IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

IMPROVING SYSTEM RELIABILITY THROUGH PLACEMENT OF AUTOMATIC CIRCUIT RECLOSERS: THE CASE OF CENTRAL PANGASINAN ELECTRIC COOPERATIVE SAN CARLOS 20MVA SUBSTATION

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Abstract: This research evaluated the system reliability metrics and performance indicators, quantify distribution feeder performance in terms of feeder downtime, availability, interruption rate, and overall system reliability. Monte Carlo Simulation was utilized to compare the reliability metrics before and after the implementation of automatic circuit reclosers to provide practical insights for CENPELCO, and to enhance system reliability through strategic placement of automatic circuit reclosers.

The results have shown a notable reduction in the duration of sustained interruptions, leading to a corresponding increase in availability. This reduction in interruptions translates to improved feeder reliability which has a direct positive impact on the overall availability of the substation.

The most significant outcome of the study is the substantial decrease in downtime, approximately 2,204.602 minutes, which can be attributed to the integration of Automatic Circuit Reclosers (ACRs). This device emerges as the preferred protective devices for swiftly re-energizing circuits after clearing transient faults, to minimize downtime.

Moreover, the reliability forecast based on the results indicates that reliability has remained relatively constant resulting in the conversion of the saved SAIFI into MAIFI, which effectively constrains the overall number of interruptions. The study also substantiates that it is possible to maintain reliability while simultaneously increasing availability through the utilization of ACRs. This dual achievement not only enhances system performance but also contributes to increased customer satisfaction due to the reduction in downtime. Furthermore, this study provides validation for NEA's decision to exclude CAIDI and MAIFI from its reliability assessment mechanism. The observed pattern indicates that as SAIFI values are converted into MAIFI, there is a corresponding proportional reduction in SAIDI. Consequently, CAIDI, which measures restoration time, remains relatively constant. It is recommended to perform fault analysis and protection coordination before actual installation of ACRs considering actual ratings of all components of the feeders.

***Index Terms* – Reliability, Substation, Monte Carlo, System.**

I. BACKGROUND OF THE STUDY

The concept of reliability pertains to a system's conscientious and adequate performance. In power systems, reliability plays a crucial role by addressing power supply matters like service interruptions and power quality issues. According to Crismundo (2021), referencing a Department of Energy Executive, the energy sector has received orders from the energy department to guarantee ample power supply and reserves to prevent yellow and red alerts. These alerts indicate power supply conditions: yellow refers to a limited reserve based on supply and demand and red suggests either zero ancillary service or a generation deficiency (Parnala, 2022). The Energy Regulatory Commission (ERC) oversees Distribution Utilities (DUs) in the Philippines. Based on the EPIRA of 2001, ERC is mandated to ensure reliable and efficient service by all Electric Cooperatives (ECs). Electric cooperatives, serving as both providers and owners, cater to their member-consumers simultaneously (NEA, 2019).

Improving the system reliability of a substation distribution network is essential to ensure consistent and uninterrupted power supply to consumers. There are several methods to enhance the reliability of such networks, along with various assessment methods to evaluate their effectiveness. To name a few of these methods are adding redundancy and backup systems which can be done by adding to critical components such as transformers, circuit breakers and communication system to ensure power availability during outages; implementing load shedding or load shifting strategies to help balance the network during peak demand periods and prevent overloading; integrating renewable energy sources like solar panels and wind turbines at the distribution level to add redundancy and reduce the reliance on centralized power generation; using advanced analytics and machine learning algorithms to predict equipment failures and identify potential fault locations and to improve response times and reduce downtime; and implementing automatic switching devices such as automatic circuit reclosers (ACRs) to isolate faulty sections of the network and restore power to unaffected areas more quickly.

The main office of the Central Pangasinan Electric Cooperative (CENPELCO), Incorporated, is in San Carlos City within the Pangasinan Province. The cooperative aspires to become a globally recognized and self-reliant regulator in the electric power industry. Its primary aim is to impartially advocate for and safeguard the interests of consumers and various stakeholders. This commitment is geared towards fostering lasting advantages that contribute to consistent economic advancement and an elevated quality of life for all.

To uphold this mission, CENPELCO diligently focuses on sustaining the reliability of its system. This involves regular evaluations of its performance and adherence to the guidelines set forth in the National Electrification Administration (NEA) Memorandum No. 2021-35 (NEA, 2021). CENPELCO encompasses 16 subareas and 13 substations, with its central office situated at the San Carlos City Area Office. One of its noteworthy installations is the San Carlos 20MVA Substation, emblematic of its commitment to robust power infrastructure.

Despite the passing remarks regarding the system reliability indices established by the NEA, CENPELCO San Carlos Main Office continues to grapple with an influx of complaints and grievances from customers via social media platforms due to recurrent power interruptions. This issue can be attributed to the oversight of the Customer Average Interruption Reliability Index (CAIDI) when evaluating system reliability. The CAIDI serves as a metric for the average duration of interruptions and plays a crucial role in measuring utility response time and power restoration. Therefore, it becomes imperative to delve into the CAIDI of the distribution system, as it directly correlates with consumers' perceptions.

Enhancing the CAIDI necessitates a reduction in the duration of interruptions achieved by converting sustained interruptions into shorter, momentary outages through the integration of Automatic Circuit Reclosers (ACRs). As a result, a decrease in CAIDI not only indicates an improvement in System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI), but it also results in an increase in the Momentary Average Interruption Frequency Index (MAIFI).

This scenario highlights the fact that although CENPELCO receives satisfactory remarks regarding power reliability indices, these figures are perceived differently by electricity consumers in terms of customer service. Further advancements in refining the CAIDI of the CENPELCO San Carlos 20MVA Substation would help bridge the gap between power reliability indices and the perceived quality of customer service.

The availability of a reliable and cost-effective power supply is pivotal for a country's economic growth and overall development. Thus, the impact of distribution system reliability on customers carries an even more profound significance than the aspect of cost. Addressing the duration of power interruptions can be achieved by implementing protective measures for overhead feeders through Automatic Circuit Reclosers (ACRs). These reclosers can be strategically placed at various points along the feeder, including the distribution substation, the initial overhead primary pole, and other locations in the feeder and lateral sections.

The primary function of these ACRs is to isolate swiftly a specific segment of the feeder when faults or overload conditions occur, thereby limiting the number of customers affected by the power interruption. Additionally, they possess the capability to restore power automatically in scenarios involving temporary or momentary faults. The ACR can execute a sequence of open and reclose operations if the fault persists beyond the initial clearing attempt. A typical reclosing sequence often involves two instantaneous trips to eliminate temporary faults, followed by two delayed openings, and ultimately an opening and lockout for persistent or permanent faults between the recloser and sectionalizing fuses.

Implementing Automatic Circuit Reclosers stands to yield substantial benefits for the CENPELCO San Carlos 20MVA Substation, resulting in both significant time savings and operational cost reduction. This is due to their capacity to restore power seamlessly for momentary faults, effectively preventing the escalation of transient issues into sustained faults. As a result, the System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are notably diminished. Furthermore, in cases where power interruptions necessitate the involvement of line maintenance crews, reclosers play a pivotal role by minimizing the affected area and aiding crews in rapidly identifying the faulty section, expediting the restoration process.

The CENPELCO San Carlos 20MVA Substation’s feeder downtime, availability, interruption rate, and reliability can be estimated by collecting data on the frequency of interruptions and the durations of interruptions. The Monte Carlo analysis method can simulate the interruption and restoration history by using the statistical distributions of the feeders. Statistics are then collected, and reliability indices are estimated using statistical inference (Singh, 1995). The use of Monte Carlo analysis is widespread in the field of reliability engineering and can be performed using Microsoft Excel (Alexander, 2003).

Applying Monte Carlo Simulation (MCS) to run multiple scenarios and analyze the possible reliability of CENPELCO San Carlos 20MVA Substation requires the statistical distribution of downtime and interruption rate of individual feeders to model the system behavior over time. The simulation results can then be used to visualize the degree of attained reliability upon placing ACRs in the grid. MCS uses statistics to model mathematically the actual process and estimate the possible outcomes; it requires the generation of random events in a spreadsheet. This generation is repeated many times, and the simulation is treated as a series of real experiments (Matsuoka, 2015).

Statement of Objectives

In view of the abovementioned context, the principal goal of this study was to evaluate the performance of CENPELCO's power distribution system. It identified key areas of concern and potential vulnerabilities. It investigated the proposed improvement in the system reliability through the strategic placement and utilization of automatic circuit reclosers. The research aimed to achieve the following specific objectives:

1. Determine the following distribution parameters:
(a) feeder downtime
(b) availability
(c) interruption rate
(d) overall system reliability

2. Evaluate the existing system reliability metrics and performance indicators specifically:
(a) The System Average Interruption Frequency Index (SAIFI)
(b) The System Average Interruption Duration Index (SAIDI),
(c) The Customer Average Interruption Duration Index (CAIDI), and
(d) The Momentary Average Interruption Frequency Index (MAIFI).

3. Compare the reliability metrics before and after the implementation of automatic circuit reclosers.

4. Provide practical insights for CENPELCO to enhance system reliability through the strategic placement of automatic circuit reclosers.

Significance of the Study

In these modern times, every household is heavily reliant on continuous and reliable power supply. The vulnerability of distribution systems to interruptions demands innovative solutions. This study presents a comprehensive analysis of power system reliability through the deployment of Automatic Circuit Reclosers (ACRs) within the CENPELCO San Carlos 20MVA Substation Distribution System. By utilizing Monte Carlo Simulation techniques, this research aimed to profoundly impact the power distribution landscape.

Beyond its immediate impact, this research sets a benchmark for reliability assessment and improvement for the entirety of CENPELCO's 12 substations. By extrapolating the findings and insights garnered from the San Carlos 20MVA Substation Distribution System to a broader context, the study offers a blueprint for enhancing power distribution networks' resilience. The lessons learned and methodologies established herein hold the potential to revolutionize not only CENPELCO's distribution strategies but also those of similar utilities grappling with reliability concerns.

Furthermore, the significance of this study extends to the improvement of critical reliability indices – System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). As power interruptions pose substantial economic and social ramifications, refining these indices through innovative approaches such as ACR deployment can positively influence the consumer’s overall quality of life.

Scope and Delimitation

Primarily, this study was to assess quantitively the influence of additional ACRs on power system reliability. Through rigorous simulation, the reduction in the duration of power interruption was scrutinized, ultimately translating into minimized downtime for end-users. By strategically identifying key installation locations for ACRs, the potential for large-scale, long-duration power interruptions can be mitigated, ensuring that any disruptions remain as momentarily as possible. The scope of the study encompassed the following key aspects:

The study specifically concentrated on the distribution system associated with the CENPELCO San Carlos 20MVA Substation. The analysis considered the unique characteristics, interruption history, and network of this specific substation's distribution system. Through the application of Monte Carlo Simulation, the study assessed how the strategic installation of ACRs influences the distribution system's reliability. Different scenarios involving the placement of ACRs were simulated and evaluated to quantify the reduction in the duration of power interruptions.

The primary intervention considered in this study is the installation of ACRs. These devices play a crucial role in mitigating power interruptions by automatically restoring power after momentary faults. The study explored how the placement of ACRs optimally across the distribution system can lead to improved reliability. Furthermore, it specifically focused on reducing the duration of power interruptions. By installing ACRs at strategic points, the aim was to minimize the time consumers experience power outages, thereby enhancing the overall quality of service.

The primary scope of the study was to enhance the reliability of the distribution system. This involved a comprehensive analysis of various reliability indicators, such as SAIFI and SAIDI, under different ACR installation scenarios. However, the study's scope was limited to the technical evaluation and reliability enhancement within the CENPELCO San Carlos 20MVA Substation's distribution system. While the findings and methodologies may have broader implications for similar systems, the study's direct applicability extends to this specific substation.

Literature Review and Related Studies

Ford and Bailey (2022) highlighted that electric cooperatives originated in the United States to extend power and telephone services to rural regions. Their inception played a significant role in driving global rural electrification, including in the Philippines (Lo and Kibalya, 2023), as pointed out by Paredes and Loveridge (2018). Their contribution, while modest, positively impacted wage growth for rural communities, transcending mere service provision. Electric cooperatives operate as privately-owned distribution utilities, unique in that their consumers are also members and owners.

In the Philippines, Presidential Decree Number 269 initiated the establishment of electric cooperatives with the goal of achieving nationwide electrification, a mission continued through the Republic Act No. 10531 amendment in 2012 (PD 269, 1973). While the registration of electric cooperatives was transferred to the Cooperative Development Authority (CDA) via R.A. 6939 (1990), the National Electrification Administration (NEA) maintained supervision and regulation over CDA-registered electric cooperatives. Guided by its vision and mandate, NEA strives to be a proactive driver of sustainable rural development, partnering with competitive electric cooperatives and empowered consumers. Its mandate includes empowering electric cooperatives to adapt to industry restructuring stemming from the government's electrification program (R.A. 10531, 2012).

In 2019, NEA issued a memorandum to electric cooperatives (ECs) that aimed to establish a comprehensive and objective system of evaluating the EC performance in terms of financial, institutional, and technical aspects, as well as their compliance with NEA rules and regulations. It also contained the criteria and scoring system for each performance indicator, as well as the classification and incentives based on their overall performance rating (NEA, 2019). Although the memorandum had a noble purpose, the Philippine Rural Electric Cooperatives Association (PHILRECA), though a resolution, urged the NEA to review and upgrade the existing policy/guidelines on EC overall performance assessment (PHILRECA, 2020). In response, NEA circulated memorandum number 2021-035 dated 6 Augst 2021. The memo proposes a policy on EC categorization based on their overall performance assessment. The policy aims to measure the ECs' financial, institutional, and technical performance, thus determining their credit worthiness, level of development, service reliability and protection, empowerment, and satisfaction of their member-consumer-owners (MCOs).

The Central Pangasinan Electric Cooperative, Inc. (CENPELCO) is a beneficiary of PD 269, headquartered in San Carlos City within Pangasinan. Its operational scope encompasses 16 subareas, and 13 substations. Aligned with NEA's vision, CENPELCO aims to be a globally respected and autonomous regulator within the electric power industry, promoting consumer and stakeholder interests. The objective is to deliver enduring benefits that foster sustainable economic growth and an improved quality of life. This study was undertaken to explore means of enhancing CENPELCO's electrical system reliability and providing its member-consumers-owners with uninterrupted electricity supply.

The modern era has ushered in distinct social and work behaviors, intensifying the demand for a continuous electricity supply. This heightened expectation necessitates electric distribution utilities to deliver uninterrupted services. However, as pointed out by Billinton and Allan (2003), achieving 100% power system reliability remains a challenge. Nevertheless, advancements can be made through diverse technical and management measures (ZMS, 2021) to address service interruptions and power supply losses (Medjoudj, Beiaft and Aissani, 2017).

Improving the system reliability of a substation distribution network is essential to ensure consistent and uninterrupted power supply to consumers. To name some, installation of animal guards, sectionalizing fuse, lightning arresters, regular line patrolling, vegetation control, adding redundancy to critical components such as transformers, UPS, emergency generators or batteries can minimize the impact of failures (Cyansi, 2019) and can ensure power availability during outages (Brown, 2021). Similarly, a distributed generation can also add redundancy and reduce the reliance on centralized power generation. According to Spalding et al. (2016) a fault location, isolation, and service restoration (FLISR) system are becoming more necessary in power distribution networks for automatic restoration of power.

To balance supply and demand by mitigating service interruptions and power supply losses, CENPELCO seeks to evaluate its network's reliability indices, particularly focusing on the San Carlos 20 MVA substation. This analysis aims to pinpoint optimal locations for the deployment of automatic circuit reclosers (ACRs), primarily aimed at minimizing the impact of substantial and prolonged power interruptions.

Over ninety percent of transmission line faults stem from single-line to ground short circuit with over eighty percent of these faults being transient or momentary in nature, encompassing single-line to ground, double-line to ground, line-to-line, and three-phase faults (Iman Nilofer, 2018). Hence, enhancing power supply reliability holds paramount importance, achievable by swiftly re-energizing the faulted section or feeder once transient faults are resolved. This can be facilitated by automatic reclosing circuit breakers on transmission lines.

Studies of overhead distribution systems have consistently shown that the strategic deployment of automatic switching equipment and protective devices can significantly reduce system interruptions (Amohadi and Fouhi-Firuzabad, 2019). Automatic circuit reclosers, also referred to as auto-reclosers, are essential components designed to identify and interrupt transient faults originating from various sources such as lightning strikes, surges, or vegetation intrusion into exposed distribution lines. These reclosers essentially function as circuit breakers equipped with protective elements composed of current and voltage sensors and a safeguard relay that promptly restores service after momentary disruptions (EATON, 2016). Research by Mehdi et al. (2021) into existing auto-reclosing schemes for AC, DC, and hybrid (AC/DC) power transmission lines underscores that auto-reclosing is a favored protection mechanism for preventing faults and extending energy service life by neutralizing temporary faults.

When assessing the system reliability of electric cooperatives, key indices include the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI). These measures would unveil CENPELCO's capacity to meet the electricity demands of its members-consumers-owners. SAIFI is calculated by dividing the total number of sustained customer power interruptions within a specified period by the total number of customers served during the same period.

As per NEA regulations, on-grid electric cooperatives (ECs) are allotted a SAIFI of 25 interruptions per consumer per year, and off-grid cooperatives adhere to a standard SAIFI of 30 interruptions. SAIDI, conversely, quantifies the total duration of sustained customer power interruptions within a given timeframe divided by the total number of customers served during that period. For on-grid ECs, the standard SAIDI is 2,700 minutes per consumer per year, and for off-grid ECs, it stands at 3,375 minutes per consumer (NEA Memorandum No. 2021-35, 2021). Notably, in the second quarter of 2022, CENPELCO registered SAIFI and SAIDI values of 5.57 interruptions and 270.43 minutes, respectively, aligning with the stipulated standards (NEA, 2022). However, considering the recurrent occurrence of severe storms in the region, the researcher deemed it vital to undertake substantial enhancements to CENPELCO's distribution system. This enhancement hopes to curtail power outages in the EC's service areas to momentary durations, given that the financial and well-being aspects of end-users are heavily reliant on the reliability of electricity supply.

Conceptual Framework

Outlined in Figure 1 is the comprehensive blueprint of the study. It encompasses the collection of interruption data essential for quantifying reliability indices. The findings of this endeavor not only gauge the extent of protection required to avert network damage but also guide future decisions regarding infrastructure enhancements.

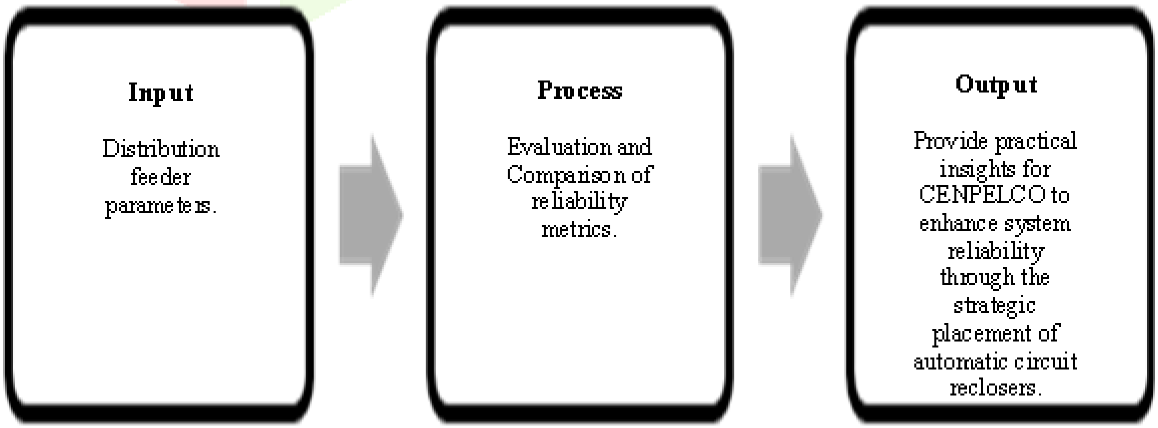


Figure 1. Research Paradigm

CEPELCO's ability to ensure a consistent and satisfactory power supply for its members-consumers-owners relies on a multitude of critical factors. These are depicted in the above figure . These encompass protection, security, and reliability. Protection involves swiftly minimizing faults and disruptions, while security pertains to the power system's agility in responding to disturbances and quickly restoring service. Reliability, in contrast, encapsulates the power system's consistent functionality over a designated timeframe.

To uphold its competitive stance within the regulatory framework of NEA, CENPELCO must devise a strategy for enhancing reliability. This strategy is pivotal in achieving the dual objectives of satisfying members-consumers-owners and adhering to governmental regulations. In this pursuit, it should formulate benchmarks for reliability by delving into indicators like SAIDI and SAIFI for reliability analysis. This approach encompasses evaluating outage duration, frequency of outages, system availability, and response time. The outcomes of these assessments would substantiate the proposed deployment of automatic circuit reclosers at strategically identified points within CEPELCO's network.

Definition of Terms

ACR – Automatic Circuit Recloser. It is a self-contained device with the necessary intelligence to sense overcurrent to time and interrupt fault currents and to re-energize the line by reclosing automatically.

CAIDI – Customer Average Interruption Frequency Index. It indicates the average time required to restore the service.

CENPELCO – Central Pangasinan Electric Cooperative. It is an electric distribution utility registered to the National Electrification Administration.

Distribution Utility – It refers to any electric cooperative, private corporation, government-owned utility, or existing local government m unit which has an exclusive franchise area to operate a distribution system.

MCS - Monte Carlo Simulation. This is a powerful statistical tool for modelling system reliability.

MVA – Megavolt-Ampere. It is the unit used for the apparent power in an electrical circuit.

NEA – National Electrification Administration. It ismandated to pursue the total electrification of the country through the Electric Cooperatives.

Power Interruption – It is a short - or long-term state of electric power loss in a given area or section of a power grid.

Reliability – It is the extent to which supply is always available.

SAIDI – It indicates the total duration of interruption an average customer experiences.

SAIFI – This indicates how often an average customer is subjected to sustained interruption.

Substation – This transforms voltage from high to low, or the reverse, or perform any of several other important functions.

II. METHODS AND SOURCES OF DATA

RESEARCH DESIGN

This researcher employed the sequential explanatory mixed-methods design in conducting this study. The choice for selecting this research methodology was due to its flexibility and adaptability to be applied across various research disciplines such as bringing together quantitative and qualitative approaches and methodologies (Othman et al., 2020) to provide a holistic view of the impact of ACR placement on improving system reliability. Finally, comparing the quantitative reliability indices obtained with the qualitative insights gathered to identify patterns, discrepancies, and correlations between the quantitative findings and qualitative findings could be done in this method.

Research Locale

The study was conducted at the CENPELCO San Carlos 20 MVA Substation.

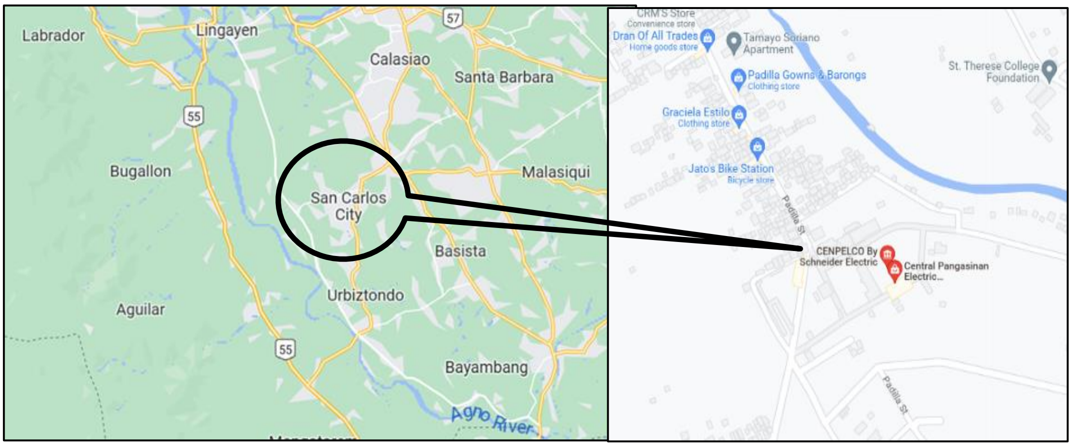


Figure 2. San Carlos 20 MVA Substation Location Map

Data Gathering Instruments and Procedure

Quantitative Technique: Survey and Data Collection

This involved a conduct of survey to gather quantitative data related to power outage frequency, duration, and other relevant reliability indices from historical records and operational data of CENPELCO.

A quantitative analysis of the collected data was undertaken to calculate reliability indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), and Momentary Average Interruption Frequency Index (MAIFI).

The data gathered are the five-year power interruption report and single line diagram for the existing distribution system of San Carlos Substation. From the power interruption data report, SAIFI, SAIDI, MAIFI, and CAIDI for feeder interruptions due to the tripping action of switchgears during faults, scheduled interruptions, National Grid Corporation of the Philippines (NGCP), and fortuitous events were computed, classified, and tabulated per year. Afterwards, the reliability indices for each feeder were computed and tabulated per year for a span of five years. Then, using Monte Carlo Simulation to analyze the mean and standard deviation of interruption rate, availability, and downtime of each feeder; estimated initial reliability parameters after one thousand (1,000) simulations were obtained.

The System Average Interruption Frequency Index (SAIFI), which is about the average frequency of sustained interruptions per customer over a predefined area (Okorie, Patrick & Page, & Aliyu, U & Jimoh, B & Sani, S. (2015) has the formula:

$$SAIFI = \frac{Total\ number\ of\ customer's\ interruption\ (CI)}{Total\ number\ of\ customers\ served\ (C)}$$

$$SAIFI = \frac{\Sigma(\mathrm{Ni})}{\mathrm{Nt}}\ \text{per year}$$

where,
Ni = Total number of customers interrupted
Nt = Total number of customers served.

The System Average Interruption Duration Index (SAIDI) or the customer minutes of interruption or customer hours. Conveys an information about the average time that the customers are interrupted. The formula is as follows:

$$SAIDI = \frac{Sum\ of\ all\ customer\ minutes\ interrupted\ (CMI)}{Total\ number\ of\ customers\ served\ (C)}$$

$$SAIDI = \frac{\Sigma(\mathrm{Ri} * \mathrm{Ni})}{\mathrm{Nt}}, \mathrm{minutes/year}$$

where,
Ri = Restoration time, minutes
Ni = Total number of customers interrupted
Nt = Total number of customers served.

The Customer Average Interruption Duration Index (CAIDI), which is the average time needed to restore service of affected customers per sustained interruption, was computed using the formula:

$$CAIDI = \frac{SAIDI}{SAIFI}, minutes$$

The Momentary Average Interruption Frequency Index (MAIFI) measures the average number of momentary interruptions that a customer experiences during a given time. Its value was estimated by the formula:

$$MAIFI = \frac{Sum\ of\ all\ customers\ momentary\ interruptions\ (CME)}{Total\ number\ of\ customers\ served\ (C)}$$

$$MAIFI = \frac{\Sigma(\mathrm{IDi} * \mathrm{Ni})}{\mathrm{Nt}}$$

where,
ID = Number of interrupting device operations
Ni = Total number of customers interrupted
Nt = Total number of customers served

The value of downtime drawn from the above-mentioned measurements was used to summarize feeder availability using:

$$\mathrm{Downtime} = \mathrm{Sum\ of\ all\ SAIDI\ in\ minutes}$$

$$\mathrm{Availability} = \frac{Total\ hours\ of\ operation\ in\ one\ year}{525600}, \%$$

Reliability is the probability of the system to perform its intended function for a specific time duration. It follows an exponential decay, which means that it reduces as the time duration considered for reliability calculations elapses. Therefore, the reliability of a system is high at its initial state of operation and gradually reduces to its lowest magnitude over time. It is computed using the formula:

$$R(t) = e^{-\lambda * t}$$

where,
λ = Interruption rate
t = Specific time duration in minutes

For a feeder, there could be interruptions after a certain period in minutes. If the feeder is energized or operational for a certain period before interruption/s occurred, then, feeder interruption rate is computed using the formula below as derived by Texas Instruments (TI.com, n.d.).

$$\lambda = \frac{number\ of\ interruptions}{sum\ of\ time\ periods\ before\ interruption\ occurs} = \frac{number\ of\ interruptions}{availability}$$

Treatment of Data

This section outlines the data process procedure employed to ensure the validity of the results. The dataset covers a five-year span of power interruption reports, focusing on switchgear tripping incidents during faults, scheduled outages, and unexpected events. These data points are crucial for calculating reliability indices for each feeder. The process utilized the Monte Carlo Simulation within MS Excel to analyze mean and standard deviation, yielding interruption rates, availability, and downtime for each feeder. After running one thousand simulations, initial reliability parameters were estimated.

After the initial reliability parameters were obtained, targeted actions were taken to enhance grid performance. Specifically, Automatic Circuit Reclosers (ACRs) were integrated into the grid infrastructure to mitigate interruptions, particularly those of transient nature. This initiative aimed to reduce SAIFI (System Average Interruption Frequency Index), SAIDI (System Average Interruption Duration Index), and CAIDI (Customer Average Interruption Duration Index).

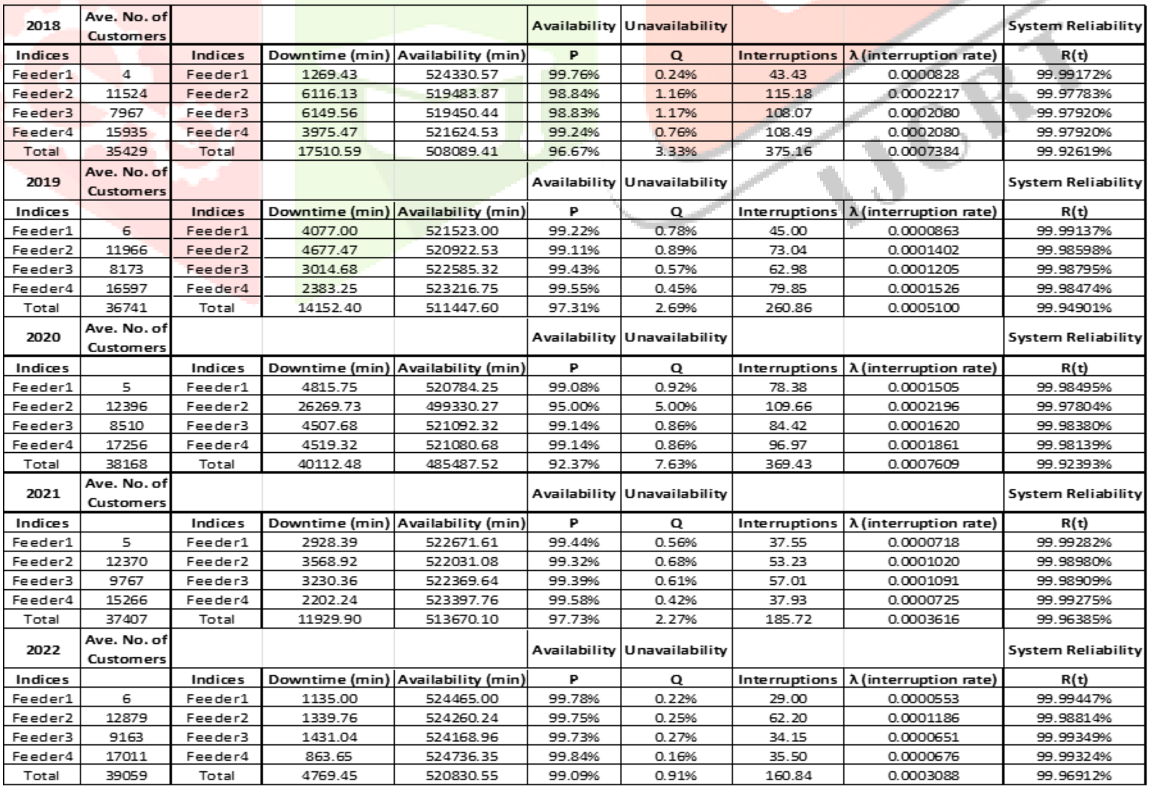
III. RESULTS AND DISCUSSION

In this chapter, the researcher thoroughly explored the empirical findings extracted from meticulously gathered data encompassing a five-year span of monthly interruptions. These significant findings were systematically elucidated in harmony with the precise research objectives delineated within the study.

1. The Distribution Feeder Parameters in Terms of Feeder Downtime, Availability, Interruption Rate, and System Reliability.

The foregoing computations of feeder reliability parameters led to acquiring the substation feeders' downtime, availability, interruption rate and system reliability.

Table 1. CENPELCO San Carlos 20MVA Substation Distribution Feeders Downtime, Availability, Interruption Rate, and System Reliability



2018	Ave. No. of Customers				Availability	Unavailability			System Reliability
Indices		Indices	Downtime (min)	Availability (min)	P	Q	Interruptions	λ (interruption rate)	R(t)
Feeder1	4	Feeder1	1269.43	524330.57	99.76%	0.24%	43.43	0.0000828	99.99172%
Feeder2	11524	Feeder2	6116.13	519483.87	98.84%	1.16%	115.18	0.0002217	99.97783%
Feeder3	7967	Feeder3	6149.56	519450.44	98.83%	1.17%	108.07	0.0002080	99.97920%
Feeder4	15935	Feeder4	3975.47	521624.53	99.24%	0.76%	108.49	0.0002080	99.97920%
Total	35429	Total	17510.59	508089.41	96.67%	3.33%	375.16	0.0007384	99.92619%
2019	Ave. No. of Customers				Availability	Unavailability			System Reliability
Indices		Indices	Downtime (min)	Availability (min)	P	Q	Interruptions	λ (interruption rate)	R(t)
Feeder1	6	Feeder1	4077.00	521523.00	99.22%	0.78%	45.00	0.0000863	99.99137%
Feeder2	11966	Feeder2	4677.47	520922.53	99.11%	0.89%	73.04	0.0001402	99.98598%
Feeder3	8173	Feeder3	3014.68	522585.32	99.43%	0.57%	62.98	0.0001205	99.98795%
Feeder4	16597	Feeder4	2383.25	523216.75	99.55%	0.45%	79.85	0.0001526	99.98474%
Total	36741	Total	14152.40	511447.60	97.31%	2.69%	260.86	0.0005100	99.94901%
2020	Ave. No. of Customers				Availability	Unavailability			System Reliability
Indices		Indices	Downtime (min)	Availability (min)	P	Q	Interruptions	λ (interruption rate)	R(t)
Feeder1	5	Feeder1	4815.75	520784.25	99.08%	0.92%	78.38	0.0001505	99.98495%
Feeder2	12396	Feeder2	26269.73	499330.27	95.00%	5.00%	109.66	0.0002196	99.97804%
Feeder3	8510	Feeder3	4507.68	521092.32	99.14%	0.86%	84.42	0.0001620	99.98380%
Feeder4	17256	Feeder4	4519.32	521080.68	99.14%	0.86%	96.97	0.0001861	99.98139%
Total	38168	Total	40112.48	485487.52	92.37%	7.63%	369.43	0.0007609	99.92393%
2021	Ave. No. of Customers				Availability	Unavailability			System Reliability
Indices		Indices	Downtime (min)	Availability (min)	P	Q	Interruptions	λ (interruption rate)	R(t)
Feeder1	5	Feeder1	2928.39	522671.61	99.44%	0.56%	37.55	0.0000718	99.99282%
Feeder2	12370	Feeder2	3568.92	522031.08	99.32%	0.68%	53.23	0.0001020	99.98980%
Feeder3	9767	Feeder3	3230.36	522369.64	99.39%	0.61%	57.01	0.0001091	99.98909%
Feeder4	15266	Feeder4	2202.24	523397.76	99.58%	0.42%	37.93	0.0000725	99.99275%
Total	37407	Total	11929.90	513670.10	97.73%	2.27%	185.72	0.0003616	99.96385%
2022	Ave. No. of Customers				Availability	Unavailability			System Reliability
Indices		Indices	Downtime (min)	Availability (min)	P	Q	Interruptions	λ (interruption rate)	R(t)
Feeder1	6	Feeder1	1135.00	524465.00	99.78%	0.22%	29.00	0.0000553	99.99447%
Feeder2	12879	Feeder2	1339.76	524260.24	99.75%	0.25%	62.20	0.0001186	99.98814%
Feeder3	9163	Feeder3	1431.04	524168.96	99.73%	0.27%	34.15	0.0000651	99.99349%
Feeder4	17011	Feeder4	863.65	524736.35	99.84%	0.16%	35.50	0.0000676	99.99324%
Total	39059	Total	4769.45	520830.55	99.09%	0.91%	160.84	0.0003088	99.96912%

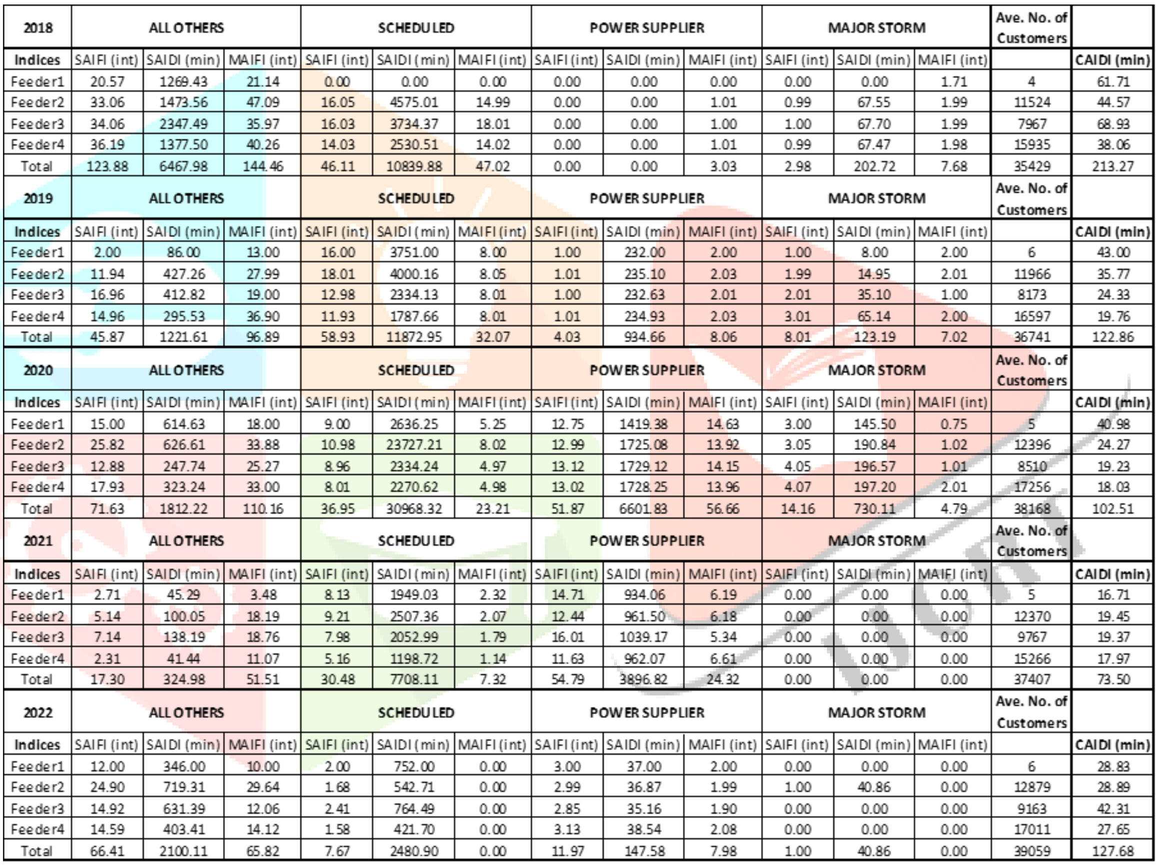
In power systems parlance, downtime refers to the period during which a power system or a specific component within it is not operational or functioning as intended. It represents the duration when electrical power is not available due to maintenance, unscheduled and scheduled outages. Availability, which is usually expressed in percentage, is just the opposite of downtime. Low interruption rate, on the other hand, indicates a more reliable power system. These are key indicators of the performance and robustness of a distribution utility such as the Central Pangasinan Electric Cooperative.

True to their commitment and aware of the repercussions brought about by the non-compliance issue indicated in NEA Memo. No. 2021-35, CENPELCO engineers are looking at integrating ACRs as an improvement measure to optimize San Carlos Substation distribution system performance to ensure a steady and dependable supply of electricity to consumers, minimizing disruptions and maximizing customer satisfaction, and comply with the standards set by relevant regulatory authorities. In addition, several technical manuals of ACRs manufacturers have shown that these devices are designed to detect and clear temporary faults in overhead power lines by automatically opening and reclosing the circuit, therefore, they can help reduce downtime experienced by consumers and increase availability of power supply by minimizing the impact of transient faults resulting in a resilient distribution network.

2. Evaluation of the Existing System Reliability Metrics and Performance Indicators; SAIFI, SAIDI, MAIFI, CAIDI

Table 2 unveils a comprehensive record of reliability indices spanning five years, encompassing the four feeders of CENPELCO San Carlos Substation.

Table 2. Reliability Evaluation of San Carlos 20 MVA Substation Network



2018	ALL OTHERS			SCHEDULED			POWER SUPPLIER			MAJOR STORM			Ave. No. of Customers	
Indices	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)		CAIDI (min)
Feeder1	20.57	1269.43	21.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71	4	61.71
Feeder2	33.06	1473.56	47.09	16.05	4575.01	14.99	0.00	0.00	1.01	0.99	67.55	1.99	11524	44.57
Feeder3	34.06	2347.49	35.97	16.03	3734.37	18.01	0.00	0.00	1.00	1.00	67.70	1.99	7967	68.93
Feeder4	36.19	1377.50	40.26	14.03	2530.51	14.02	0.00	0.00	1.01	0.99	67.47	1.98	15935	38.06
Total	123.88	6467.98	144.46	46.11	10839.88	47.02	0.00	0.00	3.03	2.98	202.72	7.68	35429	213.27
2019	**ALL OTHERS**			**SCHEDULED**			**POWER SUPPLIER**			**MAJOR STORM**			**Ave. No. of Customers**	
Indices	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)		CAIDI (min)
Feeder1	2.00	86.00	13.00	16.00	3751.00	8.00	1.00	232.00	2.00	1.00	8.00	2.00	6	43.00
Feeder2	11.94	427.26	27.99	18.01	4000.16	8.05	1.01	235.10	2.03	1.99	14.95	2.01	11966	35.77
Feeder3	16.96	412.82	19.00	12.98	2334.13	8.01	1.00	232.63	2.01	2.01	35.10	1.00	8173	24.33
Feeder4	14.96	295.53	36.90	11.93	1787.66	8.01	1.01	234.93	2.03	3.01	65.14	2.00	16597	19.76
Total	45.87	1221.61	96.89	58.93	11872.95	32.07	4.03	934.66	8.06	8.01	123.19	7.02	36741	122.86
2020	**ALL OTHERS**			**SCHEDULED**			**POWER SUPPLIER**			**MAJOR STORM**			**Ave. No. of Customers**	
Indices	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)		CAIDI (min)
Feeder1	15.00	614.63	18.00	9.00	2636.25	5.25	12.75	1419.38	14.63	3.00	145.50	0.75	5	40.98
Feeder2	25.82	626.61	33.88	10.98	23727.21	8.02	12.99	1725.08	13.92	3.05	190.84	1.02	12396	24.27
Feeder3	12.88	247.74	25.27	8.96	2334.24	4.97	13.12	1729.12	14.15	4.05	196.57	1.01	8510	19.23
Feeder4	17.93	323.24	33.00	8.01	2270.62	4.98	13.02	1728.25	13.96	4.07	197.20	2.01	17256	18.03
Total	71.63	1812.22	110.16	36.95	30968.32	23.21	51.87	6601.83	56.66	14.16	730.11	4.79	38168	102.51
2021	**ALL OTHERS**			**SCHEDULED**			**POWER SUPPLIER**			**MAJOR STORM**			**Ave. No. of Customers**	
Indices	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)		CAIDI (min)
Feeder1	2.71	45.29	3.48	8.13	1949.03	2.32	14.71	934.06	6.19	0.00	0.00	0.00	5	16.71
Feeder2	5.14	100.05	18.19	9.21	2507.36	2.07	12.44	961.50	6.18	0.00	0.00	0.00	12370	19.45
Feeder3	7.14	138.19	18.76	7.98	2052.99	1.79	16.01	1039.17	5.34	0.00	0.00	0.00	9767	19.37
Feeder4	2.31	41.44	11.07	5.16	1198.72	1.14	11.63	962.07	6.61	0.00	0.00	0.00	15266	17.97
Total	17.30	324.98	51.51	30.48	7708.11	7.32	54.79	3896.82	24.32	0.00	0.00	0.00	37407	73.50
2022	**ALL OTHERS**			**SCHEDULED**			**POWER SUPPLIER**			**MAJOR STORM**			**Ave. No. of Customers**	
Indices	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)	SAIFI (int)	SAIDI (min)	MAIFI (int)		CAIDI (min)
Feeder1	12.00	346.00	10.00	2.00	752.00	0.00	3.00	37.00	2.00	0.00	0.00	0.00	6	28.83
Feeder2	24.90	719.31	29.64	1.68	542.71	0.00	2.99	36.87	1.99	1.00	40.86	0.00	12879	28.89
Feeder3	14.92	631.39	12.06	2.41	764.49	0.00	2.85	35.16	1.90	0.00	0.00	0.00	9163	42.31
Feeder4	14.59	403.41	14.12	1.58	421.70	0.00	3.13	38.54	2.08	0.00	0.00	0.00	17011	27.65
Total	66.41	2100.11	65.82	7.67	2480.90	0.00	11.97	147.58	7.98	1.00	40.86	0.00	39059	127.68

The data presented in Table 2 were thoroughly calculated following the guidelines laid out in ERC Resolution No. 12, series of 2006. These figures correspond to reliability indices associated with diverse outage scenarios including those resulting from significant storm-related disasters, supply barriers, and planned maintenance activities.

Under the label “All Others,” it includes interruptions arising from human errors, lightning strikes, vegetation, overloads, equipment malfunctions, and seismic events. In contrast, the category “Scheduled” pertains to power interruptions deliberately initiated through the shutdown of distribution transformer within the substation or the temporary removal of specific lines segments from service for maintenance or other activities. The term “Power Supplier” denotes outages that can either be scheduled or unscheduled and affect line or substations under the ownership of the National Grid. Lastly, the “Major Storms” classification pertains to service disruptions brought about by the impact of typhoons.

CENPELCO operates and competes within the context of deregulated electricity market as stipulated in the Electric Power Industry Reform Act (EPIRA) of 2001. This regulatory framework underscores the motivation behind CENPELCO’s periodic assessments of its network’s performance. These are critical to ensuring that a tough technical infrastructure and financial sustainability are maintained while it adheres to the standards established by the NEA as outlined in Memorandum No. 2011-020 series of 2011. Furthermore, it serves as basis for developing performance incentive mechanisms for CENPELCO's officials and employees. These standards that NEA established are called Key Performance Standards for power reliability. The NEA's recommended standards for power reliability, NEA Memorandum N0. 2021-35, s.2021.

Table 3. San Carlos 20MVA Substation Distribution Network Reliability Indices

	2018			2019		
Feeders	SAIFI	SAIDI	Remarks	SAIFI	SAIDI	Remarks
1	20.57	1269.43	Passed SAIFI/SAIDI	2	86	Passed SAIFI/SAIDI
2	33.06	1316.66	Failed SAIFI	12	427.26	Passed SAIFI/SAIDI
3	34.06	1699.38	Failed SAIFI	17	412.82	Passed SAIFI/SAIDI
4	39.19	1336.45	Failed SAIFI	15	295.53	Passed SAIFI/SAIDI
	2020			2021		
Feeders	SAIFI	SAIDI	Remarks	SAIFI	SAIDI	Remarks
1	15	614.63	Passed SAIFI/SAIDI	3	45.29	Passed SAIFI/SAIDI
2	26	626.61	Failed SAIFI	5	100.05	Passed SAIFI/SAIDI
3	13	247.74	Passed SAIFI/SAIDI	7	138.19	Passed SAIFI/SAIDI
4	18	323.24	Passed SAIFI/SAIDI	2	41.44	Passed SAIFI/SAIDI
	2022					
Feeders	SAIFI	SAIDI	Remarks			
1	12	346	Passed SAIFI/SAIDI			
2	25	719.31	Passed SAIFI/SAIDI			
3	15	631.39	Passed SAIFI/SAIDI			
4	15	403.41	Passed SAIFI/SAIDI			

Table 3 evidently shows that from year 2019 to 2022 CENPELCO successfully achieved the performance level established by NEA. Although compliant regarding SAIFI and SAIDI, NEA's evaluation of electric cooperatives operating in the Philippines during the 2nd quarter of 2022 resulted in categorizing 66 electric cooperatives, CENPELCO was included as moderately performing. This determination was reached due to three of the 15 standards and parameters not being met. Consequently, CENPELCO received a Yellow-1 classification. To address the areas that require improvement and align with NEA's expectations, the company was subjected to ongoing monitoring.

3. Comparison of the Reliability Metrics Before and After the Implementation of Automatic Circuit Reclosers.

Stated in earlier chapter was the use of Monte Carlo Simulation within MS Excel to analyze the mean and standard deviation of interruption rates, availability, and downtime for each feeder. The following results were tabulated and presented below beginning with Table 4 containing the distribution feeders' reliability indices without automatic circuit reclosers followed by Table 5 for the simulated reliability indices with automatic circuit reclosers.

Table 4. Monte Carlo Simulation Without ACRs

	Interruptions	Downtime(min)	Availability(min)	Availability(%)	λ	R(t)
Feeder 1	47.31018	2824.21595	522775.78405	99.46267%	0.000090498	99.99095%
Feeder 2	84.43592	8398.45388	517201.54612	98.40212%	0.000163255	99.98368%
Feeder 3	70.63358	3727.75160	521872.24840	99.29076%	0.000135346	99.98647%
Feeder 4	73.12435	2812.92871	522787.07129	99.46482%	0.000139874	99.98601%
System Average	68.87601	4440.83754	521159.16247	99.15509%	0.000132243	99.98678%

Table 5. Monte Carlo Simulation with ACRs

	Interruptions	Downtime(min)	Availability(min)	Availability(%)	λ	R(t)
Feeder 1	46.16036	2433.01831	523166.98169	99.53710%	0.000088233	99.99118%
Feeder 2	81.47584	7840.14937	517759.85063	98.50834%	0.000157362	99.98427%
Feeder 3	70.37133	3035.99254	522564.00746	99.42238%	0.000134665	99.98653%
Feeder 4	72.35686	2405.05019	523194.94981	99.54242%	0.000138298	99.98617%
System Average	67.59110	3928.55260	521671.44740	99.25256%	0.000129640	99.98704%

Presented in Table 6 is the achieved reliability parameters following a simulation that involved the integration of Automatic Circuit Reclosers (ACRs) strategically positioned within the grid. The primary objective was to reduce the annual duration of sustained feeder interruptions caused by faults reaching the substation.

Table 6. Degree of Attained Feeder Performance Improvement

Degree of attained feeder performance improvement						
	Interruptions	Downtime	Downtime Reduced (min)	Availability (%)	λ	R(t)
Feeder1	3.37900%	16.41845%	480.20410	0.09179%	3.46769%	0.00032%
Feeder2	0.42565%	8.06309%	682.61931	0.13183%	0.55691%	0.00009%
Feeder3	1.18121%	16.19313%	597.27967	0.11431%	1.29417%	0.00017%
Feeder4	0.75144%	16.00272%	444.49895	0.08495%	0.83575%	0.00011%
System Average	2.19892%	11.30993%	2204.60203	0.09925%	2.29599%	0.00030%

Table 6 reveals a notable reduction in downtime for all feeders. The values provided indicate that based on the simulation conducted the integration of Automatic Circuit Reclosers (ACRs) at each feeder would reduce downtime.

4. Provide Practical Insights for CENPELCO to Enhance System Reliability Through the Strategic Placement of Automatic Circuit Reclosers.

Table 7 shows the recommended strategic locations to install ACR and rating using practical distribution system design consideration for ACR as mid-feeder protection, prioritizing the point in the feeder to cover half of the total number of consumers connected to the particular feeder. The feeder is divided into three sections based on the existing distribution system protection, laterals, and consumers. Monte Carlo Simulation was used to simulate the interruptions to determine the approximate number of consumers combined via lateral sections to be covered for the mid-feeder protection reducing their duration of sustained interruptions encountered. In the case of feeder 3, the simulation provided validation for the CENPELCO's decision to install the sole existing ACR in the grid along the midpoint of feeder 3. Therefore, the recommended additional ACR for feeder 3 should be installed in the upstream of the backbone along Roxas Blvd. For feeder 4, due to large number of consumers in section 3, MCS was run again to identify a second strategic location which was found to be along the backbone along Brgy. Taloy.

Table 7. Recommended ACR Installation Location and Rating

Feeder	Consumers per section			Simulated Interrupted Consumers	Recommended ACR installation location	ACR Rating (Pole Mounted)
	Section 1	Section 2	Section 3	Mid-Feeder Protection		
Feeder 1	1	4	1	2	Midpoint of feeder 1.	15.5kV Max. Voltage, 110kV Basic Impulse Level, 630A Continuous Current, 12.5kA Short Circuit Current, Symmetrical, 31.0kA Making Current, Asymmetrical Peak, 125kV BIL
Feeder 2	5060	3098	3854	4003	Back-bone of Feeder 2 going Brgy. Ilang	
Feeder 3	1756	6636	3666	4008	Back-bone of Feeder 3 going Roxas Blvd.	
Feeder 4	6547	6372	16628	7886	Back-bone of Feeder 4 going Brgy. Baldog	
				11312	Back-bone of Feeder 4 going Brgy. Taloy	

Feeder 1 had a reduced downtime of approximately 480.20410 minutes. It could be considered a relatively high improvement. This could imply that placement of ACR can enhance the reliability of this feeder, which is shown in Fig. 3.

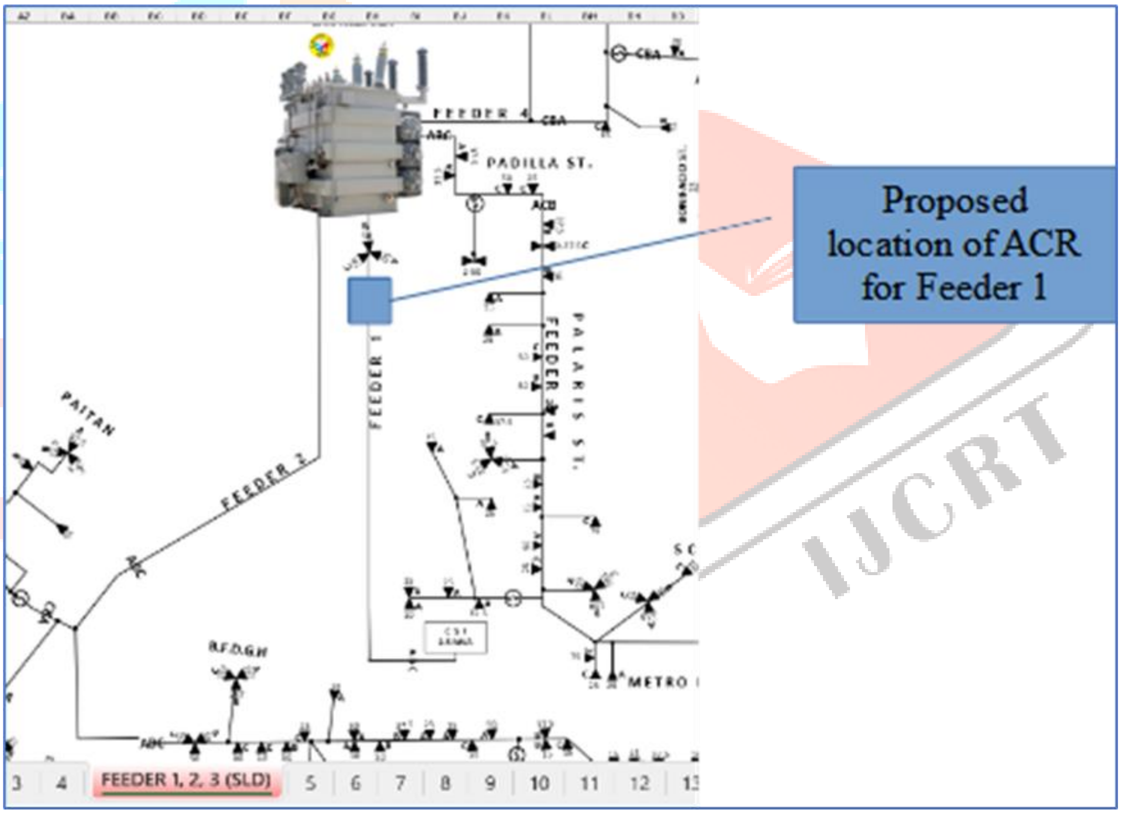


Figure 3. Suggested Location of ACR for Feeder 1

Similarly, Feeder 2 had a reduced downtime of approximately 682.61931 minutes The proposed improvement through integration of ACRs is shown in Fig. 4.

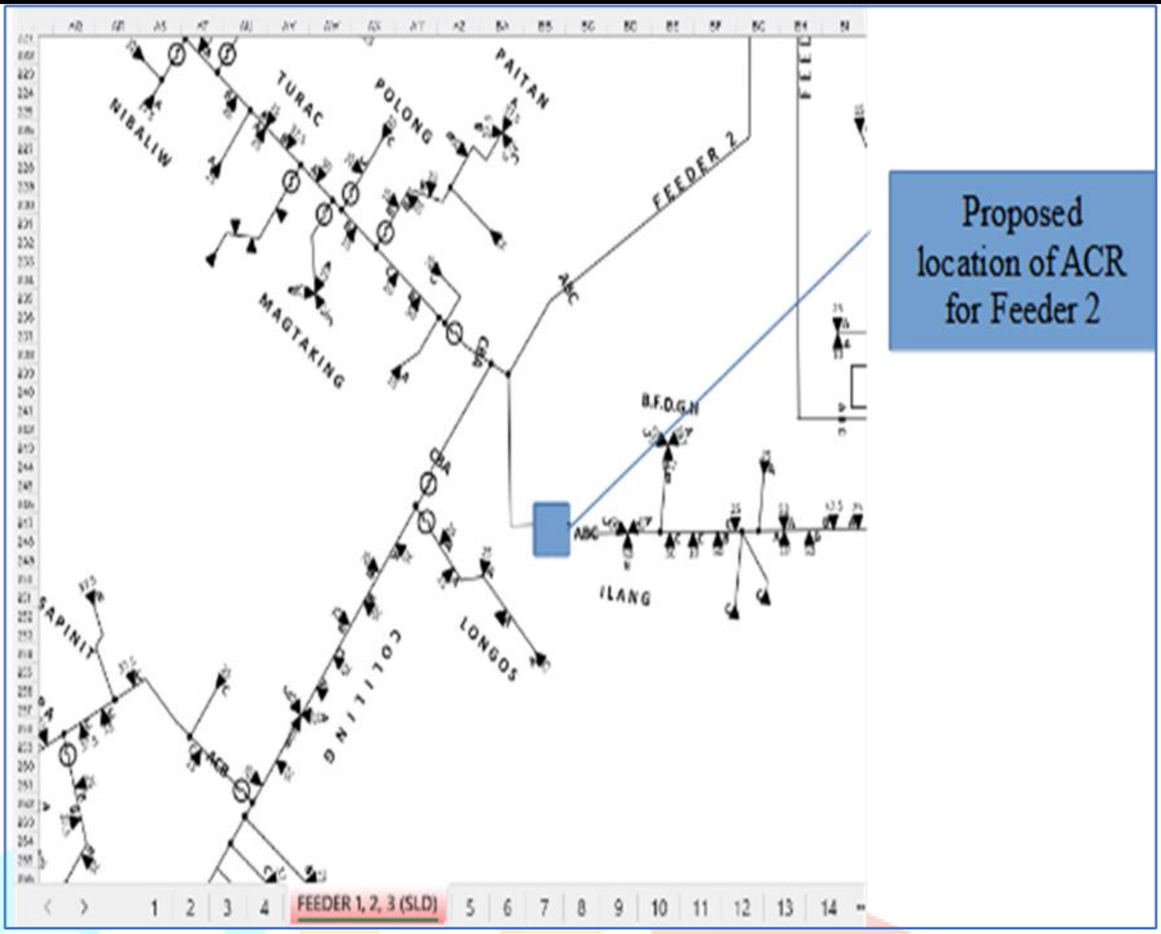


Figure 4. Proposed Location of ACR for Feeder 2

Feeder 3, on the other hand, had a reduced downtime of 597.27967 minutes. This value suggests that the integration of ACRs has had a positive impact on its reliability. Feeder 3 is the only feeder with an existing ACR. To enhance its reliability further, placement of ACR is recommended.

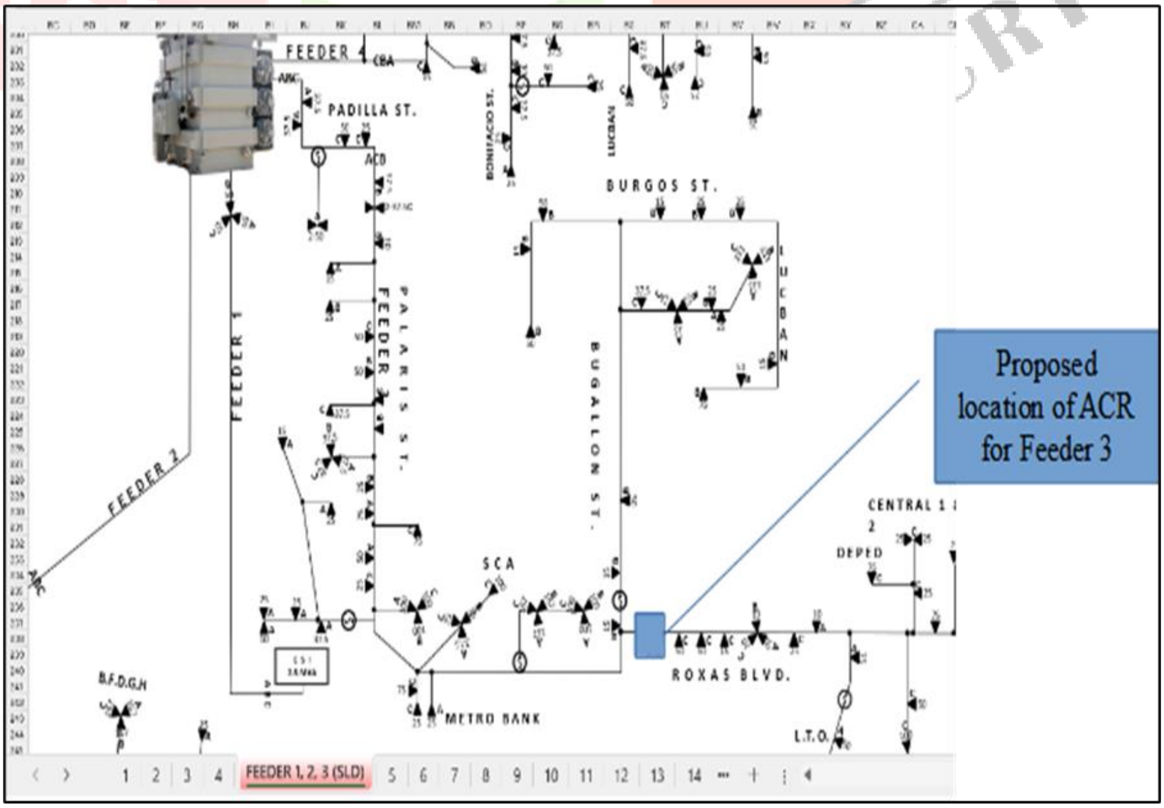
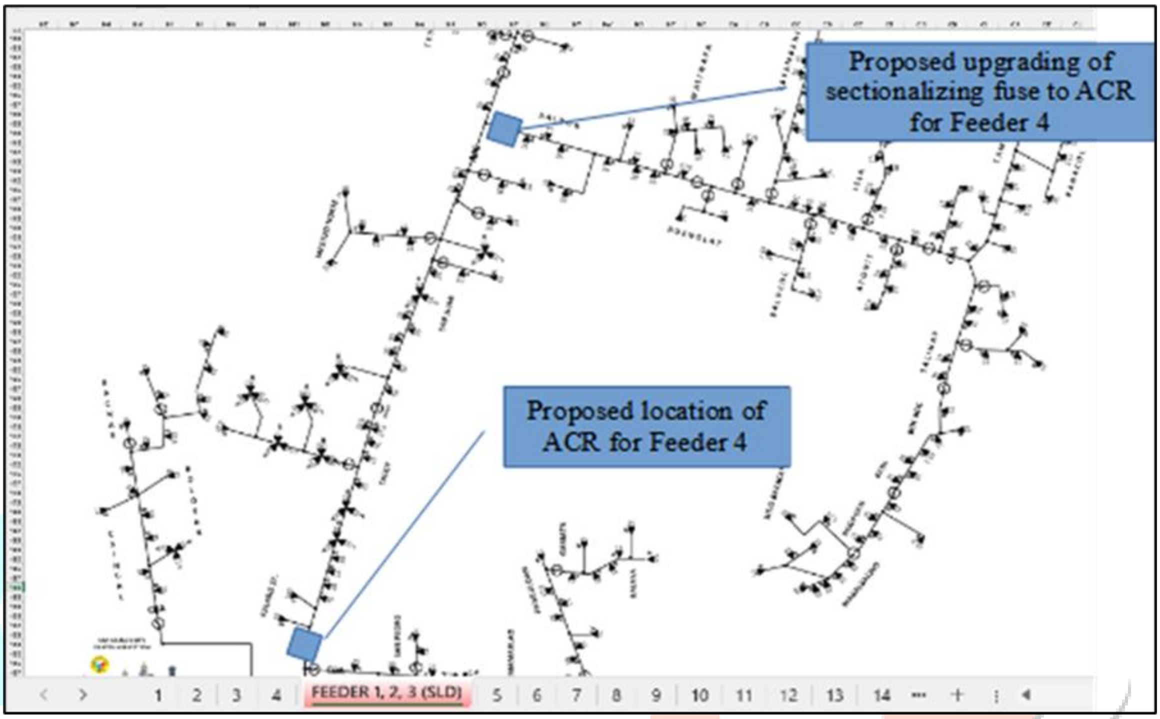


Figure 5. Recommended Location of ACR for Feeder 3

Feeder 4 also had a reduced downtime with approximately 444.49895. While not as high as Feeder 2, Feeder 4 has experienced an improvement in reliability with the integration of ACRs.

This feeder had the largest number of customers being served and mostly heavily vegetated and prone to flooding. The placement of ACR is proposed at two locations along the Brgy. Taloy lines and the other is along the Brgy Baldog lines. The former is for additional backbone protection which will be coordinated with the existing lateral fuses and two backbone sectionalizing fuses, and the latter is for replacing the existing sectionalizing fuse of the lateral.



Proposed upgrading of sectionalizing fuse to ACR for Feeder 4

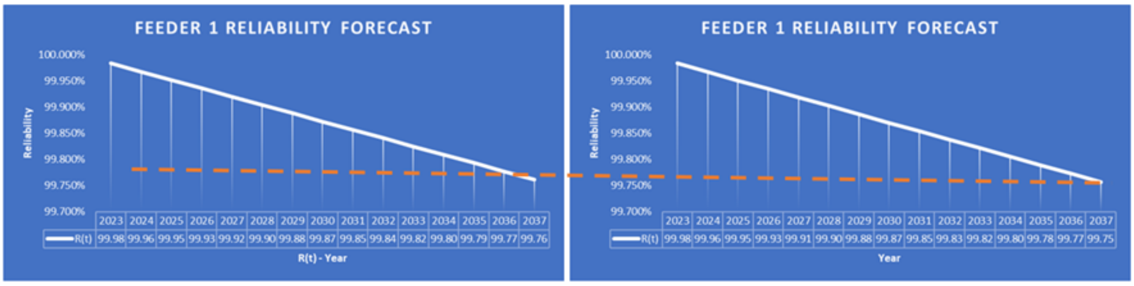
Proposed location of ACR for Feeder 4

Figure 6. Proposed Locations of ACRs for Feeder 4

A 15-year reliability forecast for all feeders with and without ACRs was also undertaken. By forecasting reliability, utilities can plan for necessary infrastructure investments, such as upgrading aging components, improving grid automation, or adding redundancy to critical equipment. In terms of budgeting and cost management, reliability forecasting with time frame ensures that CENPELCO's financial resources are allocated effectively to maintain and enhance reliability while minimizing unnecessary expenditures.

Furthermore, it is crucial for CENPELCO to ensure MCOs satisfaction because they depend on electricity for various aspects of their daily lives, and interruptions can lead to inconvenience and economic losses. Thus, accurate reliability forecasts could help CENPELCO management set realistic expectations for MCOs and work towards delivering a more reliable service.

Lastly, relevant regulatory authorities and many regulatory bodies impose reliability standards on utilities, CENPELCO included. Therefore, accurate forecasting helps utilities assess their ability to meet these standards over the long term and plan for compliance. Failure to meet reliability standards can result in penalties and increased regulatory oversight. The following charts present comparison of the reliability forecast for CENPELCO San Carlos 20 MVA from 2023 – 2037 between without and with ACRs installed on its distribution network.

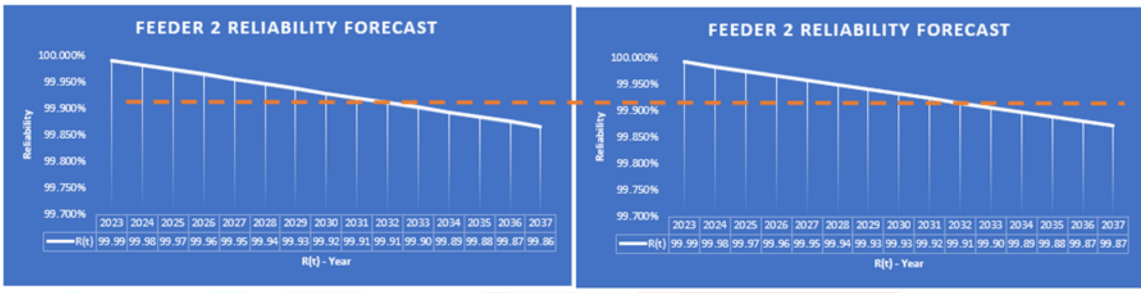


a) Without ACR

b) With ACR

Figure 7. Reliability Forecast for Feeder 1

It appears from the two charts that ACR contributes to the overall sustainability and resilience of Feeder 1 as it remains low compared to no ACR installed in the feeder.

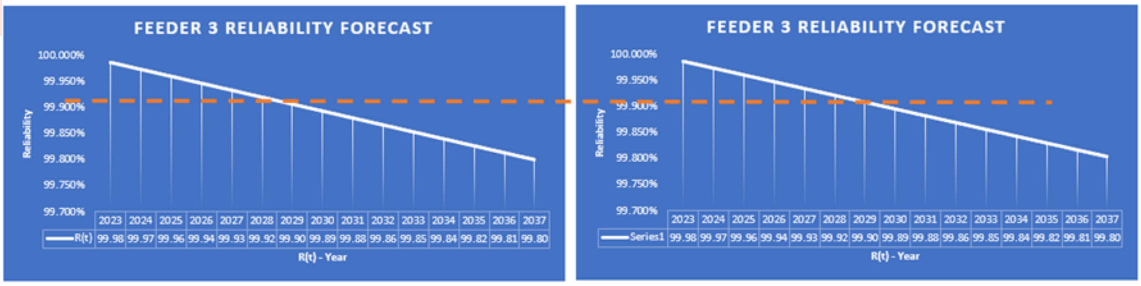


a) Without ACR

b) With ACR

Figure 8. Reliability Forecast for Feeder 2

In Figure 8, it becomes evident that the reliability of Feeder 2, despite the installation of ACR, begins to decline starting from the year 2031. As a result, it is recommended that a thorough assessment of its reliability be initiated beginning in that year.

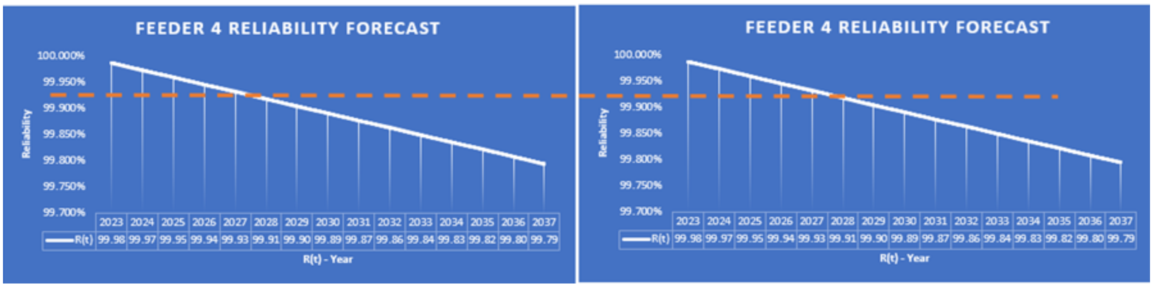


a) Without ACR

b) With ACR

Figure 9. Reliability Forecast for Feeder 3

The reliability of Feeder 3 experiences improvements following the installation of an ACR in 2023. However, a reduction in reliability becomes evident starting in 2028.



a) Without ACR

b) With ACR

Figure 10. Reliability Forecast for Feeder 4

Feeder 4's reliability began to deteriorate earlier compared to the other feeders, primarily due to its heavier load. As indicated by the chart, this decline becomes noticeable in the year 2027.

IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Primary data for the study were collected from historical power interruption data and obtaining a single-line diagram of the CENPELCO San Carlos 20MVA Substation. Interruption reports served as the bases for calculating reliability indices for the years 2018 to 2022, following the classification outlined in NEA Resolution No.12 Series 2006. Subsequently, reliability indices for feeders 1, 2, 3, and 4 were computed, and the mean and standard deviations of other reliability parameters, including interruptions, availability, and interruption rates, were calculated. These values were then used as input for the Monte Carlo Simulation, conducted using Microsoft Excel, to simulate various scenarios and analyze potential outcomes.

Based on the findings and discussions presented in Chapter 3:

1. The computed reliability indices of the San Carlos 20MVA Substation demonstrated compliance with the reliability parameters standards established by the National Electrification Administration (NEA).

2. Prior to the onset of the COVID-19 pandemic, the annual reliability indices for the feeders consistently exceeded the NEA standards for System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI), which were set at 25 interruptions and 2700 minutes, respectively. During the pandemic period, however, there was an observed decrease in these indices, indicating improved reliability across most feeders. Feeder 2 exhibited a consistently higher number of interruptions compared to other feeders, particularly in the years 2020 and 2022.

3. The impact of integrating ACRs at the San Carlos 20MVA Substation has led to a significant improvement in the annual SAIFI and SAIDI. Consequently, this improvement has extended to the five-year average values, all of which now adhere to the standards established by the NEA. Owing to this, CENPELCO's performance is aligned with that of Green-classified Electric Cooperatives (Green-ECs), particularly when SAIFI and SAIDI, including the remaining twelve substations, are factored into the overall assessment conducted by management. Furthermore, the results reveal an inverse proportional trend, i.e., as SAIFI and SAIDI decreased, the MAIFI increased. This trend indicates that the availability of the system has significantly improved, highlighting one of the primary advantages of incorporating ACRs into transmission lines. Furthermore, this study provides validation for NEA's decision to exclude CAIDI and MAIFI from its reliability assessment mechanism. The observed pattern indicates that as SAIFI values are converted into MAIFI, there is a corresponding proportional reduction in SAIDI. Consequently, CAIDI, which measures restoration time, remains relatively constant.

   Concerning the degree of improvement attained, the results have shown a notable reduction in the number of interruptions, leading to a corresponding decrease in the interruption rate. This reduction in interruptions translates to improved feeder reliability which has a direct positive impact on the overall availability of the substation. The most significant outcome of the study is the substantial decrease in downtime, approximately 2,204.602 minutes, which can be attributed to the integration of Automatic Circuit Reclosers (ACRs). This device emerges as the preferred protective devices for swiftly re-energizing circuits after clearing transient faults that minimize downtime.

4. Strategic locations of ACRs were selected by considering the replacement of the first sectionalizing fuse on the backbone, customers affected, heavily vegetated areas, flood prone areas, and proximity to the substation as a last protective device to prevent a wide scale sustained interruption. The best locations were also based on the result of simulating the number of consumers combined via lateral sections to be covered for the mid-feeder protection.

a. Feeder 1

Serving the least number of customers but with the largest power customer which is CSI Mall, has the shortest and clearest line among the four feeders. However, interruption reports show that despite the small area of coverage of feeder 1 it encounters interruptions with fault level reaching the substation without any downstream protection. In line with this, it is recommended to install the proposed ACR along Palaris St. for ease of access and will serve as the downstream protection of feeder.

b. Feeder 2

It has the second largest number of customers served and comes with heavily vegetated areas. In coordination with the existing two backbone sectionalizing fuses and their lateral fuses, it is recommended to install the ACR along Brgy. Ilang backbone.

c. Feeder 3

As the only feeder with an existing ACR along the midpoint of the backbone, however, faults still reach the substation causing widescale interruption due to lack of backbone protective device behind the existing ACR. In coordination with the existing ACR and sectionalizing fuses, it is recommended to install an additional backbone ACR along Roxas Blvd.

d. Feeder 4

It has the largest number of customers served and the most heavily vegetated and flood prone areas. There are two proposed locations for the installation of ACRs, the first one is along Brgy. Taloy for additional backbone protection which will be coordinated with the existing lateral fuses and two backbone sectionalizing fuses. The second ACR will be installed along Brgy Baldog replacing the existing sectionalizing fuse of the lateral.

Moreover, the reliability forecast based on the results indicates that reliability has remained relatively constant resulting in the conversion of the saved SAIFI into MAIFI, which effectively constrains the overall number of interruptions. The study also substantiates that it is possible to maintain reliability while simultaneously increasing availability through the utilization of ACRs. This dual achievement not only enhances system performance but also contributes to increased customer satisfaction due to the reduction in downtime.

Conclusion

The reduction of the duration of sustained interruptions with the utilization of ACRs translates to improved feeder reliability which has a direct positive impact on the overall availability of the substation. Moreover, it is possible to maintain reliability while simultaneously increasing availability through the utilization of ACRs.

Recommendations

1. CENPELCO has to perform fault analysis and protection coordination before actual installation of ACRs considering actual ratings of all components of feeders.

2. To further improve system reliability, it is recommended that CENPELCO incorporate Supervisory Control and Data Acquisition (SCADA), to utilize fully the potential benefits of protection coordination and data collection. Moreover, CENPELCO has to implement tie-lines between feeders, vegetation control, installation of lightning arresters, shield wires, animal guards, and regular line patrols.

V. ACKNOWLEDGMENT

I am grateful to the Tarlac State University, especially to Dr. Arnold E. Velasco, the University President, and Dr. Agnes M. Macaraeg, the Vice President for Academic Affairs, for providing me with the opportunity to pursue my graduate studies at the College of Engineering.

I would also like to give my warmest thanks to Dr. Marie Wendy J. Frany, the Dean of the College of Engineering, for allowing me to achieve an advanced specialized engineering education. Furthermore, this endeavor would not have been possible without the continuous encouragement of the Chairperson of the Engineering Graduate School and at the same time my Thesis Adviser, Dr. Miriam S. Galvez.

In addition, I offer my special thanks to the following professors who acted as panelists, namely, Dr. Leo P. Piao, Dr. Enalyn T. Domingo, Engr. Crispin I. Flora, and Engr. Maan B. Florendo, foremost of which is their brilliant comments and suggestions let my defense a fruitful moment.

Moreover, I am deeply indebted to my professors in the graduate school for sharing their immense knowledge and plentiful experience.

To the Central Pangasinan Electric Cooperative management, for allowing me to conduct the study at the San Carlos 20MVA Substation and for unselfishly providing the necessary data needed for this study.

To God the Almighty, for endowing me with the gift of knowledge and for this I are more than grateful to share it to those in search of knowledge as well..

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