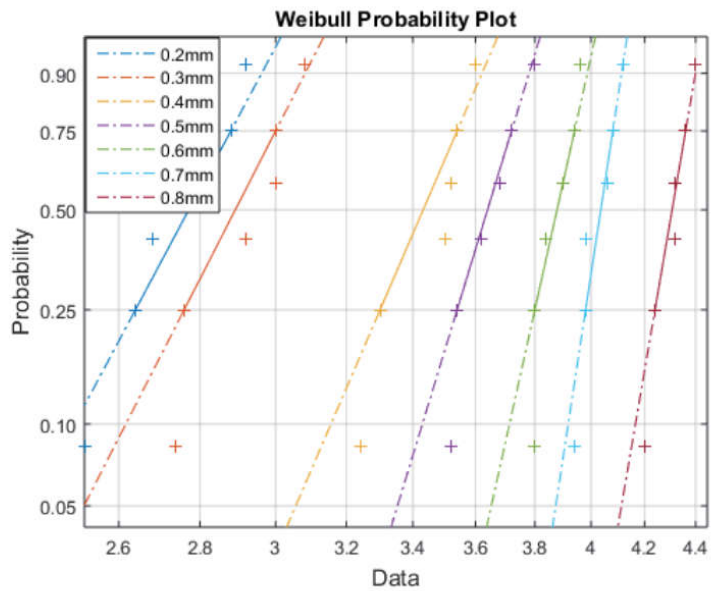


Figure 11: Weibull distribution for the PCB breakdown altering the distance of electrodes.

It is seen that the slope of the curves is parallel, or the shape parameter β does not change with the distance between the electrodes. The scale parameter α makes the curve intercept the probability axes, which can be understood more significantly; the increasing distance between the plates leads to the more significant PCB board's insulation reliability.

To consider the influence of duty ratio, the distance between the two plates fixed to be 0.4 mm. The duty ratio of the D.C. supply changed from 60% to 90%, and the graph produced using Weibull distribution, as shown below:

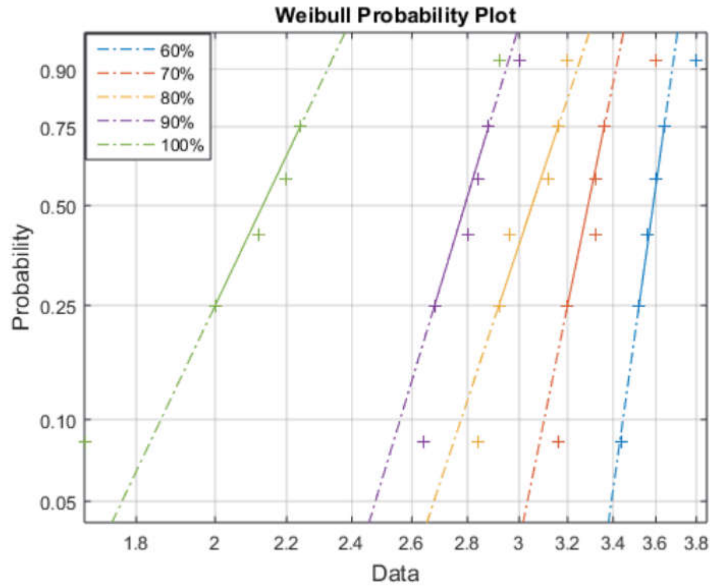


Figure 12: the Weibull distribution for different duty ratios and breakdown probability.

It can be seen that the breakdown under several duty ratios is not immediate; the reasons behind this are the following three reasons: a) due to external factors, the free electrons will be produced in the medium. b) the free electrons will be absorbed by gas molecules, and c) in ionization, due to the external factors, the ionization of the medium will be terminated. Ultimately, increasing the duty ratio will increase the supply energy time, reducing the breakdown voltage.

To study the effects of the temperature on the PCB breakdown, the distance between the two electrodes is 0.4mm, the duty ratio 60%, and the temperature varying from 25 to 85 ºC. The Weibull distribution curve is produced as shown for different temperature levels inside the test tank.

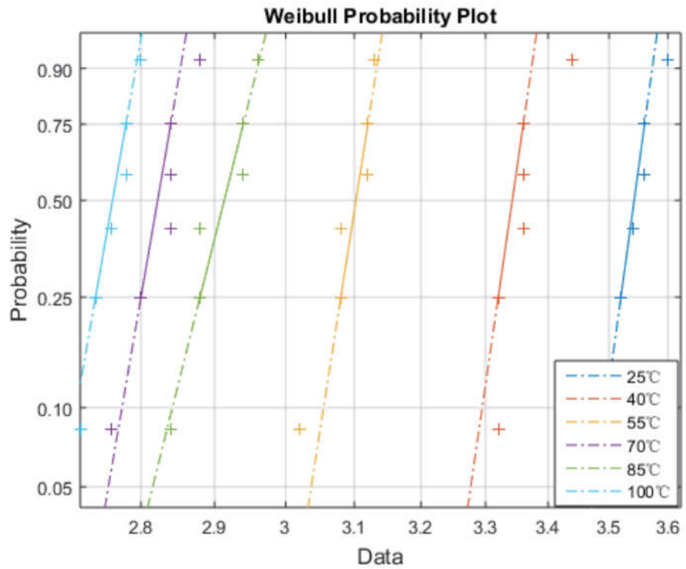


Figure 13: Weibull distribution of different temperature levels and the probability of breakdown.

The increase in temperature causes the breakdown in lower voltages. The reason is apparent when the material is subjected to heat, the charge migration speed will be accelerated, and the material's conductivity will increase, which leads to a break down in lower voltages.

Finally, the influence of pressure can be found by applying and controlling the pressure inside the test tank from 1kPa to 101kPa. With the six groups of breakdown voltage, the average was taken to draw the following graph.

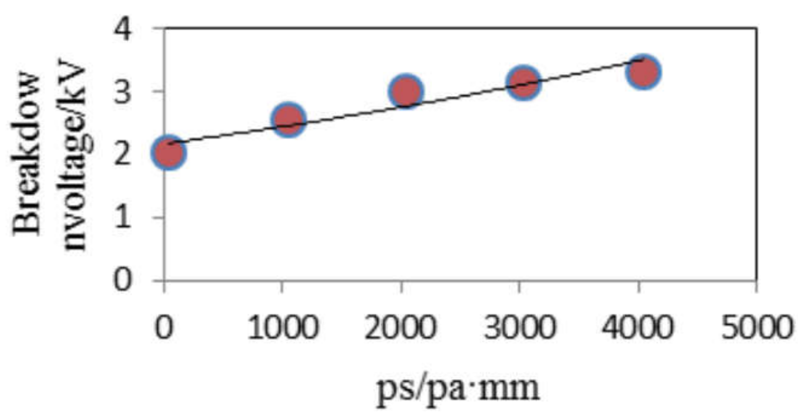


Figure 14: The breakdown under different pressure values.

The breakdown voltage will decrease when the pressure increase.

The same work with minor differences was presented in (Meng *et al.*, 2011)

3-3 Lifetime Estimation of P.V. modules

In (Wang *et al.*, 2019) work, a practical procedure to select the best statistical model that describes the degradation and estimating the lifetime of Photovoltaic modules was proposed. The probability plots and hypothesis tests were used. Three distributions were tested Weibull, lognormal, and exponential.

The cost of the P.V. module plants includes current plant costs and future plant costs. The cost of the plant should be taken into account carefully before going to the next step. So The lifetime of P.V. modules is an essential factor for making the decision and calculating the plant's profit margin. According to the manufacturers, the P.V. modules are estimated to last up to twenty years. Nevertheless, the P.V. modules are subjected to stress factors such as abnormal temperature, mechanical and moisture stresses.

These factors can negatively impact the P.V.'s lifetime and increase the module's degradation level and then shorten the unit's life. It is necessary to derive a model that describes the degradation of P.V. modules with time. The two ways used to model and estimate the P.V. module's life are deterministic and statistical models. The first way describes the performance degradation and operation time as a linear or non-linear regression formula. This model cannot estimate the P.V. module's life because it cannot describe the degradation's probabilistic nature, and the P.V. itself has individual differences. So the best model to be used is the statistical models. For that reason, the life distribution is estimated to be either Weibull, lognormal, or exponential.

For reducing the cost and duration of the test time, the accelerated life tests applied to the P.V. module under the test. In this study, the damp-heat test is applied for ALT of the P.V. module.

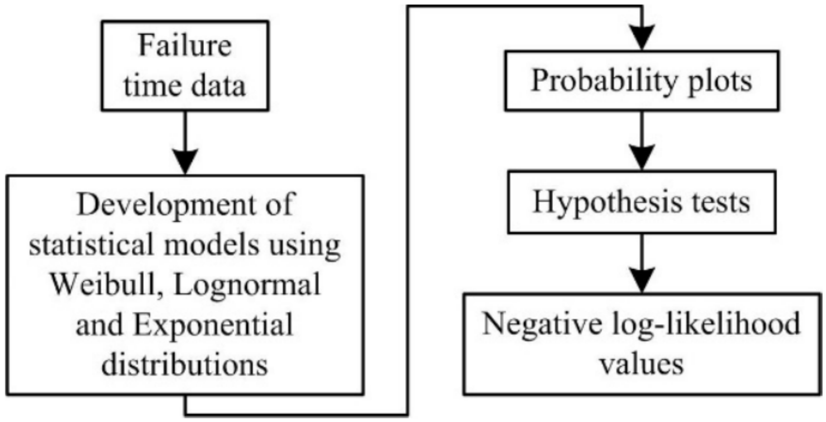


Figure 15: the overview of the methodology.

In the study, three distributions will be applied to model the P.V. module's degradation, then probability plots, NLL, and hypothesis test will be utilized to evaluate the three models. In **Figure** 15, an overview of the whole process of this work is presented.

The failure time data are shown in the **Table** below. Three groups of D.H. tests under different stress levels were carried out and recorded. The data for Three Samples A, B, and C, were selected, and the samples' normalized power is shown in the **Figure** below.

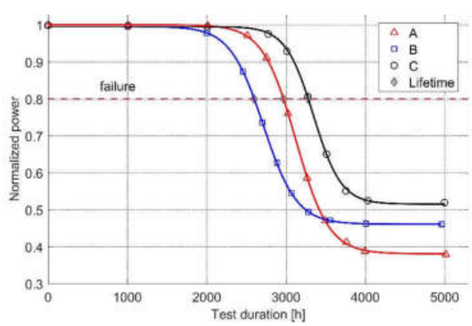


Figure 16: Normalized Maximum power for the three samples, A, B, and C.

The "Boltzmann" growth function can describe the relation of degradation and time by this formula.

$$p(t) = b + \frac{a}{1+\exp[-k\times(t-t_c)]} \qquad (11)$$

Where b, a,k, and t_c are the regression parameters.

Samples	Stress levels of accelerated testing	Failure time T_f (h)	Acceleration factor a_T	T_f transformed to data at 85°C/ 85%rh (h)
A	85°C/ 85%rh	2968.9		2968.9
	75°C/ 85%rh	5023.4	0.5940	2983.9
	90°C/ 85%rh	2349.0	1.2836	3015.3
B	85°C/ 85%rh	2599.6		2599.6
	75°C/ 85%rh	5049.2	0.5190	2620.3
	90°C/ 85%rh	1922.6	1.3695	2632.9
C	85°C/ 85%rh	3280.5		3280.5
	75°C/ 85%rh	6000.4	0.5394	3236.4
	90°C/ 85%rh	2431.0	1.3444	3268.2

Table 3: accelerated life test ALT data for three samples.

When the P.V. module loses 20% of its power, it is considered the end of its life. The lifetime of the three P.V. modules tested above, A, B, and C, can be calculated using the fitted regression equation below under 85 C° and 85% of stress level.

$$t_{\text{lifetime}} = t_c - \frac{1}{k} \times \ln\left(\frac{a}{p(t_{\text{lifetime}}) - b} - 1\right) \qquad (12)$$

The failure value is $p(t_{\text{lifetime}})$, it is the P.V. module's normalized power; its value is estimated to be 0.8. Two assumptions were made, the stress levels are counted to be the same, and stress levels are presupposed to come from the same parametric distribution family. The change in temperature from one value to another value will result in accelerating the lifetime.

$$a_T = \exp\left[-\frac{E_a}{R} \times \left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] \quad (13)$$

R is the gas constant (8.314 J/mol·K), and E_a is the degradation's thermal activation energy. The above equation can be represented in a logarithm scale, having the slope of Ea/R, and then, the calculation of Ea will follow it using the values in **Table** 3.

The Weibull distribution probability plots are shown below for the failure times based on the data shown in **Table** 3.

Failure time T_f	Scale parameter a	Shape parameter b	Mean lifetime (h)
$T_f$obs75trans85	3061.4	14.1	2950.5
$T_f$obs85	3076	12.5	2952.1
$T_f$obs90trans85	3062.3	11.2	2926.6
$T_f$trans85	3067	12.5	2943.3

Table 4: Estimated mean lifetime for the Weibull distribution.

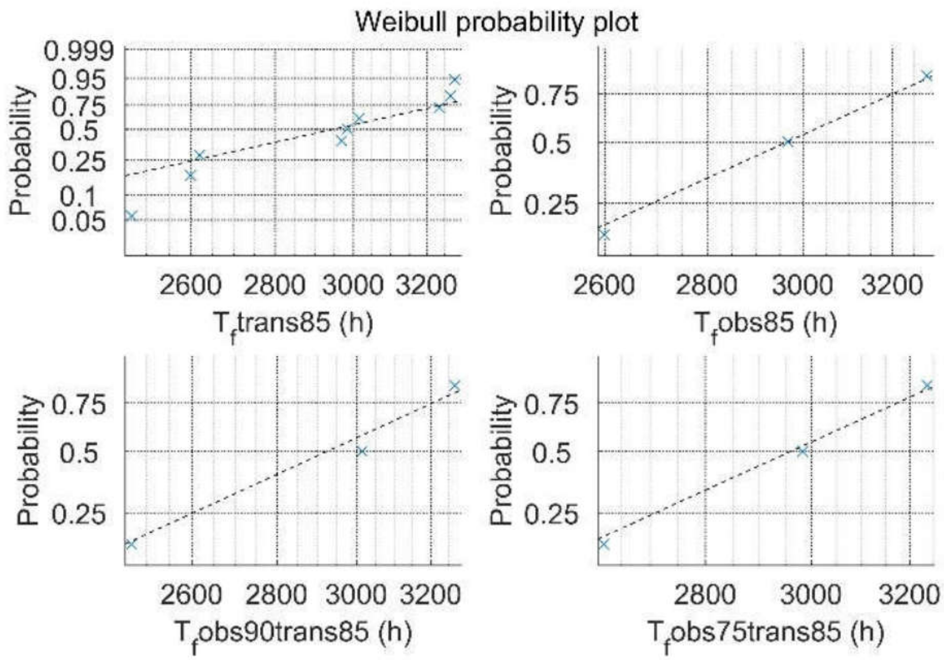


Figure 17: Weibull probability plot for the failure time data.

Weibull distribution is the most adaptive distribution used in lifetime estimation. It is accurate for the three-stages of product lifetime. Mathematically the probability distribution function mentioned at the beginning of the Introduction section can be used. The plots in **Figure** 17 are drawn from the data in **Table** 3. If the data follows the Weibull distribution, then it should have linear line characteristics. As it is clear from the plots, the failure time follows the Weibull distribution nicely.

The maximum likelihood estimation is used to estimate Weibull distribution parameters, and the mean life can be calculated after this process. The result is shown in **Table** 4. The Weibull probability distribution plots are shown in the **Figure** below:

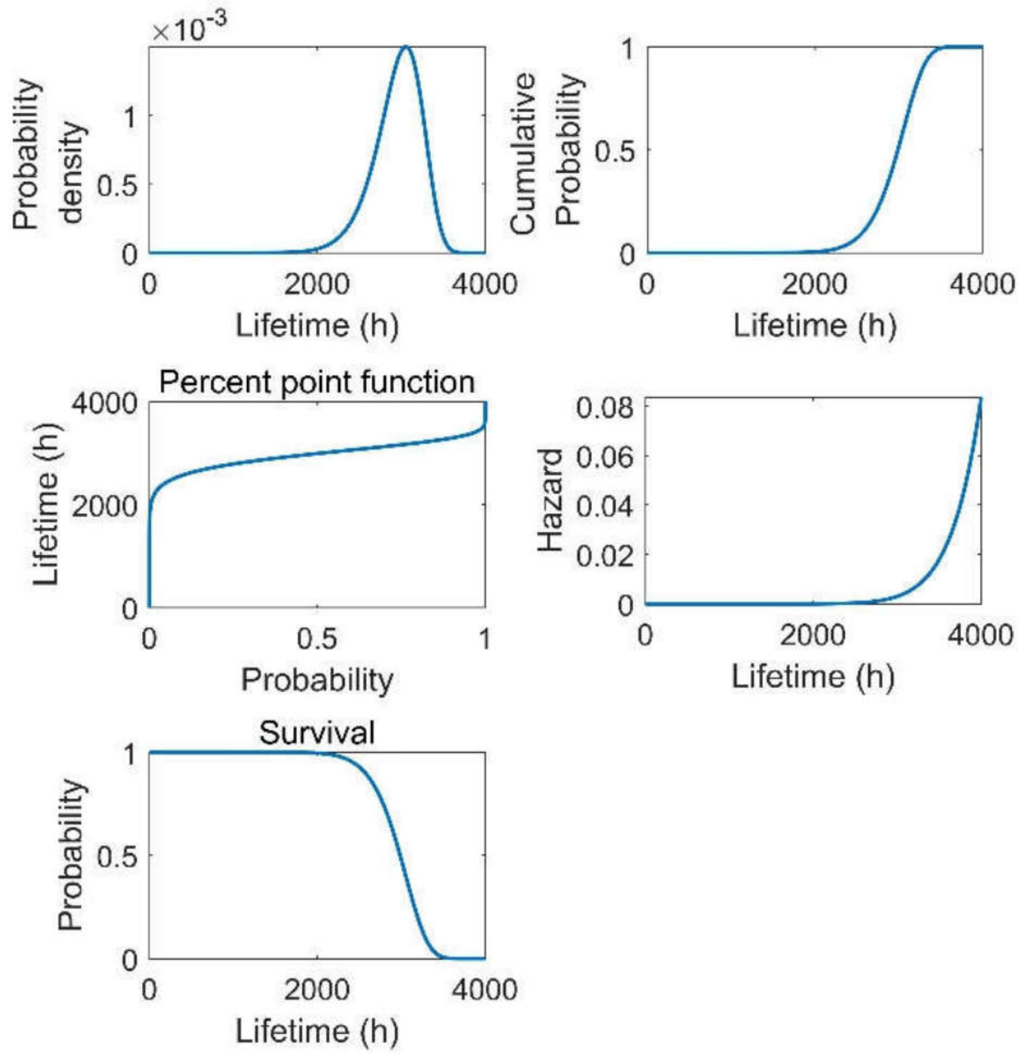


Figure 18: Weibull probability distribution for the data in **Table** 4.

For lognormal distribution, the PDF is defined as:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(\ln x-\mu)^2}{2\sigma^2}} \quad x > 0; \sigma > 0 \quad (14)$$

The distribution is Lognormal because the failure data is linear; observing the plots in **Figure** 19, they are linear and follow the Lognormal distribution.

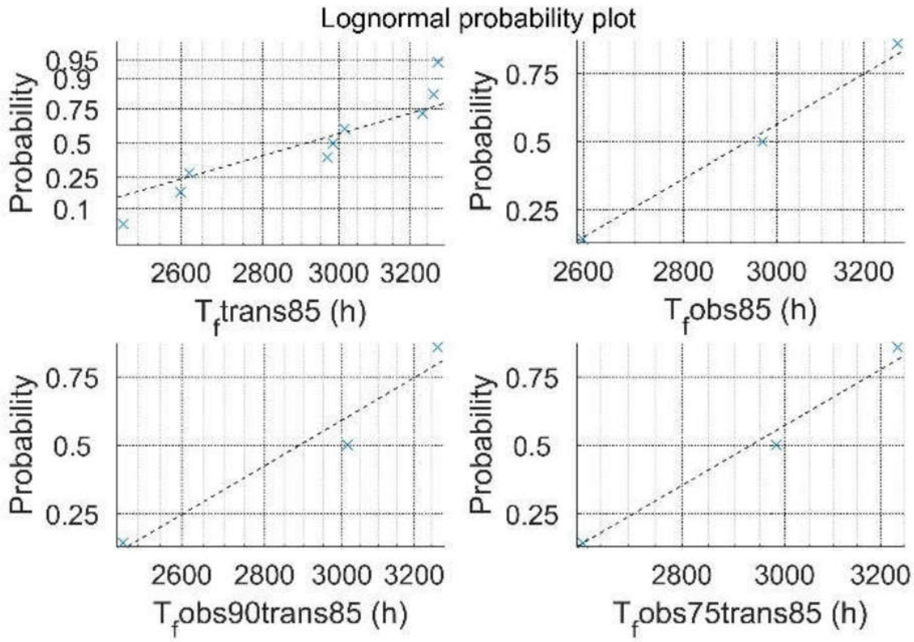


Figure 19:Lognormal probability plot for the failure time in **Table** 3.

The lognormal distribution data estimated again using the MLE, and the result is shown in the **Table** below:

Failure time T_f	**Scale parameter μ**	**Shape parameter σ**	**Mean lifetime (h)**
$T_f$obs75trans85	7.9847	0.1065	2952.5
$T_f$obs85	7.9849	0.1167	2956.4
$T_f$obs90trans85	7.9715	0.1446	2927.7
$T_f$trans85	7.9804	0.1073	2940

Table 5: the parameter for the Lognormal distribution and the mean lifetime.

It is clear that the shape parameter increases with the increase of the temperature. Conversely, the shape parameter of the Weibull distribution was decreasing with the increase of temperature.

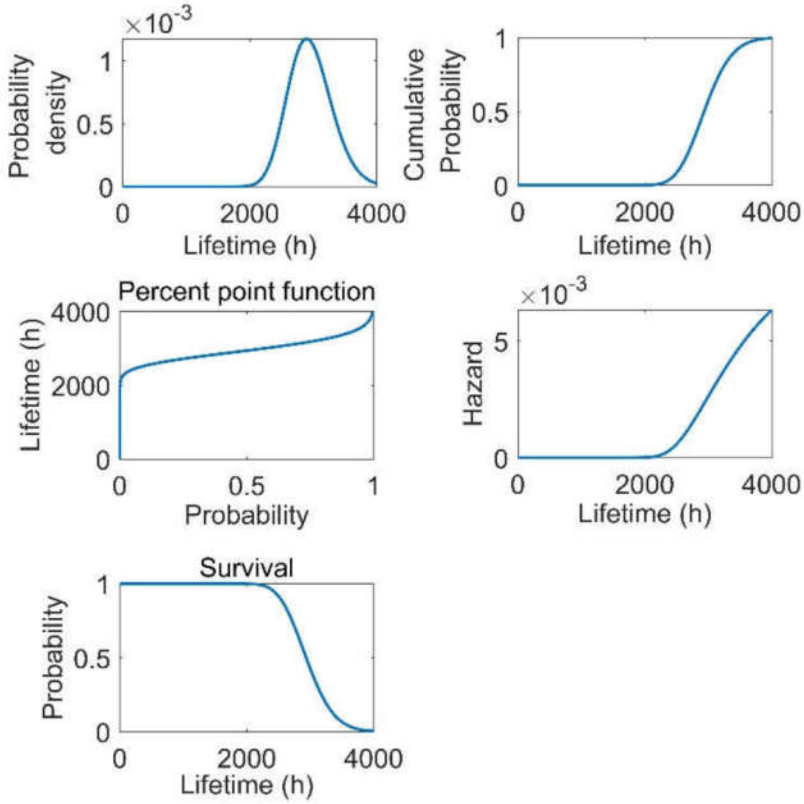


Figure 20: Lognormal plots concerning the data in **Table** 3.

For the exponential distribution, the PDF equation can be expressed as follows:

$$f(x) = \frac{1}{\beta} e^{-\frac{x}{\beta}} \quad x \geq 0; \beta > 0 \qquad (15)$$

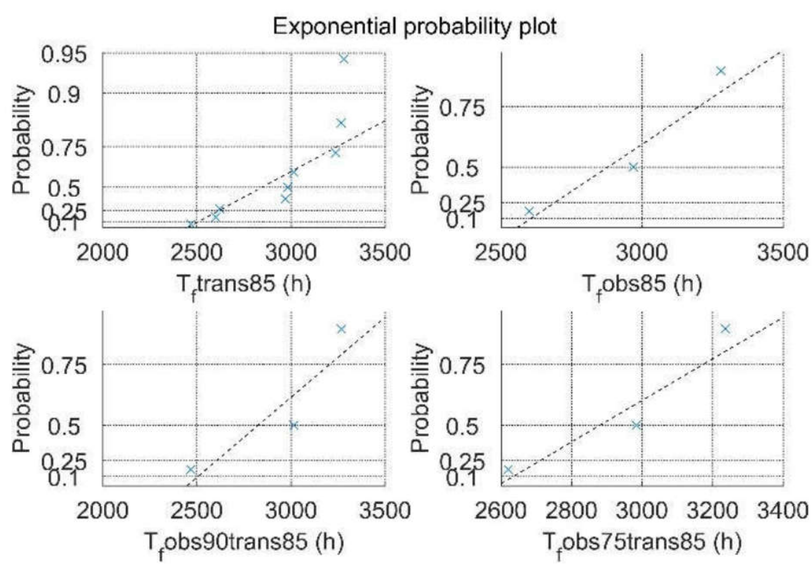


Figure 21: exponential probability plot for the failure time in **Table** 3.

According to the least square line, the curves are not linear because of the large deviations in the data. As a result, we can refuse the hypothesis H_o that T_f can be transferred to data at 85 C° can be exponentially distributed.

Failure time T_f	**Parameter β**	**Mean lifetime (h)**
$T_f$obs75trans85	2946.8	2946.8
$T_f$obs85	2949.6	2949.6
$T_f$obs90trans85	2917.1	2917.1

Table 6: The parameters of exponential distribution and lifetime failure.

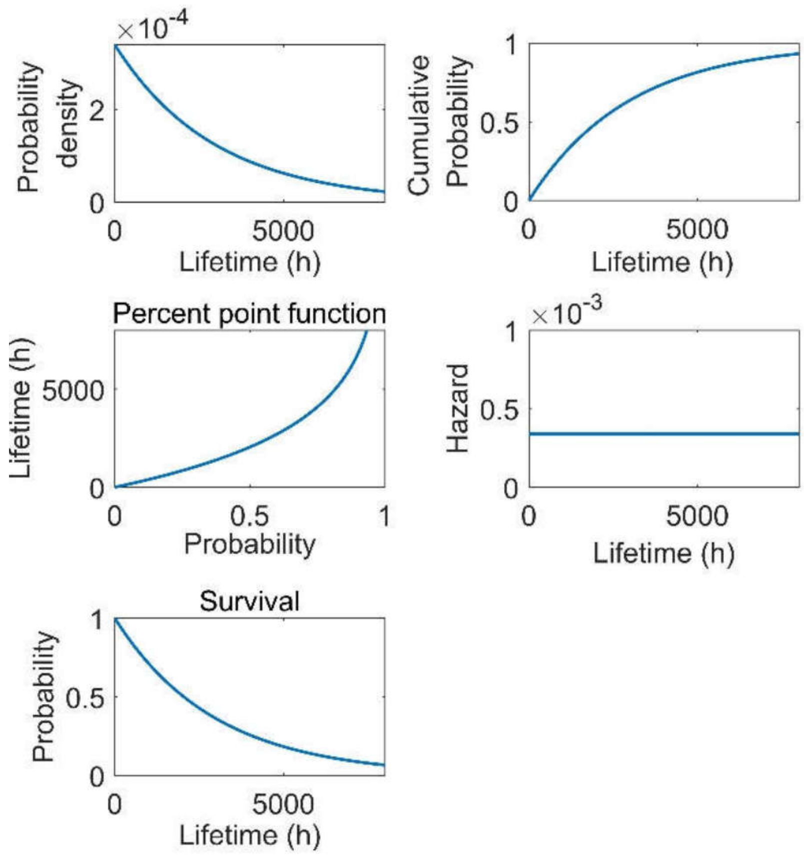


Figure 22: exponential probability plot and the failure lifetime.

The Kolmogorov-Smirnov and Lilliefors tests were applied first to select the best distribution to describe the lifetime degradation. It's usually used to test the hypothesis. Using these two tests helps test the distributions and analyze them, but it is not sufficient to decide whether which of the distributions are more describing the problem. The NLL test is then applied to the estimated parameters of the distributions over the failure time.

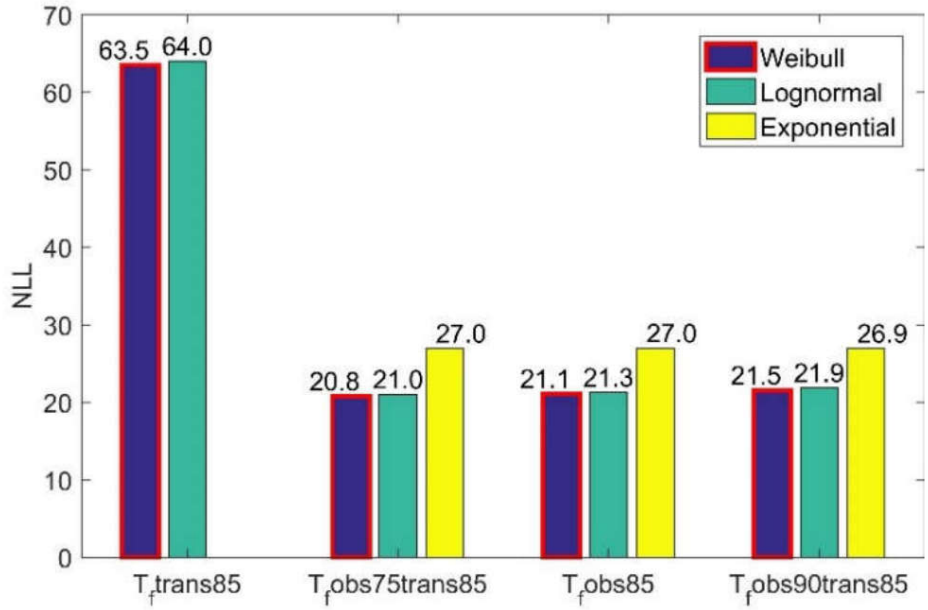


Figure 23: The NLL for the distributions over the sample of failure times.

The NLL output is shown in the **Figure** above, and it shows that the Weibull distribution has the minimum NLL values for all the samples. So the result shows that the P.V. module's failure time can be described in the best way using the Weibull distribution. In (Laronde, Charki and Bigaud, 2011) same author investigated the same work using temperature measurements.

3-4 Lifetime Estimation of Switching Devices.

In (Suntaranurak, Suwanasri and Suwanasri, 2020) work, the failures in powers circuit breakers and the disconnecting switches were recorded, and by using statistical distribution, the failure events were analyzed. The classification of different types of Circuit breakers and the Circuit breakers' parts and disconnecting switches were presented in this work. With the help of using Weibull distribution, the failure rate and lifetime of all the components and subcomponents were calculated. The study is useful to realize the replacement and maintenance of the component-time and avoiding power failure in the utility.

For studying the performance of any H.V. plant first, the reliability of the station should be considered. Most of the high voltage stations' critical components are circuit breakers (C.B.) and disconnecting switches (D.S.). D.S. is mainly useful to disconnect the station's part during the maintenance period. C.B. is the essential device used for carrying current during the load and abnormal situation. The C.B. needs to be checked for maintenance before the failure to avoid outage of the power.

The recorded data shows 124 failure records in C.B. and 101 for the D.S. from 2015 to 2018.

The necessary components and subcomponents are shown in the **Table** below:

Major Components	Sub-components	No. of failure	Total No. of failure
1.Interrupting Unit	Fix Contact/Terminal Plate	-	-
	Moving Contact	-	
	Arc quenching System	-	
2.Operating Mechanism	Energy Storage System	13	55
	Latching	2	
	Linkage	27	
	Motor	3	
	Dashpot	10	
3.SF6 Gas System	Gas Density Gauge/Pressure Switch	3	26
	Gas Quality	-	
	Gas Tightness	23	
4.External Insulation	Cleanliness of Surface	-	-
5.Control and Auxiliary Circuit	Closing Circuit	-	43
	Tripping Circuit	1	
	Electrical Supply/Wiring	1	
	Auxiliary Switches	4	
	Magnetic Contactor	2	
	Heater Circuit	-	
	Counter	35	

Table 7: the components of C.B. and the failures.

The components of D.S. are also shown below, and their subcomponent with the failure records are shown.

Major Components	Sub-components	No. of failure	Total No. of failure
1.Contact System	Fix Contact	6	13
	Moving Contact	4	
	Blade Rotating System	3	
2.Operating Mechanism	Motor Operation	12	19
	Manual Operation	-	
	Interlocking System	4	
	Mechanical Linkage	3	
3.Porcelain Insulation	Cleanliness of Surface	-	-
	Damage of Creepage	-	
4.Control and Auxiliary Circuit	Electrical Circuit/Wiring	18	69
	Auxiliary Switch	13	
	Closing/Opening Circuit	1	
	Magnetic Contactor	37	
	Heater Circuit	-	
5.Frame and Structure	Base Frame	-	-
	Steel Structure	-	

Table 8: The D.S. component and the failure records.

The Weibull distribution is widely used in estimating any device's life, and it perfectly covers the three phases of failure. The failure phases are the burn-in period, regular operation, and wear period. This work sorts the order of failures and then calculates the median rank of Xi of the event "i" as follows:

$$X_i = \frac{i - 0.3}{n + 0.4} \qquad (16)$$

Variable n denotes the total number of data. The Weibull parameters can be found using the following equations:

$$y_i = mx_i + c \qquad (17)$$

$$x_i = \ln(t_i) \qquad (18)$$

$$y_i = \ln\ln\left(\frac{1}{1 - F(t)}\right) \qquad (19)$$

The shape and scale parameters, PDF, and CDF can be calculated by the relevant equations mentioned in the above sections.

n	t_i	x_i	X_i (Median rank)	y_i
1	48.4	3.88	0.11	-2.156
2	58	4.06	0.265	-1.175
3	69.2	4.23	0.422	-0.6
4	87.9	4.476	0.578	-0.147
5	95.1	4.555	0.734	0.282
6	98.2	4.587	0.89	0.794
SUM		25.795	-	-3.003

Table 9: Reliability Parameters.

Shape parameter β	3.594
c	-15.953
Scale parameter η	84.643
$f(t)$	0.0000024
$F(t)$	0.081
$R(t)$	0.918
$\lambda(t)$	0.0000026

Table 10: the results of reliability parameters.

Tables 9 and 10, when the β is more astonishing than one, means that the component is eroded in age. The increased rate of hazard rate function means that the older components in age are more probably will fail than newer components. In this period, the component can be replaced to increase reliability.

The Weibull parameters for the subcomponents are shown in the **Table** below.

Major Components of power circuit breaker	Weibull Parameters		
	β	η	λ
F: Operating Mechanism	9.091	23.037	0.186
G: SF6 Gas System	2.015	20.617	0.094
H: Control and Auxiliary Circuit	7.144	21.635	0.275

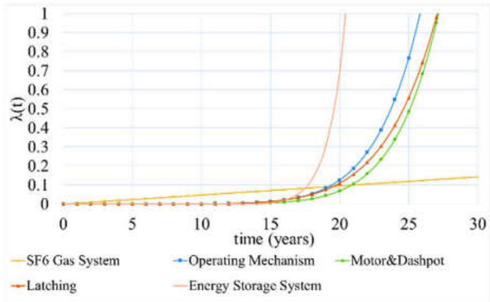
Sub-components of operating mechanism and control and auxiliary circuit	Weibull Parameters		
	β	η	λ
A: Energy Storage System	16.814	20.224	0.697
B: Latching	8.316	23.491	0.3
C: Motor and Dashpot	9.76	24.45	0.34
D: Tripping Circuit and Electrical Supply/Wiring and Auxiliary Switches and Magnetic Contactor	4.173	21.367	0.185
E: Counter	8.223	21.689	0.3

Table 11: Weibull parameters for all primary and subcomponents of C.B.

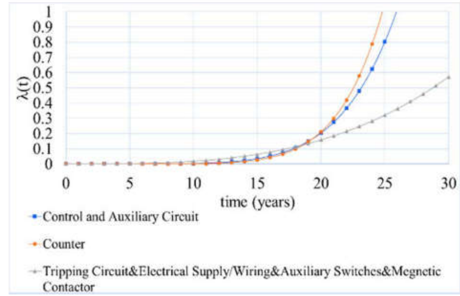
Major Components of disconnecting switch	Weibull Parameters		
	β	η	λ
Contact System	4.011	19.74	0.211
Operating Mechanism	2.6	16.17	0.158
Control and Auxiliary Circuit	5.29	19.13	0.27

Sub-components of operating mechanism and control and auxiliary circuit	Weibull Parameters		
	β	η	λ
Fix Contact	5.416	21.73	0.263
Moving Contact	2.426	18.96	0.128
Electrical Circuit/Wiring	3.3	17.136	0.189
Auxiliary Switch	9.817	20.1	0.467
Magnetic Contactor	8.37	19.181	0.407

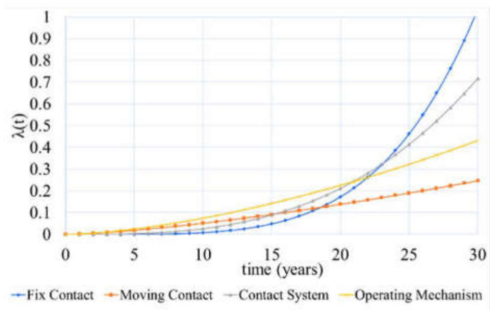
Table 12: Weibull parameters for all primary and subcomponents of D.S.



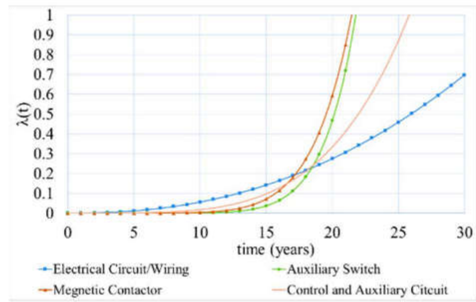
a) The failure rate of C.B. subcomponents



a) The failure rate of C.B Main components



a) The failure rate of D.S. components



a) The failure rate of D.S. main components

Figure 24: Failure rates for C.D. and D.S. components and subcomponents.

4- Conclusion

In (Yudong et al., 2016) work, the Weibull distribution contributes significantly to finding electrical equipment's life span. The data in this work shows that the method depicted was useful and accurate. This method's advantages are maintaining a schedule for maintenance, avoiding failure, and extending the device's life.

In (Xiong et al., 2017), the PCB board's breakdown characteristics can be significantly influenced by the distance between the interconnections, temperature, duty ratio, and pressure. The experiments show that the breakdown voltage will decrease with the increase of temperature, pressure, and duty ratio, but inversely, it increases when the distance between the interconnections is increased. The breakdown characteristics of the PCB is a breakdown in the solid-gas medium and follows the Weibull distribution. The Weibull distribution is advantageous in analyzing the breakdown of PCBs and their characteristics. The pressure characteristic of the PCB breakdown follows Bashin Law.

In (Wang *et al.*, 2019) study, three different distribution techniques were used to model the P.V. modules' failure, and the distributions are Weibull distribution, Lognormal, and exponential. Three P.V. modules were tested for failure under the ALT, and based on the data; probability distributions were plotted for each distribution. Then MLE is used to estimate the lifetime parameter. It was found that the lifetime failure data obey the Weibull distribution and the Lognormal distributions but not the exponential. Afterward, to decide which distribution is more applicable to describe the P.V. modules' failure, the NLL test was used successfully. The result shows the superiority of the Weibull distribution.

In (Suntaranurak, Suwanasri and Suwanasri, 2020) work, In conclusion, this study aims to estimate the CD and S.D. components' failure rate in the distribution stations using Weibull distribution. The operating mechanism's lifetime is twenty-three years, and for the auxiliary mechanism, it is twenty-one years. The lifetime of the gas sealing is calculated to be twenty years. In this way, the lifetime of the components is calculated, and then it can be predicted at which period the maintenance or replacement is needed for avoiding outage of power, increase the reliability of the system, and longer life spans of the other parts in the utility.

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