

SAIDI and SAIFI indicators for the control of feeder A4502 of the Concepción transformer electrical substation

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ABSTRACT

This study evaluated the reliability of feeder A4502 of the Concepción substation (Huancayo, Peru) through the analysis of system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) indicators. The 46-year-old infrastructure presented 805 structural deficiencies (59%), with a predominance of corrosion in iron poles. Automatic recloser devices were implemented at strategic points, based on the fact that 67% of the 73 interruptions in 2021 were transient faults. Post-intervention results (2024) showed significant improvements: SAIDI was reduced from 9.87 to 7.39 hours (25%), nearing the regulatory limit of 7 hours; SAIFI decreased from 4.29 to 2.71 events (37%), falling within the limit of 4. Pearson correlation analysis confirmed a statistically significant relationship between structural deficiencies and the indicators ($r = 0.62$ SAIDI, $r = 0.58$ SAIFI, $p < 0.05$). The integrated approach—diagnosis of deficiencies + automation with reclosers—proved to be technically viable and economically justifiable, also allowing for the meeting of new energy demands (240 kVA available). The results constitute a replicable model for other aging Latin American networks, validating the viability of regulatory compliance without prohibitive investments.

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1. INTRODUCTION

Electrical distribution in densely populated urban areas faces growing challenges related to service continuity and quality. In feeder A4502 of the Concepción transformer electrical substation (SET-C), these limitations manifest as frequent and long-duration interruptions, affecting the reliability of the electrical supply [1]–[3]. Although indicators such as system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) allow for evaluating service continuity, their effective application is restricted by a lack of specific diagnoses, infrastructure obsolescence, and low levels of automation. In expanding distribution networks, reliability depends on adequate fault management, infrastructure modernization, and strict compliance with regulatory standards. Previous studies have demonstrated the efficacy of automation, advanced monitoring, and operational reconfiguration to improve system efficiency; however, their full implementation in intermediate urban zones remains limited by budget restrictions, the age of structures, and increased load density, which demands solutions adapted to real scenarios like that of feeder A4502 [4]–[6].

Despite these advances, a significant gap persists in the literature: there are no studies that simultaneously integrate the temporal analysis of SAIDI and SAIFI indicators, the detailed physical evaluation of structural deficiencies in the field, and regulatory verification based on Supervising Agency for Investment in Energy and Mining (OSINERGMIN) procedures. The majority of research focuses on simulations or theoretical models without directly correlating infrastructure degradation with continuity indicators or proposing operational methodologies applicable to real feeders [7]–[11]. Likewise, recent investigations have shown the contribution of advanced metering systems, geographic information system (GIS) methodologies, and energy management tools; however, these solutions still face limitations due to insufficient diagnostic equipment, structural degradation, and vulnerability to climatic events, factors present in the case of feeder A4502 [11]. Therefore, a comprehensive methodological approach is required that articulates technical analysis, physical diagnosis, and regulatory compliance.

In this context, the present study focuses on a comprehensive analysis of the SAIDI and SAIFI indicators for the feeder, adopting a quantitative approach aligned with internationally recognized reliability assessment methodologies for distribution systems [12]. The use of this framework ensures that the calculation of performance indices and the classification of events follow the most recent technical criteria in the industry. Furthermore, the SAIDI and SAIFI indicators are approached as strategic tools for feeder management through the correlation between their values and the structural deficiencies identified in the field. This approach allows for prioritizing interventions, optimizing resource allocation, and strengthening end-user satisfaction, backed by recent studies highlighting the relevance of these indicators for improving supply reliability in rural areas [13]–[16].

2. METHOD

The research was conducted on feeder A4502 of the SET-C, part of the electrocentro medium-voltage distribution system in Huancayo, Peru. The feeder operates between 13.2 kV and 13.8 kV and consists of 1,362 structures, primarily wooden poles installed in 1978. This aging infrastructure, now exceeding 40 years of service, is directly linked to increased technical deficiencies and prolonged interruptions, a problem consistent with international studies on deteriorating distribution networks [17]. Furthermore, urban growth has led to non-compliance with maximum permissible limits (minimum safety distance DMS), affecting feeder stability [18]. According to international benchmarking and local regulatory frameworks, these deficiencies directly impact service quality and can result in significant financial penalties and compensatory sanctions [17]–[19]. The methodological design was quantitative, descriptive-correlational, and non-experimental, based on the systematic collection of historical information and direct field observation without intervention in the system. Data acquisition was structured in three phases: i) review of interruption records for the year 2021 in accordance with procedure OSINERGMIN No. 074-2004-OV/CD [17]; ii) elaboration of the physical inventory using the “feeder A4502 structure sheet” according to resolution OSINERGMIN No. 011-2004-OV/CD [18]; and iii) field inspections following the quality standards and efficiency metrics for electrical supply recognized in the comparative literature of the Peruvian sector [19].

2.1. Service interruption records

For the analysis of service reliability corresponding to the year 2021, the SAIDI and SAIFI indicators were calculated using (1) and (2). Where: t_i = duration of each interruption (in hours), n_i = number of users affected by each interruption, N = total number of users served by the electrical system. SAIDI measures the average duration of interruptions experienced by users, while SAIFI measures the average frequency of such interruptions [20], [21].

$$SAIDI = \frac{\sum_{i=1}^n (t_i \times n_i)}{N} \quad (1)$$

$$SAIFI = \frac{\sum_{i=1}^n n_i}{N} \quad (2)$$

The data comes from the official interruption registry system of electrocentro, prepared according to procedure OSINERGMIN No. 074-2004-OS/CD, which constitutes the mandatory format for measuring continuity indicators in all distribution systems in the country. Each record includes date and time, duration, number of affected users, type of interruption, and associated structure code. The company does not have supervisory control and data acquisition (SCADA) or smart metering implemented comprehensively in this area, so the data comes exclusively from manual operational records. All events were validated with the monthly reports sent to the regulator, ensuring consistency and traceability. For the calculation, only sustained interruptions (duration >3 minutes) were considered, in accordance with the technical standard for the quality of electrical services (NTCSE) and procedure OSINERGMIN No. 074-2004-OS/CD. Momentary

interruptions (≤ 3 minutes) were excluded, as they are not part of the official calculation. It was assumed that η_i corresponds to the total users downstream of the fault point, and N was treated as constant because the annual variation of the user registry is less than 2%. The calculation was automated using an algorithm developed in Python, which iterates over each record applying the aforementioned equations. The procedure was implemented using data structures that allow validating duplicates, overlaps, and incomplete values, ensuring reproducibility and regulatory consistency. The variables used were duration of each interruption event (duration in hours), number of users impacted by each event (Number_of_affected_users), and total number of users connected to the feeder (Total_number_of_users). The dataset included 73 interruptions, all validated according to OSINERGMIN No. 074-2004-OS/CD. Feeder A4502 operates at 13.2 kV, has a mixed two-phase–three-phase configuration, uses AAC 120 mm² conductor, cut-out equipment, and one recloser; all structures have grounding, and lightning arresters are counted at distribution electrical substation (SED) and assemblies. In total, it serves 1,400 users, a value used as parameter N . Figure 1 shows the algorithm that allows automating the SAIDI and SAIFI calculations, reducing manual errors, and ensuring the repeatability of the procedure according to applicable regulatory standards. Table 1 summarizes the initial values of the indicators as well as the NTCSE tolerance for the year 2021.

```

X Calculation of SAIDI and SAIFI v
1 # Calculation of SAIDI and SAIFI in Python
2
3 # Input data
4 durations = [9.5, 9.2, 10.2, 9.5] # List of interruption durations in hours
5 affected_users = [150, 200, 100, 250] # List of number of users affected per event
6 total_number_of_users = 1000 # Total number of users connected to the feeder
7
8 # Initialize variables
9 total_duration = 0
10 total_interruptions = 0
11
12 # Processing each interruption
13 for i in range(len(durations)):
14     total_duration += durations[i] * affected_users[i]
15     total_interruptions += affected_users[i]
16
17 # Calculating SAIDI and SAIFI
18 SAIDI = total_duration / total_number_of_users
19 SAIFI = total_interruptions / total_number_of_users
20
21 # Output results
22 print(f"SAIDI = {SAIDI:.2f} hours")
23 print(f"SAIFI = {SAIFI:.2f} interruptions per user")
24

```

Figure 1. Python code to evaluate the SAIDI and SAIFI indicators

Table 1. Results of the SAIDI and SAIFI indicators

Indicators	Unit	Indicators 2021	Tolerance NTCSE
SAIDI	Hours	9.87	7
SAIFI	Number of times	4.29	4

Note: overview of categories for maneuvers without notice, preventive maintenance, and transient failures (2021)

2.2. Physical inventory of the network

To identify critical points, a physical inventory of the network was developed. Table 2 summarizes the technical deficiencies classified by incidence code. 805 deficiencies were identified in 1,362 structures. The highest incidence corresponds to code 1002 (metal poles perforated or cracked), followed by code 1034 (DMS non-compliance) and 1074 (guy wires without insulator or grounding). These results agree with studies indicating that crossarm deterioration, weathering, and fungal attacks compromise the structural rigidity of components [22], [23].

Table 2. Technical deficiencies by eststructure

Structure	Incidence code	Quantity
In an iron post with holes or cracks in the base	1002	701
Post that does not comply with the DMS regarding construction	1034	79
Retained without a traction insulator or without a grounding connection	1074	25
Total		805

Note: 1362 MT structures examined (by 2024)

2.3. Field inspections

During field inspections, forms based on the guidelines of the technical standard for quality of electrical services (NTCSE, 1997) and OSINERGMIN resolutions were used. The forms served to systematically record the physical state of each structure (pole, guy wire, and insulators), measure DMS using laser rangefinders with ±1 cm precision, and document observed incidences according to official codes. Figure 2 shows an example of a structure with an inclination deficiency according to code 1008.

“ANALYSIS OF THE TECHNICAL DEFICIENCIES TO OPTIMIZE THE A4502 FEEDER OF THE SET-C DISTRIBUTION SYSTEM – ELECTROCENTRO – HUANCAYO”

OBSERVATION FORM

Company: Electrocentro S.A.		Electrical system: Mantaro Valley 2	
Junin Department	Huancayo Province	Hualhuas District	
Standard for Applying: N°011-2004-OS/CD.			

Typical deficiencies	Code
Deteriorated pole with visible and corroded hardware; wood-rotted pole; metal pole with holes or base cracks.	1002
Pole tilted more than 15°	1008
Pole violates DMS regarding building	1034
Guy wire without insulator or without grounding connection	1074

Structure to be Inspected

1. Photo of the Structure



2. Characteristics

Pole Type:	Wood
Height:	13 m
Load:	---
Owner:	ELCTO
Year:	---
Code:	1008
N° Phases:	3
Assembly Type:	Angular
Insulator Type:	Porcelain

3. UTM Coordinates

X (East): 471220.8
Y (North): 8675845.4

4. GPS Code: Mn19

Observations:

Deficiencies found in the structures include: deteriorated posts inclined more than 5°

Inspector Signature: _____
Full Name: _____

Engineer in charge Signature: _____
Full Name: _____
N° CIP: _____

Figure 2. Structure that shows a tilt deficiency greater than 15°

The root cause analysis showed that structural deterioration due to age (1978) is the main cause of interruptions, which is related to the high proportion of transient faults (67%). Non-compliance with DMS and deficiencies in guy wires were also observed, all with a direct impact on service continuity. For data normalization, interruptions were classified into planned (preventive maintenance and expansion/reinforcement) and unplanned (transient faults, maneuvers without notice, third parties), according to NTCSE and OSINERGMIN No. 074-2004-OS/CD. Table 3 presents the percentage incidence by category (73 validated events).

Table 3. Incidents for each type of interruption

No	Description	Quantity	Incidence (%)
1	For an unannounced maneuver, short	6	8
2	Preventive maintenance	13	18
3	Transient failures	49	67
4	Others and/or third parties	4	5
5	Interruption due to expansion and reinforcement	1	1
Total		73	100

Note: feeder A45022 (al 2021)

Based on the diagnostic results, the strategic installation of automatic reclosers in critical branches was implemented to mitigate both the duration and frequency of power outages. Two recloser devices were installed at disconnectors serving the highest density of users (codes E19431784 and E15562621), prioritizing locations that maximize the improvement of reliability indices. Additionally, critical structures were targeted for reinforcement or replacement based on the physical inventory findings. Reclosers function as automatic protection devices that enable service restoration during transient faults, thereby minimizing maintenance crew deployments and significantly enhancing supply continuity [24], [25]. Subsequently, the indicators were recalculated for 2024, presented in Table 4.

Table 4. Results of the SAIDI and SAIFI indicators

Indicators	Unit	Indicators 2024	Tolerance NTCSE
SAIDI	Hours	7.39	7
SAIFI	Number of times	2.71	4

3. RESULTS AND DISCUSSION

The comprehensive analysis of feeder A4502 allowed for the identification and correction of technical and structural deficiencies affecting service continuity, through a quantitative approach based on historical data, physical inventories, and regulatory criteria. Following the implementation of automatic reclosers and the correction of critical structures, the SAIDI and SAIFI indicators showed significant improvement: in 2024, 7.39 hours were obtained for SAIDI and 2.71 interruptions for SAIFI, values that comply with the limits established by the NTCSE (7 hours and 4 interruptions, respectively). Table 5 summarizes this evolution, showing a sustained reduction compared to 2021. These results coincide with studies like [26] and [27], which evidence comparable improvements after network automation, with SAIDI reductions exceeding 30% and relevant decreases in SAIFI.

Table 5. Optimization of SAIDI and SAIFI indicators

Indicators	Unit	Indicators 2021	Indicators 2024	Tolerance NTCSE
SAIDI	Hours	9.87	7.39	7
SAIFI	Number of times	4.29	2.71	4

Figure 3 compares the trend between 2021 and 2024, showing that both indicators converge towards the NTCSE normative value, while Figure 4 evidences the percentage improvement associated with the implemented interventions (A-4). Although SAIDI still slightly exceeds the regulatory threshold, the trend confirms the efficacy of using reclosers and structural reinforcement, aligning with the literature on automation and reliability.

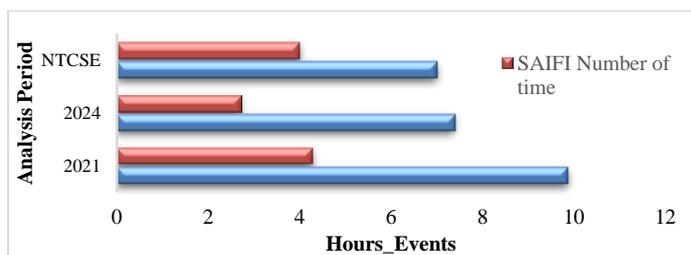


Figure 3. Comparison of SAIDI and SAIFI indicators and the NTCSE reference

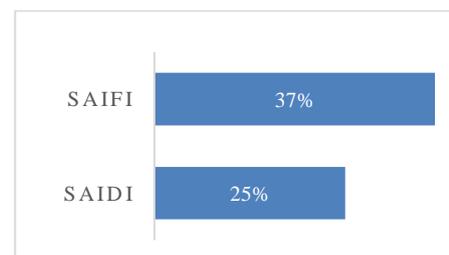


Figure 4. Percentage improvement of the SAIDI and SAIFI indicators

The values obtained were also compared with the IEEE Std 1366 standard, which proposes typical ranges of 1-10 hours for SAIDI and 1-6 interruptions for SAIFI in systems with mixed loads [6]. After optimization, feeder A4502 is situated within these margins, which backs the technical validity of the improvement process (C-1). The absence of disaggregated data by feeder for the entire company did not allow for an internal comparison with electrocentro, but the results are considered adequate under international reference.

To deepen the understanding of the effect of technical deficiencies, a Pearson correlation analysis was applied [20], [21]. Table 6 shows moderate and statistically significant correlation coefficients

($r = 0.62$ for SAIDI and $r = 0.58$ for SAIFI; $p < 0.05$), confirming that structure deterioration—such as corroded poles, DMS deficiencies, or guy wires without grounding—increases both the duration and frequency of interruptions. This empirical evidence validates the central assumption of the study regarding the direct impact of infrastructure on supply continuity.

Table 6. Results of Pearson correlation analysis

Variables correlated	Pearson's r	p-value	Statistical significance ($\alpha = 0.05$)
Number of technical deficiencies vs. SAIDI	0.62	0.014	Significant
Number of technical deficiencies vs. SAIFI	0.58	0.021	Significant

From these results, relevant operational implications are derived; sectionalizing via reclosers reduces the number of users affected per fault, automation decreases switching times, prioritizing predictive maintenance on deteriorated structures reduces transient faults, and load analysis suggests the need for periodic balancing between feeders to avoid overloads and improve operational stability. The technical design of the improved feeder, summarized in Table 7, incorporates 120 and 70 mm² AAAC conductors, polymeric insulators, ZnO lightning arresters, and 800 A automatic reclosers, ensuring greater reliability in the face of new load demands. This design is consistent with literature emphasizing modernization and planning strategies for distribution networks [28], [29].

Table 7. Technical characteristics of the optimization of the A4502 feeder

Description	Characteristic's
Nominal system voltage	13.2 kV
Configuration	3Ø y 2Ø
Maximum service voltage	13.8 kV
Aerial phase conductors	120 y 70 mm ² , type AAAC
Underground phase conductors	120 y 70 mm ² , type N2XSY
Self-supporting phase conductors	120 y 70 mm ² , type NA2XSA2Y-S
Structures	CAC Poles 15/400
Frame	L-type cross-arm (75×75×6×2,690 mm) with lateral cross-bracing
Grounding	16mm Ø×2.40m long machined copper weld rod
Insulators	Polymeric pin-type, rated 24 kV 24 kV suspension-type polymeric insulator
Protective equipment	10 KA Zn0 polymeric lightning rod, class 1, 12kV C 27 kV 800 an automatic recloser Cut-out fuse disconnecter 27 kV, 100 A, 150kV BIL

Note: main materials for the design of primary networks

From a regulatory and economic perspective, the impact of technical deficiencies was evaluated according to procedures OSINERGMIN 011-2004-OS/CD and 074-2004-OS/CD, with associated fines amounting to USD 59.60 and USD 535.09, respectively [17]–[19]. These penalties are strictly aligned with the efficiency and quality benchmarks established for the electrical service in comparison with international standards [19]. Table 8 summarizes the criteria and procedures applied.

Finally, the technical, regulatory, and operational implications of the study are reflected in the need to strengthen structural maintenance plans, improve field monitoring, and adopt automation solutions replicable in other feeders. As noted by [30]–[32], incorporating social and environmental variables will allow future research to address sustainability more completely. Furthermore, improving DMS and continuity indicators also has direct repercussions on end-user satisfaction, a key aspect in contexts of greater competition in the electricity sector [33], reinforcing electrocentro role in providing a reliable and safe service.

Table 8. Summary of procedures for application

Criteria	Procedure	Application
SAIDI/SAIFI	No. 074-2004-OV/CD	Reporting service outages in protection equipment
DMS	No. 011-2004-OV/CD	Medium voltage feeder structure sheet A4502

Note: to apply the procedure, each criterion must be considered

4. CONCLUSION

The study demonstrated that the identification and correction of 805 technical deficiencies of feeder A4502 allowed for optimizing service continuity, reducing SAIDI from 9.87 to 7.39 hours and SAIFI from 4.29 to 2.71 interruptions per user between 2021 and 2024, achieving compliance with the reference values

established by the NTCSE. These results validate the hypotheses posed, evidencing that structural diagnosis and the adjustment of DMS, together with the incorporation of protection equipment and automation, strengthen operational reliability, reduce exposure to regulatory sanctions, and allow for meeting new load demands in growing areas. Likewise, it is confirmed that infrastructure degradation is directly associated with decreased reliability, reaffirming the importance of integrating field diagnosis with maintenance planning. This approach offers a replicable model for other distribution networks with similar characteristics and suggests that future research incorporate real-time monitoring technologies and the integration of renewable energies to advance towards more resilient and sustainable systems.

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AUTHOR CONTRIBUTIONS STATEMENT

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Jorge Augusto Sánchez Ayte		✓	✓	✓		✓		✓		✓	✓	✓	✓	
William Joel Baygorrea Vega	✓		✓	✓	✓	✓	✓		✓		✓			
Richard Flores-Caceres	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**ditng

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

INFORMED CONSENT

The authors declare that the study did not involve human participants.

ETHICAL APPROVAL

The authors declare that the study did not involve human or animal participants.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [JASA], upon reasonable request.

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