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MAINTENANCE STRATEGY BASED ON RELIABILITY: CASE STUDY OF A COMPANY IN THE ELECTRIC SECTOR

ESTRATEGIA DE MANTENIMIENTO BASADA EN CONFIABILIDAD: CASO DE ESTUDIO EN UNA EMPRESA DEL SECTOR ELÉCTRICO

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ABSTRACT.
In the electrical system, it is essential that the equipment remains in good condition in order to guarantee the energy supply and its continuity. Among these pieces of equipment are the circuit reclosers, which are tele-controlled devices that act on temporary faults, reducing the affected area in an occasional network failure and the time needed to restore the supply. Thus, the goal of this article is to propose a strategy based on Reliability-Centered Maintenance (RCM) for circuit reclosers used by an electric energy distributor in the Triângulo Crajubar, region localized in the countryside of Ceará – Brazil. Therefore, data related to time to failure, between failures, and until repair, was collected through the distribution company's management system and with the help of the application Proconf 2000©, it was possible to determine the reliability functions, availability and current reliability of the devices. In addition, through the risk functions, it was determined the stage in the life cycle in which the reclosers were found, making it possible to verify the best maintenance strategy in each case, according to the literature. Then, it was concluded that the most adequate maintenance strategy to reclosers is preventive maintenance at predetermined intervals.

Keywords: Circuit reclosers, medium voltage, strategy

RESUMEN
En el sistema eléctrico es fundamental que los equipos se mantengan en buen estado para garantizar el suministro de energía y su continuidad. Entre estos equipos se encuentran los reconectadores de circuitos, que son dispositivos telecontrolados que actúan sobre fallas temporales, reduciendo el área afectada en una falla ocasional de la red y el tiempo necesario para restablecer el suministro. Así, el objetivo de este artículo es proponer una estrategia basada en el Mantenimiento Centrado en Confiabilidad (RCM) para los reconectadores de circuito utilizados por una distribuidora de energía eléctrica en el Triângulo Crajubar, región ubicada en el interior de Ceará – Brasil. Por lo tanto, los datos relacionados con el tiempo hasta la falla, entre fallas y hasta la reparación, fueron recolectados a través del sistema de gestión de la empresa distribuidora y con la ayuda de la aplicación Proconf 2000©, se pudo determinar las funciones de confiabilidad, disponibilidad y confiabilidad actual de la dispositivos. Además, a través de las funciones de riesgo, se determinó la etapa del ciclo de vida en la que se encontraban los reconectadores, lo que permitió verificar la mejor estrategia de mantenimiento en cada caso, según la literatura. Luego, se concluyó que la estrategia de mantenimiento más adecuada a los reconectadores es el mantenimiento preventivo a intervalos predeterminados.

Palavras-chave: Reconectadores, Energia electrica, Estrategia

1 INTRODUCTION

In the current competitive and economically globalized scenario, companies seek to increase their productivity and quality by reducing production and maintenance costs as much as possible. Before, these costs used to be seen only as “necessary expenses”, but now the study of "expenses" has come to occupy a strategic position in most of the organizations around the globe. Here, electrical systems stand out, for their monetary gains take place according to the availability of equipment, and their failure can cause large penalties (SANTOS; COLOSIMO; MOTTA, 2007).

According to the Brazilian National Electric Energy Agency (Agência Nacional de Energia Elétrica, 2017), electricity is essential to the economic and social development of any nation. This sector is subdivided into three main ones: generators, those who produce the energy; transmitters, those who transport the generated energy to consumer centers; and distributors, those who make it available to end consumers in the correct way and amount. Among the companies operating in this sector is ENEL (Ente Nazionale per l'Energia Eletrica - an Italian energy company), a multinational operating throughout the energy chain in some Brazilian states. It has 4 distributors throughout the country, in Rio de Janeiro, Ceará, Goiás and São Paulo, and it serves around 17 million residential customers from various sectors (ENEL, 2016). The company is noteworthy for its continuous investment in innovation, and among its projects is the implementation of remote-controlled equipment in the electricity grid. They reached about 20 thousand pieces of equipment installed in Brazil by the end of 2019 (CANAL ENERGIA, 2020).

In this paper, we look more specifically at the state of Ceará, where around 4000 telecontrol devices were put into operation by the end of 2020. They allow the reduction of the affected area in case of a possible power outage and, consequently, the number of affected customers, and the time to reestablish the power supply energy (ENEL, 2021). Among these remote-controlled pieces of equipment, we highlight the automatic circuit reclosers, a type of equipment that perform a circuit’s sectioning or reconnecting automatically, according to predetermined settings, in cases when short circuits due to temporary faults are detected (KONDO, 2015). Consequently, these devices need always to be available and reliable for use, as they depend on external agents, and their failure is detrimental to the continuity of electricity supply.

Nowadays, it is evident that electricity is necessary for almost all activities carried out by mankind, and that its lack for long periods brings great harm to both consumers and distributors; the latter who must comply with indicators of continuity and quality (MOURA, 2010). Therefore, a study on the best maintenance strategy to be adopted for the automatic circuit reclosers is justified mainly because it would allow us to achieve higher levels of reliability and availability, and eventually to reduce costs (NIU; YANG; PECHT, 2010). However, in the current scenario, only corrective maintenance is being carried out by ENEL, and no study has been made so far on this subject.

According to Lafraia (2001), reliability is the probability that an equipment performs its function properly in a given period, under specific environmental conditions. Reliability-Centered Maintenance (RCM), more specifically, is a method developed with various techniques to guarantee the functionality of a system's equipment (FOGLIATTO and RIBEIRO, 2011). RCM has shown great benefit for electrical distribution systems. It is an excellent way to define the most suitable model for performing maintenance on these pieces of equipment, since this methodology is ideal for companies with continuous processes (WUTTKE and SELLITTO, 2008).

Therefore, for this case study, we chose the method RCM, which enables us to identify the failure modes and its consequences, and thus to achieve a proper maintenance model with the best cost-benefit for this company. The RCM also helps to guard the chosen model’s effectiveness, by monitoring and implementing continuous improvements to minimize the risks and failures (MACHI et al., 2012).

Now, we will look more closely at the region called Cariri, in the southeast of Ceará - Brazil, in which this research was carried out. Cariri has become a commercial, economic and industrial hub, exercising influence not only over the state where it is localized, but also over other states with proximity (OLIVEIRA; MORAIS; PEREIRA, 2013). The region has settled 3002 industries until 2015, and its GDP (Gross Domestic Product) accounted for 138 millions only in the year of 2016 (IPECE, 2019). Therefore, it has been in an excellent stage of development, being one of Ceará’s most important regions. Looking more closely, this is due mainly to the cities that form the so-called “Triângulo Crajuba” (cities of Crato, Juazeiro do Norte, and Barbalha). They have the largest part of the population, the highest socioeconomic indicators, and the highest consumption of electric energy in the region - with the three cities occupying the first three places in the ranking (LEITE et al., 2019). These are the reasons why Crajubar was chosen as the more specific spatial delimitation for this study.

In summary, this study aims to identify the most appropriate maintenance strategy for circuit reclosers installed in the medium voltage network, based on the Reliability-Centered Maintenance (RCM) methodology, and compare the results between the different models and brands that serve the company ENEL, in the “Crajubar” region.

In the following topics, we present the methodology applied for the research development (2); the results and discussion obtained (3); and, ultimately, the conclusion (4) regarding the study in its entirety.

2 METHOD

The research method will be the quantitative modeling and case study in an electricity distribution company. Initially, a survey of all reclosers installed in the Crajubar triangle region was carried out through the company's control system. The collected data were organized in spreadsheets, and then classified by manufacturer. Subsequently, a filtering of those who underwent maintenance was carried out, identifying their respective failure modes, each equipment’s start of operation dates, as well as the failure dates, so that it was possible to determine the devices’ time to failure and time until repair.

With the times to failure at hand, the free version of the Proconf 2000© program was used. It consists of an application created to adjust distributions of times to failure through analytical and graphic methods (FRITSCH and RIBEIRO, 1998). With this program, we chose the probability distribution that best suited the data, out of Exponential, Weibull, Gamma or Log-norm distributions, through the Chi-square (χ^2) and Kolmogorov-Smirnov (DN) adherence tests. Thus, the aforementioned reliability indicators for this case study were obtained: failure probability density function f(t), risk function h(t), reliability function R(t), the accumulated failure function and the mean time to failure (MTTF).

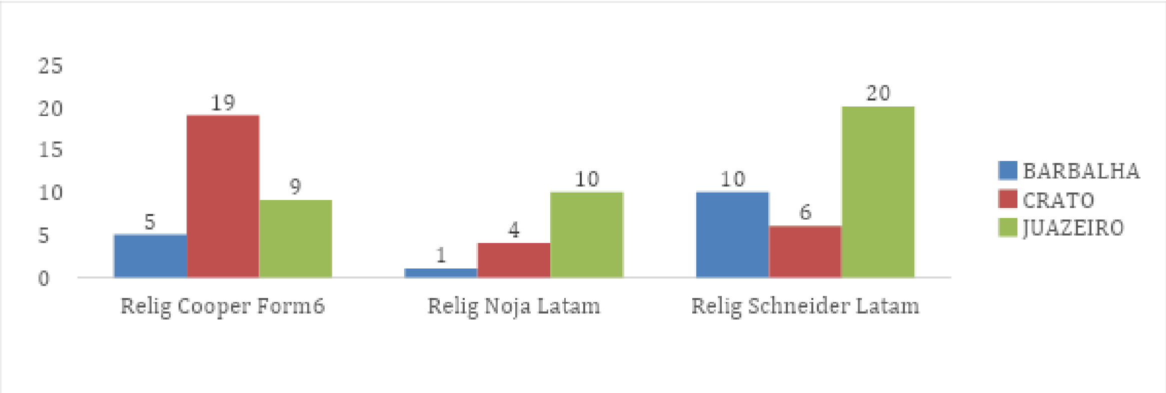
Furthermore, with the numbers of time until repair at hand, the mean time until repair (MTTR) was calculated using the same program, according to the probability distributions that best fit, considering the same parameters used for the time until repair.

Thereby, the values of MTTF and MTTR were obtained, and thus the equipment’s availability and current reliability by manufacturer were calculated. Through these indicators, and the bathtub curve, we identified the current moment in which these pieces of equipment are in their life cycle, and thus made a proposal for a new maintenance strategy based on reliability.

3 RESULTS AND DISCUSSION

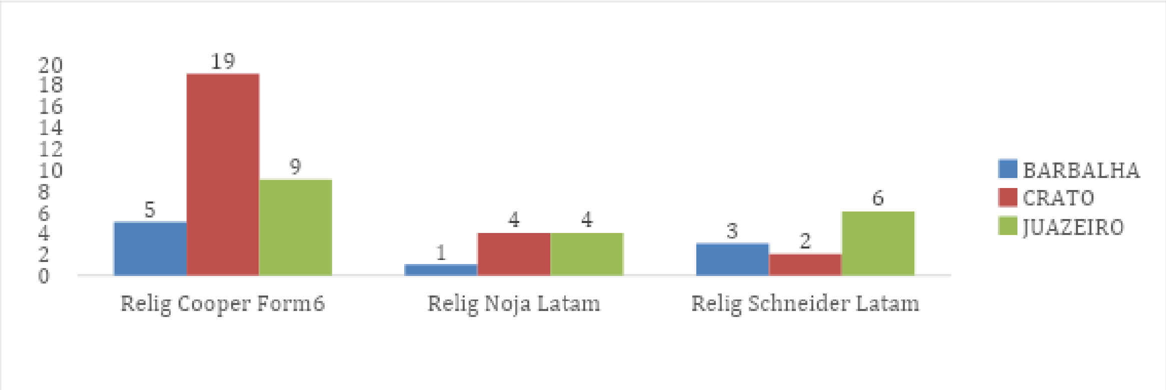
From the data collection in the system, it was possible to identify that there are 86 reclosers installed and in operation in Barbalha, Juazeiro do Norte and Crato, with 4 different models and brands: Cooper Form6, Noja Latam, Schneider Latam, and KF Lupa. However, for this work, only the first 3 models mentioned were considered, since there are only two installed units of the KF Lupa type, an insufficient quantity for this type of approach. Thus, 84 reclosers will be counted in the survey (as described in Figure 1), of which 53 underwent maintenance (as presented in Figure 2).

FIGURE 1 – RECLOSER MODELS BY CITY



SOURCE: Authors (2022)

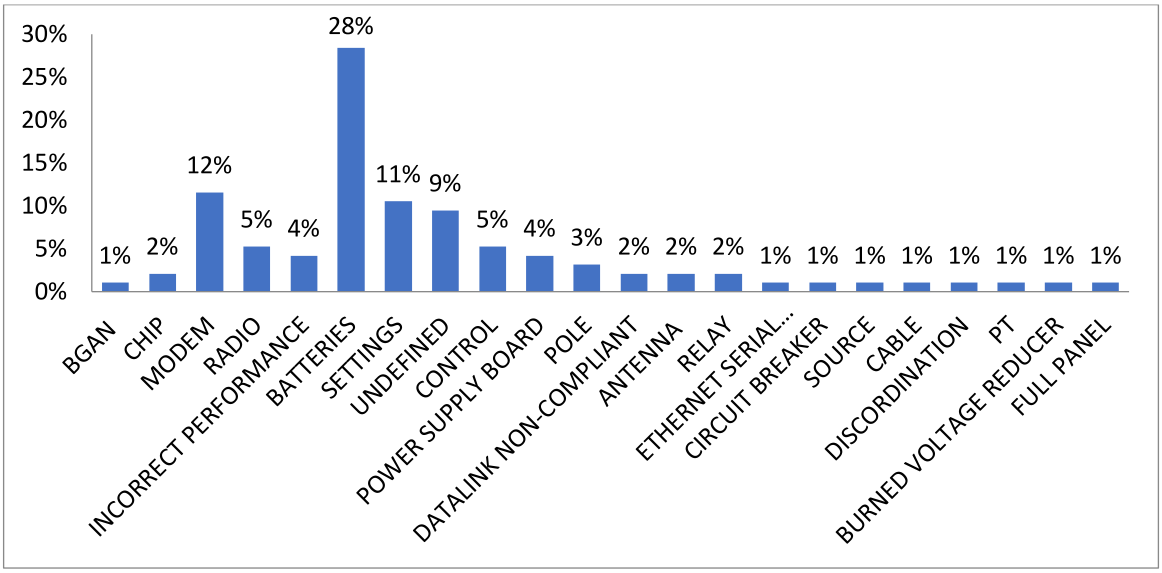
FIGURE 2 – RECLOSERS THAT HAVE UNDERGONE MAINTENANCE BY CITY



SOURCE: Authors (2022)

The pieces of equipment that underwent maintenance had 81 stops between 2019 and 2021, some of them with more than one failure mode. The problems identified were 22 in total, out of which the main ones are: battery failure, configuration, modem, radio, control or causes still undefined, as shown in Figure 3.

FIGURE 3 – FAILURE MODES AND THEIR REPRESENTATIONS



SOURCE: Authors (2022)

With the records of the equipment installation dates, their type of failures, and their dates of return to operation after repair (Tables S1, S2, and S3), the times to failure in hours were calculated, and then separated by each recloser model, as shown in Table 1.

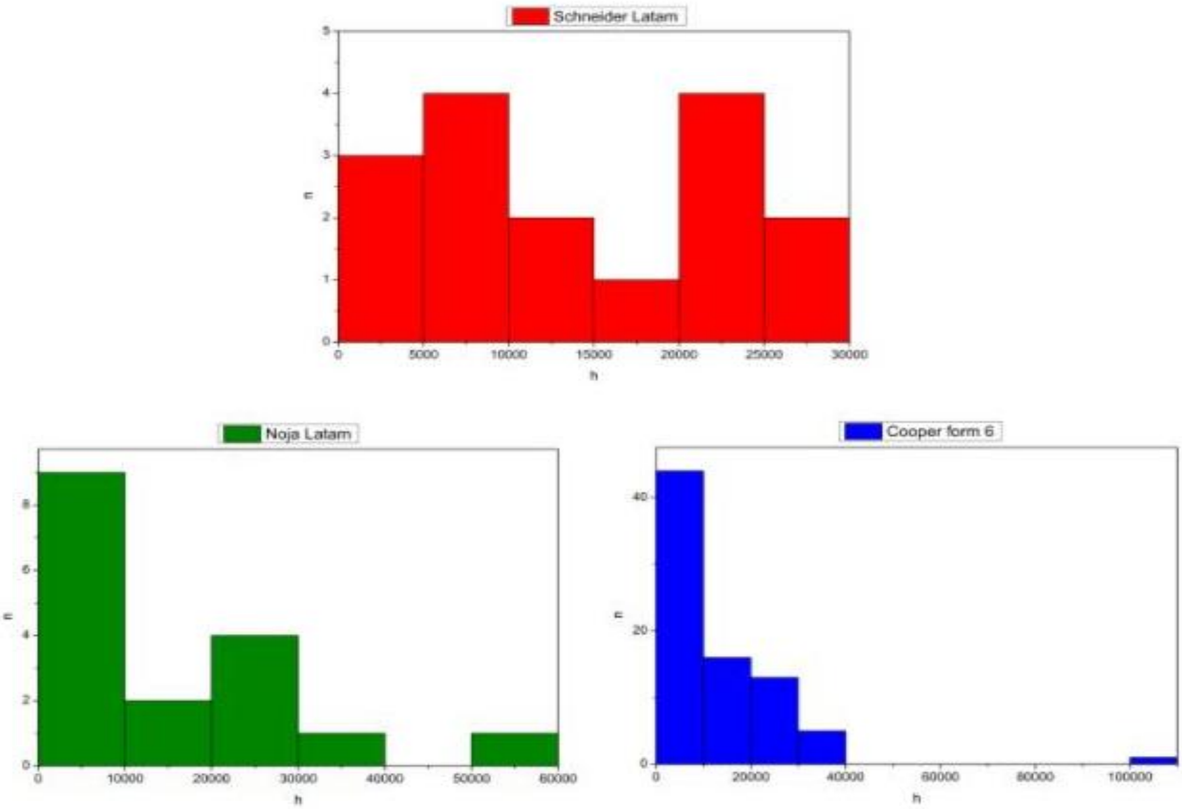
TABLE 1 – TIME-TO-FAILURE DATA IN HOURS PER RECLOSER MODEL

COOPER FORM6					NOJA LATAM	SCHNEIDER
24	1416	4560	14232	25608	51528	23712
96	1632	5040	14520	25968	6336	22344
120	1704	5472	14616	27552	21936	5736
288	1824	6240	14976	27744	25200	26136
312	2424	6240	15216	29688	26376	5472
456	2616	6672	15264	30072	32928	7176
480	2712	7656	16032	30384	14304	26688
504	2976	8856	16992	35856	21240	11016
576	3000	9024	17064	36096	15744	13032
696	3384	9144	20328	36384	7104	22536
792	3600	10032	20640	100800	2160	17232
840	3672	11256	21216		1392	2376
840	3840	12288	21576		288	21144
936	4032	12768	21936		4560	1152
960	4032	12840	23784		8496	5640
1104	4224	13776	23784		240	264
1176	4320	13992	24528		1176	

SOURCE: Authors (2022)

These times were organized in histograms that are shown in Figure 4. It is possible to observe that the number of failures in the Cooper Form6 model is much higher than the other two. This is due to the fact that they are installed in a greater number and, present more problems in relation to the others. In this case they were calculated considering the time the equipment has been in operation.

FIGURE 4 – TIME-TO-FAILURE HISTOGRAMS



SOURCE: Authors (2022)

Subsequently, the times to failure were introduced in the Proconf 2000© program, and the Chi-square (χ^2) and Kolmogorov-Smirnov (DN) adherence tests showed levels of significance for each of the four probability distribution models, as shown in the following Tables 2, 3 and 4 for the Cooper Form6, Noja Latam and Schneider Latam models, respectively.

TABLE 2 – TTF ADHESION TESTS FOR THE COOPER FORM6 MODEL

Distribution Type	χ^2 Value	Significance level - Chi-Square test	DN Value	Significance level - Kolmogorov-Smirnov test	DECISION
Exponential	35.57	0.01%	0.126	0.34%	REJECTED

Log-norm	20.85	0.19%	0.1263	0.33%	REJECTED
Gamma	5.93	43.07%	0.0738	21.39%	NOT REJECTED
Weibull	9.33	15.57%	0.0957	7.06%	NOT REJECTED

SOURCE: Authors (2022)

TABLE 3 – TTF ADHESION TESTS FOR THE NOJA LATAM MODEL

Distribution Type	**χ² Value**	**Significance level - Chi-Square test**	**DN Value**	**Significance level - Kolmogorov-Smirnov test**	**DECISION**
Exponential	0.95	39.36%	0.1528	23.19%	NOT REJECTED
Log-norm	3.88	11.66%	0.1655	14.14%	NOT REJECTED
Gamma	1.28	27.84%	0.1007	22.27%	NOT REJECTED
Weibull	1.41	26.26%	0.138	19.02%	NOT REJECTED

SOURCE: Authors (2022)

TABLE 4 – TTF ADHESION TESTS FOR THE SCHNEIDER LATAM MODEL

Distribution Type	**χ² Value**	**Significance level - Chi-Square test**	**DN Value**	**Significance level - Kolmogorov-Smirnov test**	**DECISION**
Exponential	2.99	81.35%	0.1728	20.83%	NOT REJECTED
Log-norm	4.3	11.66%	0.1891	14.14%	NOT REJECTED
Gamma	2.56	52.84%	0.1515	35.72%	NOT REJECTED
Weibull	2.67	14.36%	0.1787	17.59%	NOT REJECTED

SOURCE: Authors (2022)

According to the analysis of the data collected in the adherence tests, we could conclude that the distribution models that best fit are Gamma for the Cooper Form6 model, and Exponential for the two other models under study. As there are not many prior studies on this equipment for theoretical basis on their adherence to certain types of distributions, the lowest values of χ^2 and the lowest values of the Kolmogorov-Smirnov (DN) test were considered, which, consequently, will have the highest levels of significance.

The results of the adjustments are shown in Table 5, and the graphs related to the reliability functions are shown right after, in Figure 5.

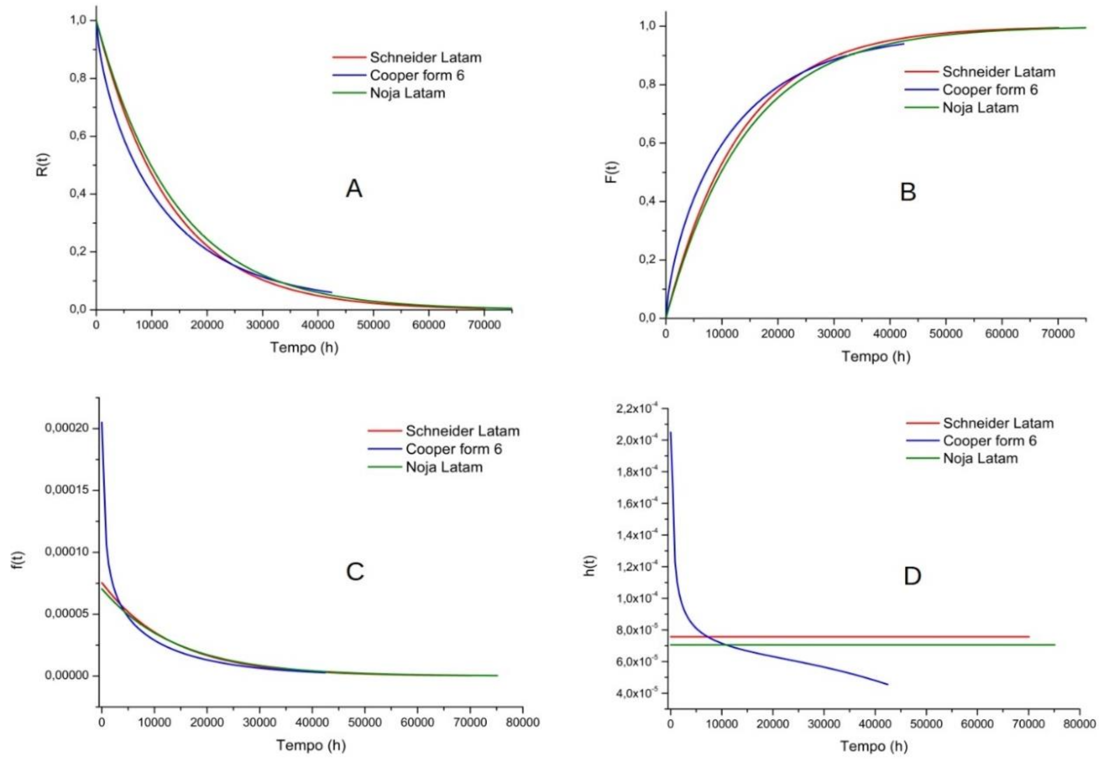
TABLE 5 – RESULTS OF THE ADJUSTMENTS

Parameter	**Results Noja Latam**	**Results Schneider Latam**	**Results Cooper F6**
t10	1493.69	1393.762	558.7294
t50	9826.707	9169.297	7095.998

Γ	-	-	0.6904
Λ	0.0000705	0.0000755	-
Confidence interval	95%	95%	95%
MTTF	14176.941	13228.5	12125.089
Location parameter	0	0	0

SOURCE: Authors (2022)

FIGURE 5 – REABILITY FUNCTION GRAPHS FOR RECLOSER MODELS



SOURCE: Authors (2022)

Then, the data of time until repair in the company's system, described in Table 6, were collected and applied to the Proconf 2000© program in order to adapt the data to a statistical distribution. Thus, we obtain the results of both the Chi-square (χ^2) and the Kolmogorov Smirnov adherence tests, as described in Tables 7, 8 and 9.

TABLE 6 – TIME TO REPAIR IN HOURS PER RECLOSER MODEL

COOPER FORM6	NOJA LATAM	SCHNEIDER LATAM

144	1656	360	1344	312	144	1272
456	144	288	672	432	768	168
600	288	504	1200	1392	120	552
240	312	816	888	696	360	360
480	216	576	456	648	360	384
528	456	576	576	432	1224	648
3960	4104	768	360	1008	384	264
1080	96	1248	1848		432	72
1968	120	384	1032		888	168
48	168	216	3432		312	264
264	2160	864	2232		168	240
3936	96	1224	1080		168	264
792	408	336	1176		240	840
144	144	144	648		96	1080
192	144	552	648		120	624
1176	144	144	744			
96	792	3456	216			

SOURCE: Authors (2022)

TABLE 7 – TTR ADHESION TESTS FOR THE COOPER FORM6 MODEL

Distribution Type	χ^2 Value	Significance level - Chi-Square test	DN Value	Significance level - Kolmogorov-Smirnov test	DECISION
EXPONENCIAL	11.4	12.22%	0.0993	6.83%	NOT REJECTED
LOG NORMAL	8.41	20.93%	0.0769	20.96%	NOT REJECTED
GAMMA	17.14	0.88%	0.0786	20.06%	REJECTED
WEIBULL	13.51	3.57%	0.0876	16.25%	REJECTED

SOURCE: Authors (2022)

TABLE 8 – TTR ADHESION TESTS FOR THE NOJA LATAM MODEL

Distribution Type	χ^2 Value	Significance level - Chi-Square test	DN Value	Significance level - Kolmogorov-Smirnov test	DECISION
EXPONENCIAL	0.43	80.51%	0.2204	4.83%	REJECTED
LOG NORMAL	0.66	41.60%	0.162	20.80%	NOT REJECTED
GAMMA	0.07	79.69%	0.1602	21.24%	NOT REJECTED
WEIBULL	0.12	73.27%	0.1587	21.63%	NOT REJECTED

SOURCE: Authors (2022)

TABLE 9 – TTR ADHESION TESTS FOR THE SCHNEIDER LATAM MODEL

Distribution Type	χ^2 Value	Significance level - Chi-Square test	DN Value	Significance level - Kolmogorov-Smirnov test	DECISION
EXPONENCIAL	0.94	62.49%	0.2286	3.38%	REJECTED
LOG NORMAL	0.63	42.69%	0.1379	26.94%	NOT REJECTED
GAMMA	0.94	33.29%	0.1506	23.64%	NOT REJECTED
WEIBULL	1.12	29.06%	0.1345	27.85%	NOT REJECTED

SOURCE: Authors (2022)

Based on the same criteria used to choose the distributions for the times to failure (TTF), it was decided to use for the times to repair (TTR): the Log-norm distribution for the Cooper Form6, and the Schneider Latam and Gamma distributions for the Noja Latam; with results of adjustments described below in Table 10.

TABLE 10 – RESULTS OF TTR ADJUSTMENTS

Parameter	Results Noja Latam	Results Schneider Latam	Results Cooper F6
t10	80.1974	140.1947	144.9493
t50	319.3374	368.9491	506.3602
Γ	1.5252	-	-
Data logarithm variance	-	0.5699	0.952
Confidence interval	95%	95%	95%
MTTR	403.2251	490.5979	815.2199
Location parameter	0	-	-
Mean of data logarithm	-	5.9107	6.2272

SOURCE: Authors (2022)

With the MTTF and MTTR values at hand, it was possible to determine the availability of equipment by model and to discover their reliability in the Meantime to Failure, through the Proconf 2000© program calculator. The results obtained are shown in Table 11.

TABLE 11 – AVAILABILITY AND RELIABILITY RESULTS

MODEL	DISPONIBILITY	RELIABILITY
SCHNEIDER LATAM	96%	36.79%
COOPER FORM6	94%	34.78%
NOJA LATAM	97%	36.79%

SOURCE: Authors (2022)

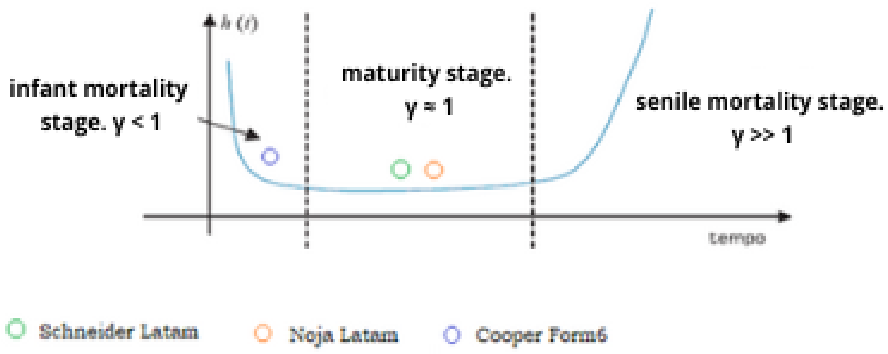
3.1 EQUIPAMENT MAINTENANCE STRATEGY

The bathtub curve generally represents the risk function h(t) throughout the life cycle of a recloser. In order to determine where the 3 models are in their life cycle, it is necessary to analyze the form factors of the risk functions h(t) based on the statistical distributions to which the data fit.

For the Cooper Form6 model, the form factor γ=0.6904 was obtained, which indicates that it is in the infant mortality stage, according to the probable position shown in Figure 5, in which the most indicated maintenance strategy is corrective (SELITTO, 2005). This type of maintenance is performed after the equipment fails, with the objective of putting it back in condition to perform its functions adequately (ABNT, 1994).

For the Schneider Latam and Noja Latam models, the form factor $\gamma = 1$ was obtained, which indicates that they are in the normal service life, according to the probable position shown in Figure 6, and need a predictive maintenance strategy (SELLITTO, 2005). This maintenance strategy aims to analyze the current conditions of the equipment, through sampling techniques or centralized supervision, to find faults in early stages and program their solutions, reducing the need for corrective and preventive maintenance.

FIGURE 6 – POSITIONS OF RECLOSERS MODELS ON THE BATHTUB CURVE



SOURCE: Adapted from SELLITTO (2005)

The reclosers studied in this article are serviced by the engineering and maintenance department of the company, which use the corrective maintenance strategy for all the models in question. After the equipment fails in a certain event, be it a disruption in the distribution of electricity in a specific region, or the equipment appearing as disconnected to the company's system (off-line), an "incident" notice is generated for problem verification.

This incident can be handled by partner companies or by the ENEL team itself. Normally, it passes through two ENEL sectors before being forwarded. The first sector checks remotely if the problem is due to equipment communication, GPRS, radio or satellite, and in cases when this situation is confirmed, it moves on to directly perform the equipment's maintenance. The second sector, in its turn, checks if the equipment responds to commands remotely in order to analyze the request origin, and if it is related to just a momentary failure or a persistent one. If the problem continues, the sector forwards the incident to a partner company or to its own team, according to the action that will be needed in the field, adequate personnel and available materials.

According to the schedule carried out by the maintenance managers, the team makes the visit, analyzes the cause of the failure, and tries to solve the problem. However, in many cases the problem is more complex than analyzed remotely, and sometimes it is necessary to replace a damaged part or carry out maintenance at a specialized location. Cases like these ask for a removal of parts of the equipment, for later replacement.

This process, in general, takes many days to be completed, and the equipment is inoperative during this period. Thus, temporary faults, that could be solved in a few minutes, end up becoming permanent.

As the different pieces of equipment are in different life stages in their life cycle, ideally, they should be treated by the maintenance team in different ways. For the Cooper Form6 model, the corrective strategy is justified, but for the others, the most suitable option is the predictive one. The motivations that guide this decision are shown in Table 12 below.

TABLE 12 – RELATIONSHIP BETWEEN LIFE CYCLE AND MAINTENANCE STRATEGIES

PHASES	STRATEGIES	CONSEQUENCES
infant mortality, failures of origin	emergency	delays or even prevents the end of infant mortality by not reinforcing the items that broke or not removing the root causes of failures.
	corrective	anticipates the end of infant mortality by reinforcing items that broke or removing the causes of source failures.
	predictive	monitors the failures in progress that could result in breakage, but these are very few at this stage (as breakages are mostly due to low resistance).
	preventive	perpetuates or even exacerbates infant mortality by exchanging exactly the strong items that have no source flaws.

normal service life, random failures	emergency	as it is limited to replacing broken components, it can make the equipment return to infant mortality if the replacements are not selected.
	corrective	is innocuous to catastrophic failures but can lower the expected failure threshold by eliminating failure modes that have passed the first stage.
	predictive	informs the beginning and monitors the progressive failure processes that will result in breaks and can predict increases in the probability of failure.
	preventive	returns to infant mortality by exchanging strong items which have no origin flaws and have not yet started to wear out.
wear out, progressive failures	emergency	allows breakages that are about to occur to take place at a lower internal cost than preventive strategy.
	corrective	it will only be useful if it is able to delay either the failure onset or the breakdown that will occur.
	predictive	monitors the progressive failure processes already started by predicting increases in the probability of breaks.
	preventive	prevents emergence by anticipating the exchange to the break that will occur, but at a higher internal cost than the emergency.

SOURCE: Adapted from SELLITTO (2005)

For the implementation of the predictive maintenance, it is necessary to have knowledge of predictive techniques, as well as their measurement equipment. In the case of line reclosers, there are three main tests to be developed: the insulation resistance, which analyzes the insulation capacity of the equipment bushings; the contact resistance, which checks the conductivity at the pole terminals; and the analysis of simulations and electrical commands, used to test equipment under field-like conditions.

However, most manufacturers discard the possibility of predictive maintenance claiming that the costs would be higher in relation to corrective maintenance. Thereby, another interesting proposal that can increase the reliability levels of these equipment, since all of them are currently below 50%, is the adoption of preventive maintenance, according to the time to failure estimated in reliability calculations, or in other words, the average time that an intervention will be necessary before failure occurs, as indicated in Table 13. This type of maintenance is carried out at pre-established time intervals, with the goal of reducing not only the possibility of failure, but also the equipment wear (ABNT, 1994).

TABLE 13 – TIME ESTIMATION X RELIABILITY

Model	**Confidence interval**	**Estimated time to failure (hours)**	**Approximate time to failure (months)**
Cooper Form6	50%	8567.12	12
	60%	5125.63	7
	70%	3003.37	4
	80%	1576.24	2
	90%	557.96	1
Noja Latam	50%	9826.72	14
	60%	7241.95	10
	70%	5056.57	7
	80%	3163.5	4
	90%	1493.69	2
Schneider Latam	50%	9169.34	13
	60%	6757.49	9
	70%	4718.3	7
	80%	2951.87	4
	90%	1393.77	2

SOURCE: Authors (2022)

Among the possibilities, carrying out the preventive maintenance program every 4 months seems consistent with the company’s needs and context, as it takes time to check the availability of teams, and to obtain the needed material, for example, as well as other internal aspects. In addition, this estimated time average will provide a very significant increase in equipment reliability: 70% for the Cooper Form6 model, and 80% for the other two.

CONCLUSION

Coming to our final considerations, the general objective of this work, which was to propose a maintenance strategy for the line reclosers of the Crajubar region (under the energy distribution company Enel Distribuição Ceará), was successfully achieved. Besides that, there are few studies on this subject, which makes this work quite relevant both for the literature and the company, since the permanence of these pieces of equipment in constant operation allows the improvement of the energy supply and its continuity.

Furthermore, all the specific objectives for this research were also met, as the results for each step of the development were successful and are detailed in section 3. Likewise, the methodology applied proved to be effective, and the results showed that the corrective maintenance, currently applied by the company, might not be the best option for it. It was proven that the corrective maintenance does not contribute to increasing equipment reliability. Instead, the preventive or predictive maintenance types should be the ones preferred, as they were proven to be capable of raising the level of equipment reliability by more than 20 percentage points, representing a considerable enough increase to justify their implementation.

Ultimately, the adoption of this type of maintenance can also contribute to the improvement of the DEC and FEC parameters, since it helps to reduce both the duration and the frequency of stops in energy supply due to equipment defects or bad performances. Finally, we highlight that having good indicators for these indices is essential, as they are inspected by ANEEL, and their irregularity leads to high fines. This, in addition to customer dissatisfaction relating to the service, and possible lawsuits for losses due to lack of supply makes the strategy for maintenance that we have proposed here of extreme relevance.

AUTHORS' CONTRIBUTIONS

- Mauro M. de Oliveira and Priscila M. F. de Oliveira conceptualized and designed the study. Priscila M. F. de Oliveira was responsible for extracting and processing the data, as well as writing the manuscript. Mauro M. de Oliveira revised the manuscript. All authors read and approved the final version of the article.

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