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RELIABILITY ANALYSIS FOR A FEEDER OF AN ELECTRIC POWER DISTRIBUTION COMPANY IN ECUADOR USING THE MONTECARLO SIMULATION METHOD

Análisis de confiabilidad para un alimentador de una empresa distribuidora de energía eléctrica en Ecuador utilizando el método de simulación Montecarlo

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Abstract

This study focuses on the evaluation of the reliability indexes of a feeder belonging to an Ecuadorian energy distribution company, reliability analysis is currently a topic of vital importance when making decisions in the area. technique for the electrical supply, in this way, in the first instance, a general evaluation of the feeder is carried out with the objective of collecting important information focused on; areas of influence, global indicators, failures and their causes. With the collection of information, we proceed to design a computational algorithm in the Matlab environment following the Montecarlo simulation methodology because this allows us to evaluate complex mathematical expressions with greater accuracy, concluding with results that allow us to estimate the reliability in the feeder to subsequently take measures to improve the reliability of the feeder.

Key words: *reliability, Montecarlo simulation, distribution feeder, indices.*

Resumen

Este estudio se enfoca en la evaluación de los índices de confiabilidad de un alimentador perteneciente a una compañía Ecuatoriana de distribución de energía, el análisis de confiabilidad en la actualidad es un tema de vital importancia al momento de tomar decisiones en el área técnica para el suministro eléctrico, de esta forma en primera instancia se realiza una evaluación general del alimentador con el objetico de recopilar información importante enfocada a; áreas de influencia, indicadores globales, fallas y sus causas. Con el levantamiento de información se procede a diseñar un algoritmo computacional en el entorno de Matlab siguiendo la metodología de la simulación Montecarlo debido a que esta nos permite evaluar expresiones matemáticas complejas con una mayor exactitud, concluyendo con resultados que permiten estimar la confiabilidad en el alimentador para posteriormente tomar acciones con la finalidad de mejorar la confiabilidad del alimentador.

Palabras clave: *confiablidad, método Montecarlo, alimentador de distribución, índices.*

1. INTRODUCTION

Electric power is one of the main bases for socioeconomic progress. Today, thanks to the progress of engineering as a discipline based on applied sciences and technology, clean technologies have been successfully implemented in power generation processes. This represents an important step towards a more sustainable and environmentally friendly future [1]. But the progressive increase of energy consumption due to the increase of loads establishes the fundamental precedent on which the present study is based, the distribution systems are subject to regulations such as ARCERNNR 002/20 for Ecuador, which decrees the indexes, quality parameters and indicators of the distribution service and commercialization of electric energy with the objective of granting reliability and continuity of the electric service to the Ecuadorian population [2].

Reliability seeks to quantify the performance of a system under specific operating conditions, the use of reliability concepts in power distribution systems emphasizes the load points considering their failures or interruptions that may occur, therefore, it is necessary to perform reliability assessments by examining all facets of engineering; design, planning and operation [3-5].

Failures are not always independent as assumed in many mathematical calculations, the failure of one element can increase the probability of failure of other equipment in a feeder, the most probable causes are lightning, snow, high winds, etc. Not only weather conditions affect the continuity of the electrical service, but also internal causes such as; protection failure, human failure, overloads, faulty equipment and short circuit failures [6-7].

The Monte Carlo method uses a quantitative perception of the data, it can be classified within the experimental methods, because it stochastically generates variables and the results are measured, without directly solving the equations, therefore, it is an efficient method that helps to perform the analysis of reliability behavior in the distribution feeder [8-10].

2. MATERIALS AND METHODS

The analysis of reliability indicators is based on the Monte Carlo simulation model for medium voltage (MV) radial distribution electrical networks, and its results are compared based on two distributions; Exponential and Weibull. The analysis is conceived from globalized indexes of duration and frequency of faults per kVA installed and is modeled from the behavior of the feeder and its components (Disconnections, Transformers and MV Lines).

2.1. Regulation 002/20 ARCERNNR.

Regulation No. 002/20 established by the Agency for Regulation and Control of Energy and Non-Renewable Natural Resources (ARCERNNR) aims to guarantee the continuity and reliability of the electric service to end users, through quality standards established in the section "QUALITY OF THE TECHNICAL SERVICE" with which different electric power distribution companies within the Ecuadorian territory are governed by regulations.

2.2. Indices used for feeder components modelling

2.2.1. Failure rate

It represents the number of failures occurred in a component of the system in the observation period (e.g. 1 year) in which such component was operating.

$$\lambda = \frac{m}{\sum Toi}\left[\frac{Failures}{Year}\right] \quad (1)$$

Where:

m = Total number of failures of element i

Toi = Duration in which the element i is in operative or available state

Σto = Cumulative duration of the maneuver of element i

2.2.2. Average time to failure

Indicates the amount of time it takes for component "i" to fail. It is obtained as the inverse of the failure rate.

$$MTTD = \frac{1}{\lambda} * 8760\left[\frac{Hours}{Failure}\right] \quad (2)$$

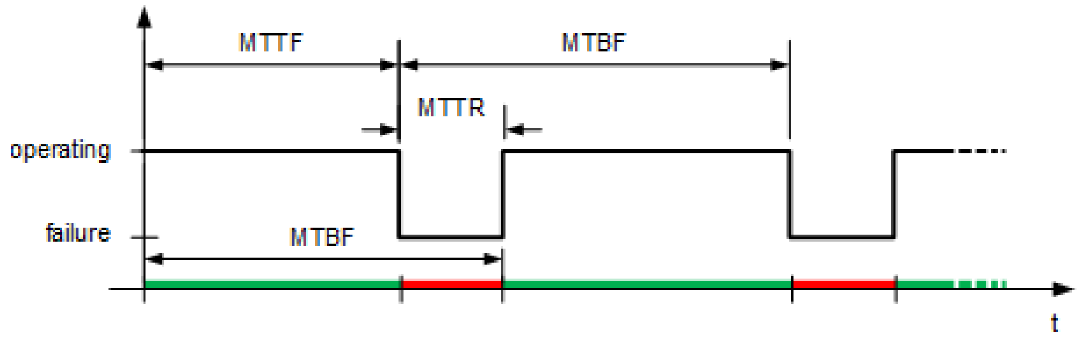

Figure 1. Temporal availability diagram used for modeling. **Source:** reliability analysis, 2019.

2.2.3. Repair rate
Indicates the number of repairs of a system component in the period in which it was operational.

$$\mu = \frac{1}{MTTR} \left[\frac{1}{Hours} \right] \quad (3)$$

2.2.4. Mean time to repair
Indicates the average time required to repair a component when it becomes unavailable or fails.

$$MTTR = \frac{\Sigma Tr}{m} \left[\frac{Hours}{Failure} \right] \quad (4)$$

The sum of the MTTF and MTTF mean times provided the mean time between failures (MTBF) as shown in figure 1.

2.3. Characteristics of the Feeder in 2020 and 2021
For the year 2021 there is a decrease in the number of users due to adverse causes, however, the growing demand can be evidenced with a differential of 419.78 kW per year in the year 2021 with respect to the year 2020.

2.4. Historical analysis of the feeder distribution system
For the evaluation of the indexes, it is necessary to categorize and classify the interruptions according to their origin, within the feeder there are scheduled and unscheduled interruptions that were recorded during the years 2020 and 2021, all interruptions exceed 3 minutes of duration and are classified into internal and external interruptions to the Distribution system. The external scheduled and unscheduled outages were:
- Transmission and Generation.

Internal scheduled and unscheduled outages were:
- Network disturbances
- Environmental
- Third-party

The feeder is a high-density urban feeder, so its FMIK limit value is 7 failures per year and the TTIK limit is 10 hours per year. These indexes reflect the total duration out of service of the distribution network, to define that a parameter "exceeds" the allowed limits in the case of FMIK its value must be less than 7 and TTIK less than 10. However, the overall indices in figure 2a exceed the values allowed by the ARCERNNR, in violation of regulation 002/20 in its "Technical Service Quality" section.

Within the historical period of record, it can be observed that the greatest number of interruptions were caused by failures in the distribution network equipment and accessories (see figure 2b), and the interruptions that left the feeder out of service for the longest time were caused by external maintenance interventions programmed by the electric power distribution company (see figure 2c). For the reliability analysis, the availability model for distribution systems is used, since this is a proactive model for diagnosing reliability and service factor of a distribution process for a period of time (2 years), it seeks to describe and characterize the current status of a process and predict its future behavior based on the reliability and configuration of its components, by analyzing the history of repairs, failures, operating conditions and technical data.

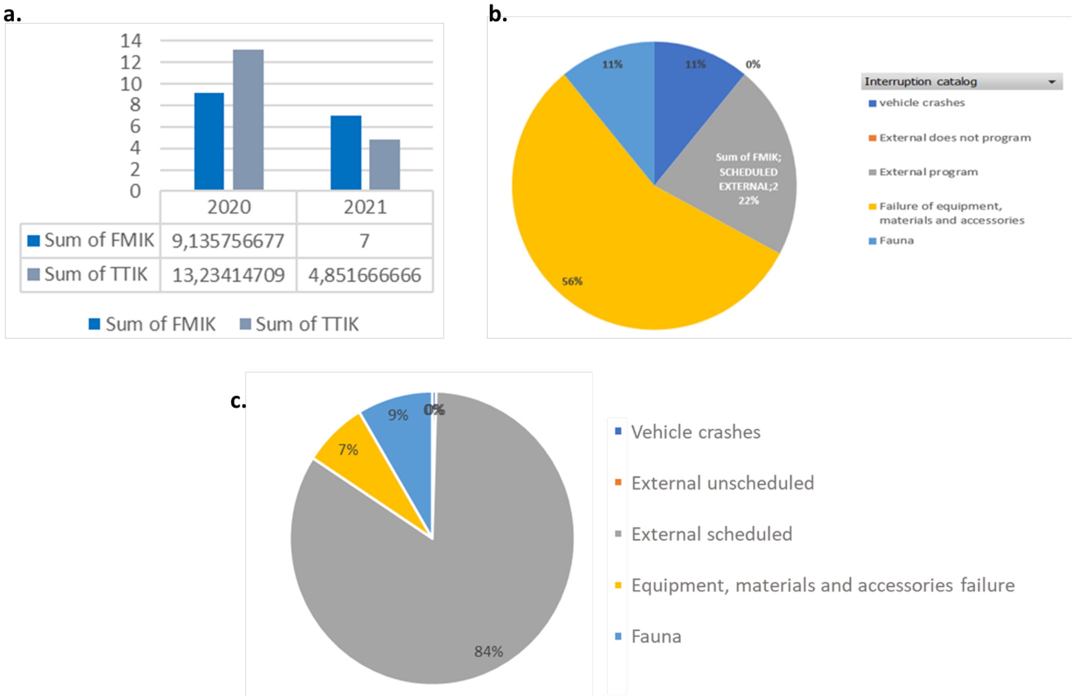

Figure 2. (a) Global indicators of total interruptions registered in the year 2020 and 2021, (b) Impact of interruptions on the Distribution Feeder and (c)Impact of interruption time on the Distribution Feeder. **Source:** authors, 2023.

Components are the equipment that make up a feeder, such as: transformers, disconnectors, transmission lines, protections, etc. Within the research field the components studied are generalized to 3 main elements which are:

- Main and lateral lines
- Disconnectors
- Transformers

For the year 2021 it can be observed that there is an improvement in the electric service quality indexes, this is due to the fact that the electric power distribution company has applied corrective and preventive maintenance measures, thus reducing the unavailability index from 68% in the year 2020 to 30% in the year 2021.

To calculate the total availability of the system, the historical record time (2 years) must be taken into account, in the case of the feeder, this period of time includes the years 2020 and 2021, resulting in a total of 1,720 hours and an availability of 99.8968%.

From the dates of failures recorded for the years 2020 and 2021, a distribution adjustment is made through goodness of fit tests to know which distribution function best fits the data obtained from the time between failures, for this purpose a description of the data for distribution adjustments is made within the STATGRAPHICS 19 program.

P-values less than 0.05 would indicate that Hours Between Failures does not come from the distribution selected with 95% confidence, while P-values close to 1 indicate that the correlation of the data coincides with 95% confidence, for this reason the research will focus on applying the Weibull Distribution model to estimate the reliability in the Excel environment under the criterion of being the second distribution with a correlation of 97.15% as shown in figure 3.

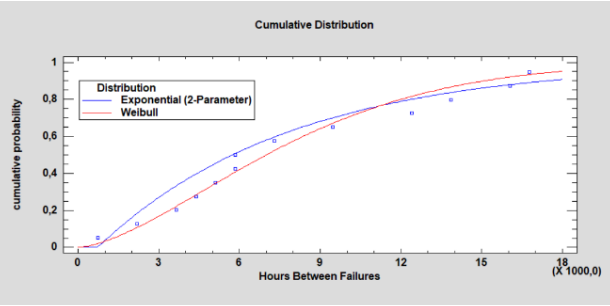

Figure 3. Comparison between cumulative distribution traces of Selected distributions. **Source:** Authors, 2023.

The Exponential distribution model is chosen for its high degree of correlation to analyze the reliability indexes; it will be designed by means of an algorithm following the Monte Carlo methodology in the MATLAB environment.

3. RESULTS AND DISCUSSION

3.1. Reliability and unavailability for the feeder using the Weibull method

Parameters to estimate the reliability through the Weibull density function are obtained by calculating the equation of the straight line, these parameters are the slope "β", the value of the scale "θ" and the constant "b", to calculate the value of the scale the exponential of the value of the constant divided by the value of the slope must be found; by performing the data curve fitting the following parameters are obtained.

3.1.1. Weibull parameters

Beta (β)=1,56564
Eta (θ)= 8853.6
Cte (b)=-11,6147

To find the Weibull density function, the eta and beta parameters are replaced in equation 6:

$$R(t)=\int_{s}^{\infty} f(s)ds = e^{\left[-\left(t-\frac{\delta}{\theta}\right)\wedge\beta\right]} \quad (6)$$

Unavailability is calculated from expression 7:

$$F(t)=1-R(T)=1-e^{\left[-\left(t-\frac{\delta}{\theta}\right)\wedge\beta\right]} \quad (7)$$

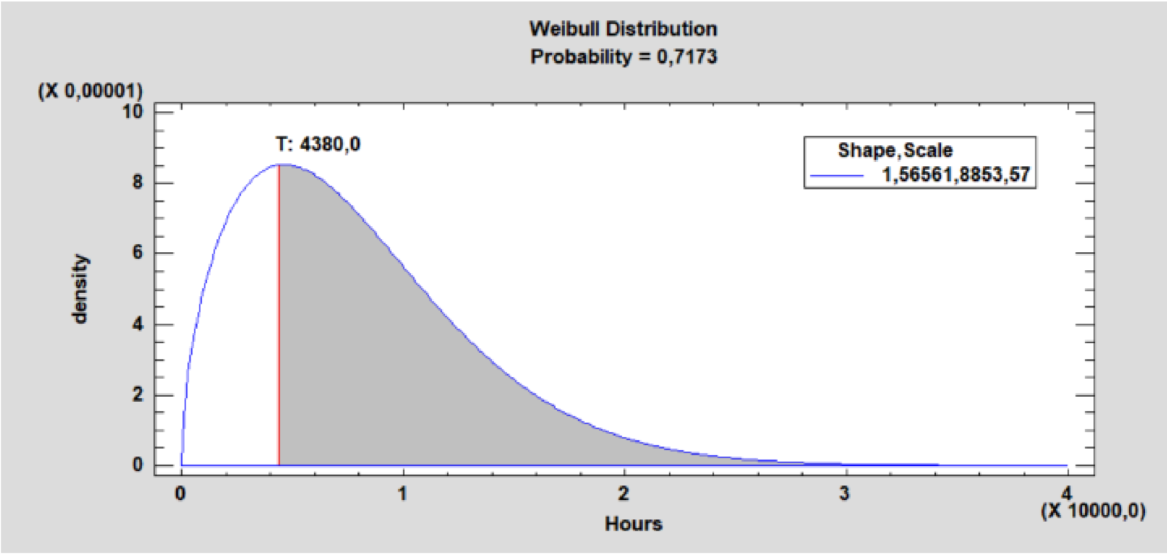

Figure 4. Distribution function for the Weibull density with t=4380. **Source:** authors, 2023.

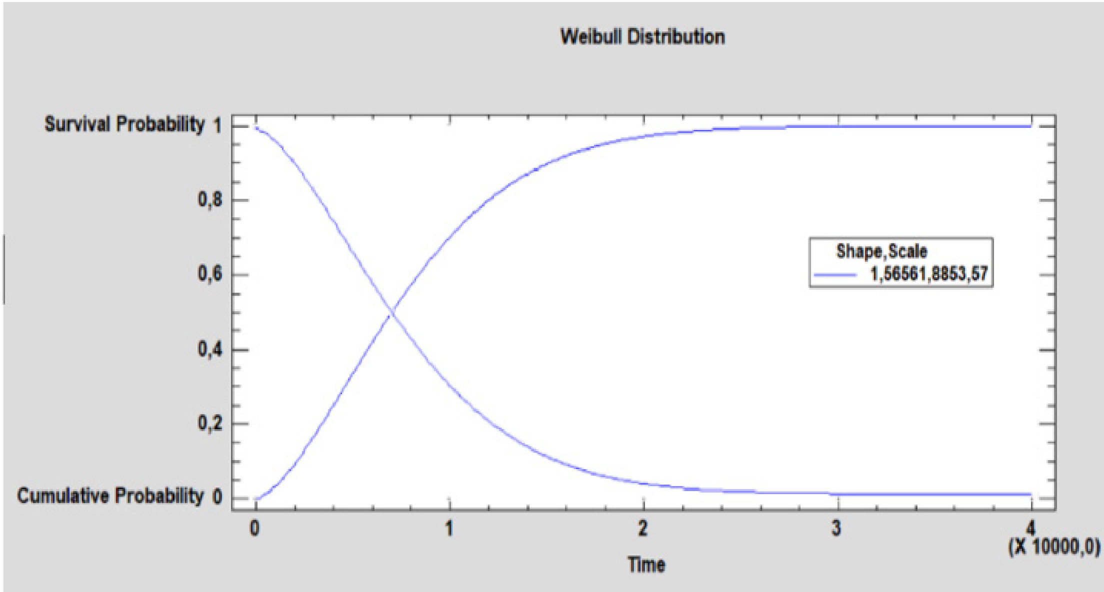

Figure 5. Reliability vs Unavailability curve Weibull analysis **Source:** authors, 2023.

In this way the reliability within a time "t" governed by parameters of this distribution is estimated as can be seen in the figure 4. To estimate the reliability of the feeder within 5 variables "t" that can take any desired value, for this case the variable "t" takes as first value the hours corresponding to 1 month and the following in jumps of 6 months to perform a semiannual analysis of the feeder behavior with respect to reliability and unavailability for a period of 2 years of estimation (see figure 5).

For example, in table 1the output indicates that the probability of obtaining an unavailability less than or equal to 730.0 hours is 0.0198994 for the fitted Weibull distribution.

The curves in function to the Weibull distribution for the reliability and unavailability of the Feeder, where the survival function indicates the probability of obtaining a value greater than or equal to that shown on the X-axis and the cumulative function indicates the probability of obtaining a value less than or equal to that shown on the X-axis.

Table 1. Reliability and unavailability using the 2-parameter Exponential distribution.

t [months]	t [hours]	Unavailability	Reliability
1	730	2,16435E-05	0,999978
6	4380	0,396056	0,603944
12	8760	0,670236	0,329764
18	13140	0,819943	0,180057
24	17520	0,901685	0,0983147

3.2. Monte Carlo algorithm to calculate and evaluate the reliability indexes in the feeder using the Exponential Distribution method

The objective of the designed program was to perform a reliability analysis, presenting at the end the global indexes for each modeled element of the feeder. Where through different components the basic structure of the Monte Carlo methodology is molded, this method is executed under the conditions of a sequential scenario with system state transition sampling. The main structure of the algorithm implemented for the Monte Carlo simulation is shown in figure 6.

The input parameters will be the evaluation time in months, the number of interactions needed according to the proximity to the actual value required (1000 interactions are recommended) and finally the projected power of the feeder in the specified time, these data will help to set the limits to which the data obtained in the process modules 2 and 3 set in Figure 7 should be adjusted.

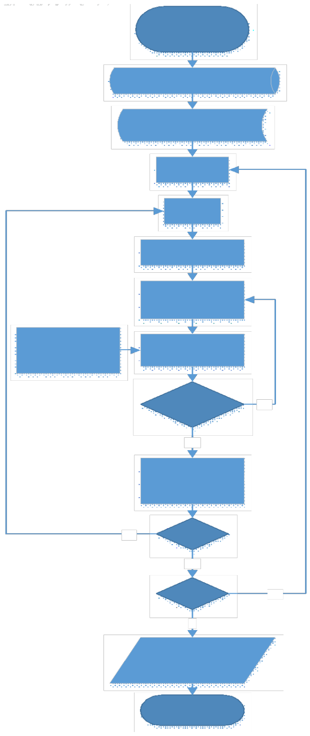

Figure 6 General structure of the implemented Algorithm. **Source:** authors, 2023.

The random variables applied to the MTTR and MTTF times with an exponential distribution of two parameters as analyzed in the previous chapter, are generated from the expression *"Exprnd"* this syntax of the Matlab language generates a random number "n" from an exponential distribution where "i" will be the value of the mean assigned by the researcher, in case of obtaining the variables of the distribution is used:

$$n = exprnd(i;\beta;\gamma)$$
$$N_{MTTR} = exprnd(\mu;\beta;\gamma)$$
$$N_{MTTF} = exprnd(\lambda;\beta;\gamma)$$

In the results window are printed the indexes to evaluate the reliability FMIK and TTIK which indicate both the failure frequency and the duration time, these indexes take the accumulated value for a time t specified by the researcher and a number of interactions that is recommended from 100 to 1000 because when using an exponential distribution, the values tend to have a greater margin of error due to the exponential accumulation of the variables after n interactions (see figure 7a).

To evaluate and estimate the reliability of the feeder, 5-time values ranging from 730 to 17520 hours, equivalent to 24 months of operation, are established as input parameters to perform the simulation under the same parameters analyzed with the Weibull distribution and to make a comparison, each one is evaluated with 1000 interactions (closer approximation to the real value), which results in the table 2.

Using 1000 interactions what is achieved is to reduce the margin of error due to the exponential accumulation of variables in the established model, it should be considered that for the results to be reliable they must have a margin of error of 5% and the convergence between the accumulation of data after n interactions results in n=1000.

From the survival and cumulative probability functions it is possible to plot the curves that describe the behavior of the feeder in terms of reliability and unavailability concepts (see figure 7b).

The results window also prints the FMIK and TTIK indices for the times evaluated in Table 1, with these data it is possible to calculate the availability of the feeder for these time periods (see Figure 7c). From the goodness tests it is determined that the exponential distribution is the one that best fits the distribution represented by the failure history, on the other hand, it is required to compare the results obtained by the implemented algorithm in terms of reliability and unavailability in a given time, for this reason the Weibull distribution is used since they are distributions widely used in the context of reliability.

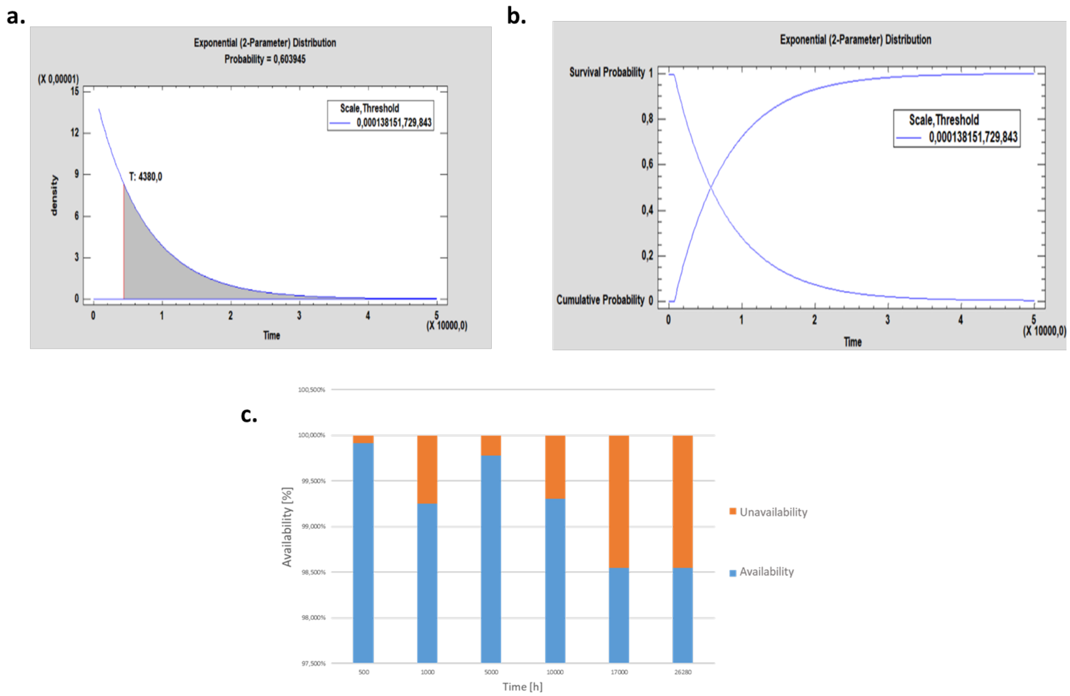

Figure 7. (a) Exponential density function with t=4380, (b) Reliability vs. unavailability curve exponential analysis 2 parameters and (c) Estimated feeder availability and unavailability results. **Source:** authors, 2023.

The statistical summary makes the comparison between the distributions generated for both models, among the main differences we have the variation coefficient that in case of the exponential distribution tends to be higher due to the size of the sample (1000 numbers) generated from random numbers according to the Monte Carlo methodology. The skewness and kurtosis remain within the allowed ranges this means that the results do not possess a significant variance that impairs the confidence of the results, these show that for the Weibull distribution the generated data tend to be close to the mean in a leptokurtic way, i.e.; the kurtosis is greater than 0, for the exponential distribution the data tend to have a skewness of 2. 18 as expected since the exponential distribution is positively skewed and has a kurtosis of 8.058 which indicates that it has a peak characteristic of this type of distribution.

Table 2. Comparison between Weibull and Exponential Distribution (2 parameters) for the distribution feeder.

Time		Weibull distribution		Exponential (2 parameters)	
t [months]	t [hours]	Unavailability	Reliability	Unavailability	Reliability
1	730	0,019899	0,98010	2,1645E-05	0,99997
6	4380	0,2827	0,7173	0,39605	0,60394
12	8760	0,626002	0,37399	0,67023	0,32976
18	13140	0,843629	0,15637	0,81994	0,18005
24	17520	0,94559	0,05441	0,90168	0,09831

4. CONCLUSIONS

The conditions and characteristics of the distribution feeder are evaluated with a record of events between 2020-2021, where the interruptions that affected the continuity of the electric service for the feeder are verified. In 2020 there were a total of 9.13 failures (FMIK) and a total interruption time (TTIK) of 13.34 hours per year. In the year 2021, due to the preventive and corrective maintenance work of the company in charge, there is a decrease for both the FMIK index of a total of 7 interruptions and an interruption time (TTIK) of 4.85 hours per year, which translates into better management and performance, but even so, the feeder does not comply with the "Quality of Energy Distribution and Commercialization Service" regulations established by the Ecuadorian regulatory body ARCERNNR 002/20.

Therefore, according to the analysis performed in the previous sections, two types of distributions have been established for which the failure times have been adjusted correlatively, using the Weibull distribution the results suggest a reliability of 5.44% in 17520 hours, the correlation factor of these data is 0.97, unlike the exponential distribution (2 parameters) which suggests a reliability of 9.83% in 17520 hours, a slightly more accurate value because this distribution has a factor r^2 slightly higher than the Weibull distribution.

By implementing the MATLAB computational software to design an algorithm capable of estimating in a period of time the reliability indexes FMIK and TTIK, it is concluded that the feeder has a high percentage of availability with a total of 98% in an estimation for 2 years with the current characteristics and with a load growth of 2 to 5%, these factors are important and should be taken into account when making expansion designs or redesigns of the feeder.

In spite of this, the indexes exceed the limits established by the Ecuadorian standard ARCERNNR 002/20 in the evaluated time, the feeder will have a higher probability of complying with the limits established for the "quality and service control" for an operation time of up to 7000 hours, that is, 9 months approximately, after which preventive and corrective maintenance maneuvers will have to be carried out.

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