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RECLOSER OPTIMIZATION IN ELECTRICAL DISTRIBUTION SYSTEMS USING RELIABILITY ANALYSIS WITH HEURISTIC ALGORITHM

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Abstract

The main objective of this research is to improve the reliability of the electrical system under study by reducing both the frequency of outages (SAIFI) and the downtime of electrical service (SAIDI). These problems are largely affected by adverse weather conditions, vegetation growth, and bird contact. To carry out the analysis, the 5011 urban feeder of Canton La Troncal was selected, since it presents critical values in terms of reliability compared to other feeders. The proposed methodology involves a mathematical model of heuristic optimization based on the Particle Swarm Optimization (PSO) algorithm. Two scenarios are defined for the modeling: the first focuses on relocating the existing recloser and the second on analyzing the impact of adding additional protection equipment. These scenarios are validated and demonstrate their effectiveness, achieving an improvement of 29.05% in the first case and 70.93% in the second case within a real conventional distribution system.

Keywords: recloser, distribution system, reliability, particle swarm algorithm, SAIFI, SAIDI

1. INTRODUCTION

An electric distribution system (EDS) must be economically efficient and, at the same time, offer a high level of continuity and quality of service [1], [2]. One of the fundamental components in the structuring and operation of the network is the inclusion of reliability and quality of service in the long, medium, and short-term model [3].

Reliability is one of the fundamental characteristics required in a distribution system. This characteristic is closely linked to the ability of the distribution system to deliver electricity continuously to the users [4].

The design of the distribution system is characterized by a high degree of complexity [5], due to the diversity of components that make up the system, such as feeders, reclosers, circuit breakers, switches, and fuses. These elements operate together to ensure the efficient and safe distribution of service to the end customers. The cost-effectiveness of the system depends to a large extent on the proper location and quantity of these components [6].

SEDs often experience both temporary and permanent failures, which can result in brief or prolonged service interruptions [7], these are mainly lack of maintenance, aging of electrical infrastructures, susceptibility of the system to environmental conditions, lack of regular pruning, animal interference, electrical storms, malfunctioning of management equipment, accidents, overloads, and unforeseen events [8]. Since most power supply interruptions originate at the distribution network level, there has been a growing interest in improving the reliability of these networks in recent years [9]. For this reason, significant resources have been allocated to mitigate the negative impacts of faults by implementing automatic protection devices, such as circuit breakers or reclosers in the electrical network [10].

One of the fundamental operational tasks to improve reliability, even in fault situations, is the procedure of identification, isolation, and restoration of service after outages [11].

The importance of reliability in the planning and operation of distribution networks is so significant that it could constitute close to 50% of the total cost of the network [12], therefore, it is established that the reliability of the power supply is inversely related to the frequency of interruptions [13].

Within these systems, feeders generally operate in radial configuration due to economic reasons and simplified fault detection [14].

That is to say, the power flow has only one direction, it starts from the substation and goes to the different load points. The feeders are divided into

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two sections: main feeder and secondary feeder or branch, both the main feeder and the branches are delimited in sections separated by protection and sectioning devices [15].

On the one hand, this system has the limitation of being unreliable. In addition, clients connected to the edge of the network experience more outages than other clients [16]. According to statistics, about 80% of power outages are caused by the distribution network. Within this percentage, about 70% of customer service interruptions result from failures in the main distribution system. Therefore, it is very important to improve the quality of power supply to users and to plan the distribution network in a timely and accurate manner to understand the operational status of the network and detect potential problems at an early stage [17].

Another factor to consider is the wide geographical dispersion of the urban and rural distribution network, which causes different types of short-circuit faults [18].

Failures are not always predictable, since they involve so many different components and components, but when they do occur, the impact on the system is catastrophic, especially when the infrastructure is complete [19].

Lack of switchable equipment and a low level of automation in the post-treatment or repair stage of the fault are some of the reasons for service interruption [20]. As a result, many companies monitor their networks' reliability using performance metrics that reflect the time and frequency in which customers are out of service [21].

In [15] and [22] it was found that properly placed protective devices within the system can significantly improve operational reliability, offering practical and reliable solutions to address power outage problems due to the simple configuration of the system. A recloser is a circuit breaker that can close its contact after a period in which it has been open due to a fault. These protection devices are controlled by electronic relays, which provide them with a wide range of functionalities in terms of service restoration, protection, and communication [17]. In addition, these devices can solve temporary downstream faults, thus avoiding prolonged power supply interruptions [23].

In these cases, the required level of system reliability is established by the regulator. In Ecuador, electric power distribution companies are regulated by Arcernnr as described in Resolution 003/23 [24].

Consequently, it is proposed to use the Particle Swarm Optimization (PSO) algorithm to improve system reliability by reducing the service interruption time (SAIDI) and the frequency of interruptions (SAIFI).

The structure of this document is as follows: section 2 deals with the work related to the research, section 3 presents the formulation of the problem, section 4 focuses on the proposed methodology, section 5 analyzes the results obtained, and finally, section 6 presents the conclusions.

2. RELATED WORK

In [25] reliability is conceptualized as the process that serves to evaluate the safety and reliability of the electrical system, identifying the equipment that is susceptible to disturbances or failures, as well as the minimum operating requirements that the system can withstand. A thorough analysis can provide information on system performance under both normal and fault conditions. However, since an electrical system is composed of various devices, such as substations, transformers, lines, and protection equipment, which may fail, it is common to perform an analysis focused on those elements with a higher probability of failure, to identify the critical components of the system and take preventive or corrective measures to ensure reliable operation.

In [26], [27], [28] the authors define the Particle Swarm algorithm (PSO) as a randomized heuristic optimization algorithm based on swarm intelligence. This feature is fundamental in the exploration process of the algorithm, allowing the particles to move and search for new solutions in the search space.

In [7] a multi-objective approach based on the Non dominated Genetic Algorithm (NSGA-II) optimization model is used. The objective functions proposed focus on economic investment and service interruption time (SAIDI), and are applied to a test system called Roy Billinton (RBTS4). To evaluate the convergence of the functions using NSGA-II, the algorithm was run five times. Another way to evaluate the results would be by using a metric known as hypervolume (HV), which quantifies the space bounded by an estimated front and a reference point dominated by all the solutions that make up that front.

In [11] an innovative approach is presented to effectively address the problem of optimizing the installation of protection equipment in distribution systems, based on the Mixed Integer Linear Programming (MILP) mathematical model, guaranteeing a globally optimal solution. The effectiveness of the proposed approach is confirmed by performing multiple case studies and evaluations on the fourth node of the Roy Billinton Test System (RBTS4).

An analysis of the Bus-Injection to Branch Current (BIBC) method in its matrix approach is carried out in [13]. By placing a recloser on a specific section of the feeder, the interruption of the electrical service for all loads upstream of the feeder is avoided. In the BIBC matrix, this section is completed with "0", while loads downstream of the feeder are completed with "1". To develop the BIBC method, a distribution network with 13 nodes in radial configuration is used, which results in a considerable reduction in the fault rate and, therefore, in the frequency of interruptions, thus improving the reliability of the system.

In [15] the proposed methodology is based on a Mixed Integer Nonlinear Linear Programming (MINLP) mathematical model, an objective function is established and developed in GAMS software to model and solve optimization problems. The effectiveness of the proposed approach is evaluated both in a test system and in a conventional real distribution system, verifying the effectiveness and applicability of the proposed method in different scenarios.

In [17] a solution to the problem of the correct location of protection equipment in a radial system is proposed. A mathematical model based on the optimization technique known as Mixed Integer Non-Linear Programming (MINLP) with a 9-node test radial system, in 2 case studies, the results obtained in the tests support the feasibility of the proposed approach.

In [18] the authors propose a Multi-Objective Partition Swarm Optimization (MOPSO) algorithm to achieve the correct location of reclosers and sectionalizers to minimize the outage cost for customers and improve system reliability through optimal investment. This algorithm allows for determining both the number and the appropriate location of reclosers and sectionalizers to meet these objectives.

In [23] the MIP (Mixed Integer Programming) model is developed to achieve a global optimal solution. The objective of this model is to minimize the costs associated with equipment and system outages. The model takes into account both prolonged and momentary outages, in addition to considering the coordination between fuses and reclosers during temporary faults. To evaluate the performance of this methodology, it was applied to a test system and a distribution network under real conditions.

In [29] the genetic algorithm is used to discover the otimal receiver location based on the SAIFI index (outage frequency). The proposed algorithm considers both the availability of the network composed of 37 nodes and with different configurations such as radial and ring, as well as the power supply from multiple sources.

In [30] the Binary Particle Swarm Optimization (BPSO) model is proposed with a technical-economic approach within a radial system for urban and rural sectors together with simulations in DigSilent Power Factory software, for their study the authors consider two real feeders, obtaining satisfactory values for reliability metrics.

In [31] the mathematical model of multi-objective particle swarm optimization (MOPSO) is used, which was carried out in a network of 34 nodes, both in radial and meshed configuration. These results highlight the proper analysis of the number of automatic reclosers in the network. In addition, the improvements in reliability, cost, and system benefits of increasing the number of automatic equipment are presented.

In [32] the authors perform their methodology using graph theory and the matrix algebra method, following the criterion of mitigating the damage caused by a power outage. It is concluded that this technique is appropriate to effectively address the problems related to feeders with or without branches, which have a single power source.

In [33] a 34-node system is analyzed using the multi-objective particle swarm optimization model (MOPSO). This method allows determining the optimal quantity and locations of the automatic equipment in the network, the model in conjunction with the incorporation of distributed generators (DG) contributes to improving the reliability of the system.

In [34], the proposal to be developed is based on a multi-objective optimization algorithm for assigning switches in radially configured electrical distribution networks. This approach is based on evolutionary mechanisms. The proposed method is applicable to analyze and optimize the reconfiguration of distribution networks in cases of unilateral supply, potentially improving the reliability of the system through its indicators.

In [35], the reliability enhancement of the 13-node system proposed for the study is obtained through an optimization strategy using a Genetic Algorithm (GA). The objective is to maximize the net gain and minimize the energy losses. For this it was necessary to execute 104 iterations and 1000 generations, the optimal solution of the GA was achieved after 104 iterations. Concluding that 4 reclosers are required to achieve an improvement in the reliability of the system.

In [36] states that it is essential to have quantitative reliability indicators that allow us to understand the system's current state. By analyzing and understanding reliability indicators, we can identify areas where improvements can be made and implement appropriate strategies to ensure a reliable and high-quality electric service for users.

In [37] the Firefly algorithm is used; this methodology aims to minimize the costs associated with power outages caused by the recloser mitigation process. The optimal configuration of a recloser involves considering parameters such as fault area and fault type (transient or permanent), which can vary according to specific circumstances.

The reliability metrics of a distribution system are defined in [38] and [39] SAIFI: It is an indicator that determines the average frequency of power supply interruptions in a given period. It also provides information on the reliability of the electric system by quantifying the number of times that customers experience interruptions in the electric supply.

$$SAIFI = \frac{CI}{NT} \qquad (1)$$

$$SAIFI = \frac{\sum Number\ of\ customer\ interruptions}{Total\ number\ of\ customer\ served} = \frac{\sum N_i}{NT} \qquad (2)$$

Where,
Ni – Number of users without service.
NT – Number of connected users in the system.
CI – Clients without service.

SAIDI: A quantitative indicator used to measure the average duration of electricity supply interruptions in a given period, allowing to evaluation of the quality of electricity supply by determining how long on average customers remain without service during interruptions.

$$SAIDI = \frac{CMI}{NT} \qquad (3)$$

$$SAIDI = \frac{\sum Customer\ interruption\ duration}{Total\ number\ of\ customer\ served} = \frac{\sum N_i r_i}{NT} \qquad (4)$$

Where,
Ni – Number of users without service.
NT – Number of connected users in the system.
ri – Event restoration time (h).
CMI – Customer interruption time (h).

3. PROBLEM FORMULATION

The (EDS) of Canton La Troncal, province of Cañar, currently has a total of 5 primary feeders, which are responsible for meeting the demand of 21,927 customers, according to the commercial system data record of Empresa Eléctrica Regional Centro Sur (EERCS), as shown in Table 1.

Table 1. Feeder Data for La Troncal Canton

FEEDER	P. INSTALLED (KVA)	CUSTOMERS
5011	3.720,50	1.310
5012	13.917,50	8.234
5013	14.422,50	5.249
5014	9.100,00	3.081
5015	17.280,50	4.053
	58.441,00	**21.927**

Figure 1 shows the single line diagram of the La Troncal substation denominated S/50 with the feeders and their respective voltage levels, for medium voltage 69 KV and distribution 13.8 KV.

Table 2 shows the current status of the different feeders that make up the La Troncal Canton, together with the corresponding reliability metrics. Feeder 5011 stands out especially due to the critical values it presents in its reliability indicators.

3.1. Analysis case: Feeder 5011

In this study, a detailed analysis of Feeder 5011 is carried out, which is considered because its reliability metrics (SAIDI - SAIFI) show critical values about the other feeders.

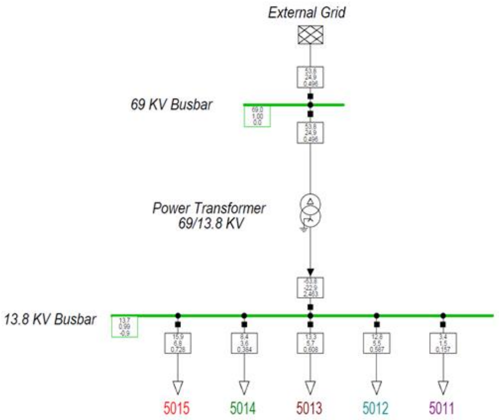

Fig. 1. Single line diagram of the feeders of the La Troncal Canton

Table 2. SAIDI – SAIFI (La Troncal Feeders)

FEEDER	SAIDI	SAIFI	SECTOR
5011	**6.67325368**	**3.19354544**	**Urban**
5012	1.16764338	0.99254269	Urban
5013	2.8512009	1.36793994	Urban
5014	2.6405105	0.78919120	Urban
5015	8.9799942	2.29297712	Urban-Rural

Table 3 presents a monthly breakdown of the historical metrics data, and the final total value is used to analyze the objective function.

Table 3. SAIDI – SAIFI Values (Feeders 5011)

MONTH	SAIDI	SAIFI
1	0.93688506	0.91954023
2	0.53790319	1.11382735
3	4.8590019	1.03432494
4	0.33866523	0.12585292
TOTAL	**6.67325368**	**3.19354544**

Table 4, and Figure 2 show the history of these indicators, the number of customers connected at each bus, and the single-line diagram of the feeder under study, which are very useful for understanding the behavior of the system.

3.2. Objective function

When determining the objective function, several factors must be considered, such as the frequency and duration of service interruptions, the network configuration, the time required to repair faults, the concentrated location of faults, the number of customers affected, and improvements in reliability metrics to minimize the objective function (O.F.) proposed.

Considering the improvement of the reliability indicators and taking into account equations (1) and (3), the following objective function to be minimized is established:

$$min\ f = SAIFI\ a_1 + SAIDI\ a_2 \qquad (5)$$

Table 4. Number of customers connected to each busbar of Feeder 5011

Link	Section	Customers	Protection	Link	Section	Customers	Protection
1	1 - 2	65	-	12	12 - 13	2	-
2	2 - 5	0	-	12	12 - 14	2	-
2	2 - 3	0	-	11	11 - 15	8	-
3	3 - 4	141	-	15	15 - 16	28	-
2	2 - 6	0	-	16	16 - 17	4	-
6	6 - 7	4	-	16	16 - 18	26	-
6	6 - 8	32	-	15	15 - 19	81	-
8	8 - 9	1	-	19	19 - 20	2	-
8	8 - 10	146	R	19	19 - 21	208	-
10	10 - 11	3	-	21	21 - 22	350	-
11	11 -12	0	-	21	21 - 23	207	-

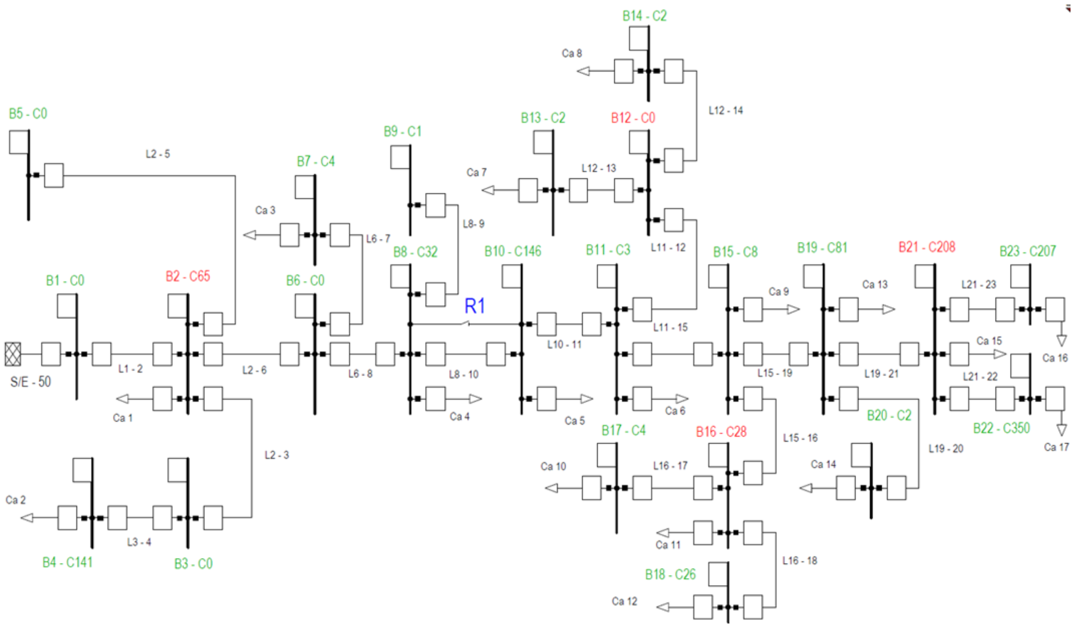

Fig. 2. Electrical distribution system Feeder 5011

Simplifying the values of equations (1) and (3), and considering NT (Total number of customers connected in the system) as a constant, based on the historical data collected by the distribution company, the following equations are obtained (5.1) and (5.2):

$$min\ f = \frac{\sum Ni}{NT}\, a_1 + \frac{\sum Ni\, ri}{NT}\, a_2 \qquad (5.1)$$

$$min\ f = \frac{1}{NT}\ [\ (\sum Ni\ a_1)\ +\ (\sum Ni\ ri\ a_2)\ ] \qquad (5.2)$$

Where,

ri – Failure restoration time (h)

a_1 y a_2 – Weighting coefficients.

3.3. Restrictions

The proposed model contemplates technical constraints, linked to the number of protection devices available for installation and the topology of the system. When considering installing a protection device, the corresponding variable is represented with a value of 1. For example, if it is desired to install a recloser on link i, this will be reflected in one of the constraints as $x_i = 1$. In addition, there is a limited number of reclosers available.

$$\sum_{i\in J}^{i} = J - M \qquad (6)$$

In equation (6), the term M represents the amount of equipment available to be placed in the circuit, while J denotes the total number of network nodes that make up the system. It should be noted that it is not feasible to install more than one piece of equipment per node in the main feeder. The existing protection equipment in the substation (S/E) is excluded, therefore, the recloser of the ES is not considered for a possible relocation.

$$x_{(S/E)}\ =\ 0$$

In the scenario where the existing protection equipment is relocated, it will be connected to one of the main nodes of the system and its value will be non-zero, as described in equation (7). Considering that the term $\boldsymbol{x_i}$ represents a possible candidate node for the installation of the protection equipment within the main feeder.

$$x_{i2}, x_{i6}, x_{i8}, x_{i10}, x_{i11}, x_{i15}, x_{i19}, x_{i21}, x_{i23} \neq 0 \tag{7}$$

Regarding the increase of protection devices, it is suggested to limit this number to a maximum of 2 reclosers in the whole system under analysis, as shown in equation (8).

$$x_{i1} + x_{i2} + x_{in} \leq 2 \tag{8}$$

Finally, to determine the weighting coefficients that minimize the O.F., the following is considered:

$$a_1 \neq a_2 \tag{9}$$

$$a_1, a_2 \in [0,1] \tag{10}$$

$$[a_1, a_2] \neq 0 \tag{11}$$

Equations (9), (10) and (11) state that the weighting values must be distinct from each other and different from 0, while the range of feasible solutions is from 0 to 1.

4. METHODS

The methodology proposed to improve the reliability of the system under study consists of two essential components: a failure simulator, used to determine the reliability indicators, and an optimizing algorithm to minimize the O.F.

The presentation of Algorithm 1 is broken down into three steps. In the first step, the essential data for the execution of the algorithm is entered, such as the matrix containing information on the number of customers on different links, the start and end points of each section, as well as the presence of protection equipment (reconnectors) in each of them. The location of this equipment is entered manually and randomly for different analysis scenarios. In addition, the link matrix is incorporated, which records the number of customers affected and the time elapsed for service restoration.

Algorithm 1: Calculation of reliability indicators

```
Step 1:  Input data
         Distribution System Parameters
         Link, Spans, Customers per link, Protection Equipment
         Matrix of link with highest recurrence of failures

Step 2:  Calculation of reliability indicators for each link
          for i = 1:  Number of links
          $\frac{\sum Ni}{NT}$ ; Frequency of interruptions
          $\frac{\sum Ni\, ri}{NT}$ ; Duration of interruptions
          end

Step 3:  Return results
         Frequency and duration of interruptions
```

The second step involves the calculation of reliability indicators. Finally, in the last step, the results obtained within the framework of the developed algorithm are returned.

After obtaining the data in the first algorithm, we proceed to a subsequent phase, which involves updating the information entered in Algorithm 2. This process is carried out in several stages to ensure the accuracy and efficiency of the analysis. In the first phase, the general data of the distribution system is entered, thus establishing a solid basis for the optimization process.

In the second phase, the values obtained in Algorithm 1, which represent the reliability indicators, are incorporated interactively employing on-screen messages. This integration ensures consistency and continuity of information throughout the optimization process.

Algorithm 2: PSO to improve system reliability

```
Step 1:  Input data
         Distribution System Parameters
Step 2:  Reliability values
          Parameters obtained in Algorithm 1
          Frequency of interruptions
          Duration of interruptions
Step 3:  Minimization of O.F.
          O.F.:
          $min\, f = \frac{1}{NT}\,[\,(\sum Ni\, a_1) + (\sum Ni\, ri\, a_2)\,]$
          Subject to:
          $\sum_{i \in J}^{i} = J - M$
          $x_{i2}, x_{i6}, x_{i8}, x_{i10}, x_{i11}, x_{i15}, x_{i19}, x_{i21}, x_{i23} \neq 0$ ;
relocation
          $x_{i1} + x_{i2} + x_{in} \leq 2$ ; increase
Step 4:  O.F. analysis with weighting coefficients
          for i = 1:  iterations
            if  $a_1$ ~= $a_2$
               if  $a_1$ >= 0 && $a_1$ <= 1 && $a_2$ >= 0 && $a_2$ <= 1
                  if  $a_1$ ~= 0 && $a_2$ ~= 0
                   break
                     fitness = [$a_1$ , $a_2$]
                  end
               end
            end
Step 5:   Show results
```

The third phase involves the introduction of the objective function (O.F.) to be minimized.

The fourth phase deals with an exhaustive analysis of the weighting values required for the objective function to meet the established optimization criteria. At this point, the algorithm adjusts the positions and velocities of the particles, which symbolize the weighting values in this context. The continuous evaluation of the objective function concerning these updated particles guides the process toward the convergence of the proposed function.

This iterative procedure is repeated until the convergence of the proposed function is reached, thus ensuring that optimal results are obtained. As a culminating phase of the optimization algorithm, the results obtained from the objective function are presented, providing a clear and detailed view of the efficiency of the optimization process implemented.

5. ANALYSIS OF RESULTS

This section analyzes the ability of the approach proposed in section 4 to identify improvements in the reliability indicators by optimizing the objective function (FO), therefore, in this research, we propose to analyze two scenarios in Feeder 5011.

Scenario 1: Relocation of existing recloser

As a possible solution to reduce the frequency and duration of interruptions in the electrical service, it is proposed to relocate the current protection equipment located on link 8 and to install it on link 10. Based on the results presented in Table 5, it is concluded that the reliability of the system is improved by 29.05% compared to the initial values of the analyzed feeder.

Table 5. SAIDI and SAIFI values for scenario 1

STATUS	SAIDI	SAIFI	a_1	a_2	O.F.
Initial	6.6732	3.1935	0.7293	0.0449	5.0104
Relocation	**6.4176**	**3.1092**	**0.1312**	**0.8724**	**3.5545**

Figure 3 provides a detailed analysis of how outage frequency and duration are influenced by relocating the existing protection equipment. A decrease in values is observed when the protection equipment is installed on link 10, specifically on span (10-11), compared to the other links.

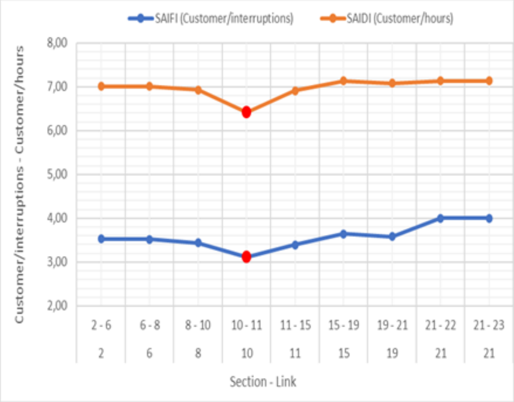

Fig. 3. Reliability indicators per link

Figure 4 illustrates the comparison between the initial values of the SAIDI and SAIFI reliability indicators and the optimal values obtained in scenario 1 of these measurements.

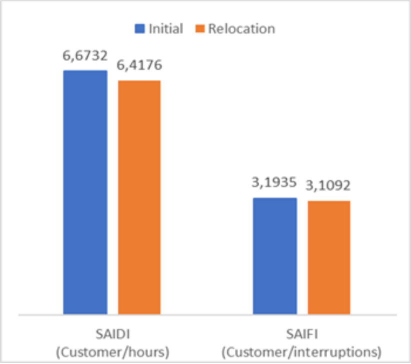

Fig. 4. Comparison of Initial vs Optimal reliability indicators (scenario 1)

Scenario 2: Increase of reclosers

The main focus in this situation is to analyze the effect of adding a piece of additional protection equipment to the system, for which two reclosers are counted and the behavior of the objective function (FO) is observed, verifying the percentage of improvements in terms of reliability. The results are presented in Table 6, showing that the system experiences that the system experiences an improvement of 70.93% compared to the nominal values of the system.

Table 6. SAIDI and SAIFI values for scenario 2

STATUS	SAIDI	SAIFI	a_1	a_2	O.F.
Initial	6.6732	3.1935	0.7293	0.0449	5.0104
Increase	**4.9114**	**1.8221**	**0.2367**	**0.1612**	**1.4564**

Figure 5 shows an exhaustive analysis of how the frequency and duration of interruptions are affected by adding additional equipment to the system, which was installed on links 10 and 19, particularly on sections (10-11) and (19-21), showing a reduction in the values compared to the other links.

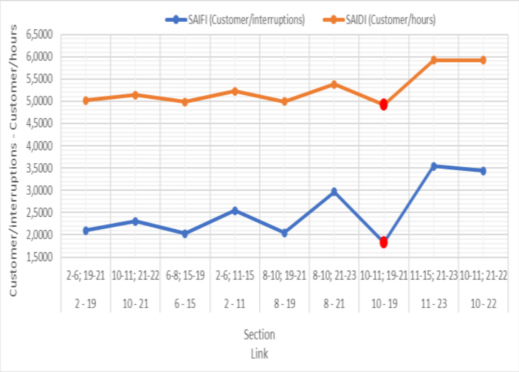

Fig. 5. Reliability indicators per link

Figure 6 shows the comparison between the initial values of the SAIDI and SAIFI reliability indicators and the optimal values obtained in scenario 2 of these measurements.

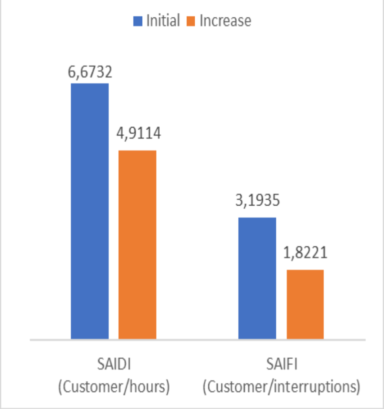

Fig. 6. Comparison of Initial vs Optimal reliability indicators (scenario 2)

Finally, Table 7 shows the optimal values for the reliability indicators comparing the analysis in the different scenarios (initial - relocation - increase).

Figure 7 shows a comparison between the initial reliability indicators, SAIDI and SAIFI, compared to the Relocation and Augmentation scenarios.

Table 7. Value of the indicators in the different scenarios

STATUS	SAIDI	SAIFI	a_1	a_2	O.F.
Initial	6.6732	3.1935	0.7293	0.0449	5.0104
Relocation	**6.4176**	**3.1092**	**0.1312**	**0.8724**	**3.5545**
Increase	**4.9114**	**1.8221**	**0.2367**	**0.1612**	**1.4564**

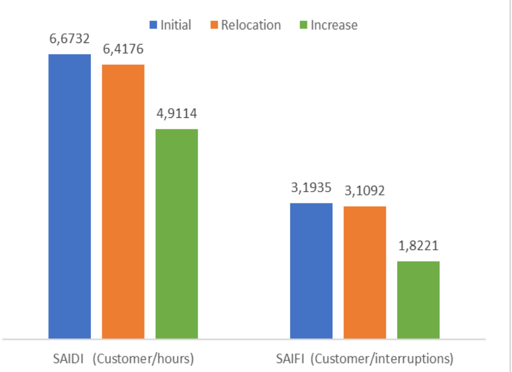

Fig. 7. Comparison of Reliability Indicators Initial vs Relocation vs Increase

6. DISCUSSION

In this study, the methodology proposed by several authors has been adopted, which contemplates the exploration of several scenarios or cases to analyze the behavior of reliability indicators in different situations, obtaining the best results in each one of them. On the other hand, several works present a technical-economic approach that demonstrates how viable the correct location of reclosers in a distribution network considering the history of failures as described in this research.

In this paper, a comprehensive analysis is carried out on the improvement of reliability in a radial electric system by determining the optimal location of the protection equipment, known as reclosers. The Particle Swarm Optimization (PSO) algorithm is used to simulate two real situations: the relocation and the increase of reclosers. Significant values are achieved in both scenarios, resulting in an improvement of 2.63% in SAIFI and 3.83% in SAIDI for the first scenario. In the second scenario, an improvement of 42.94% in SAIFI and 26.40% in SAIDI is observed.

The study [1] addresses the reduction of outage duration, the number of customers affected by faults, and the associated economic costs in a real medium voltage power distribution network in Portugal. The researchers applied the optimal normally closed (NC) circuit breaker placement strategy.

Several real scenarios were explored, with emphasis on the first and second. In the first scenario, a fault was simulated without the presence of protection equipment, which allowed determining the costs of the system under such circumstances. In contrast, the second scenario involved the simulation of the same fault, but with the installation of 4 NC disconnectors. The latter scenario resulted in a significant improvement in both reliability and system costs, reducing them by 16%.

The research [3] used an optimization model based on the Genetic Algorithm (GA) to improve reliability indicators in a radial power system with Distributed Generation (DG). The results obtained were highly satisfactory in the proposed scenarios, showing a remarkable increase of 77% in the SAIFI parameter and 78% in SAIDI from the beginning to the end of the study.

On the contrary, the study mentioned in [13] introduces the Bus-Injunction Bypass Current (BIBC) method as a strategy to increase the reliability indicators (SAIFI - SAIDI) in an electrical distribution system with 13 busbars and radial topology. By implementing this method, a 22% improvement in both SAIFI and SAIDI is achieved by installing a recloser on link number 4.

The study [15], uses the Mixed Integer Nonlinear Linear Programming (MINLP) mathematical model to improve reliability indices. This approach is applied in a real radial power system in Colombia, which consists of 14 nodes. A test system is carried out to calculate the SAIFI value, although this data is not included in the attached Table 8. In addition, a real conventional system is used to determine the SAIDI values in different scenarios, such as relocation and increase of protection equipment. In the case of relocation, an approximate improvement of 29.70 % in SAIDI is observed, while for the increase of reclosers, the SAIDI value is 50.66 %.

Table 8 presents the values of the reliability indicators provided by various authors using different algorithms. It is crucial to note that each of these studies was carried out with specific parameters and considerations adapted to the particular objectives of each investigation.

Table 8. Value of the indicators in the different algorithms

		RELOCATION		INCREASE	
ALGOR	LINK	SAIFI SADI	NUM RECLOSER	SAIFI SAIDI	NUM RECLOSER
PSO	10	2.63% 3.83%	1	42.94% 24.40%	2
AG	12	-	-	77.04% 78.04%	2
BBIC	13	-	-	22% 22%	4
MINLP	14	0 29.70%	1	0 50.66%	3

These results reflect the positive impact of the strategic relocation of protection equipment on system reliability. By optimizing the location of these devices, we were able to reduce both the frequency and duration of power outages, which directly contributed to improved reliability metrics.

7. CONCLUSIONS

Taking into account the different work methodologies mentioned above, the two study scenarios were: the relocation and the increase of protection equipment in the electrical system.

In the first study scenario, a percentage improvement was achieved in the reliability indicators SAIFI (2.63%) and SAIDI (3.83%), with the initial values.

In the second study scenario, the effect of the increase of protection equipment in the system was evaluated. A significant increase in the optimization percentage was observed, with improvements in the SAIFI (42.94%) and SAIDI (26.40%) indexes, compared to the initial values.

These research results support the importance of strategic relocation and increased protection equipment to improve the reliability of the distribution system. The observed improvements in reliability indicators in both the first and second study scenarios indicate the potential of these strategies to reduce outages.

The proposed methodology is highly adaptable since it can be implemented in different distribution systems, regardless of their size, as long as the system has a radial topology, although it is true that the optimization branch provides mathematical models with greater convergence in their functions, this will depend largely on the different scenarios to be simulated, technical characteristics and network topology.

The results obtained in this research lay the foundations for future studies that go deeper into the technical and economic aspects, evaluating the viability and feasibility for the distribution companies, the increase in the number of protection equipment (reclosers) in the electrical system, as a main element within the technical field, it is important to take into account an adequate coordination of the additional protection equipment present in the feeders, such as disconnectors, reclosers and circuit breakers in the substations.

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