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Analysis and Simulation of SCADA system for three-phase recloser circuits in electrical networks.

Campoverde Reasco José Daniel[1], Vargas Rivera Paul Cristóbal[2], Ampuño Avilés Gary Omar[3]
[1-2-3]*Salesian Polytechnic University, Guayaquil, Ecuador*

ABSTRACT

A high percentage of transient faults are not cleared correctly, therefore, the electrical service is interrupted, affecting the development of society and the quality index of distribution companies. The objective of this work is to provide a methodology to improve the quality indices in the electrical service, through the simulation of three-phase reclosers in distribution networks through the coordination of SCADA and radio link systems. The foregoing ensures the reduction of TTIK interruption times and FMIK frequencies. The case study uses real data from the three-phase reconnection system located in the middle of the feeder circuit located on Calle Colon of Canton Milagro, province of Guayas – Ecuador, the recloser is linked to the real-time measurement equipment. PMP 450i, which is incorporated into the SCADA system by means of a radio link through an IEC 870 DNP3 communications protocol. The implemented methodology consists of comparing the quality indices of the electrical service interruption reports of CNEL Milagro southern sector, during the period corresponding to the year 2021 and the first semester of 2022, based on the results carried out with the simulation using CYMDIST software throughout the entire feeder network. For this, the subscriber and subscriber module of the PMP 450i measurement equipment was configured and validated by monitoring the failures reported through the SCADA system reports. Through simulation, the study demonstrated that quality indices such as TTIK and FMIK located at one end of the half-span feeder onVictor HugoVicuña Street decreased by approximately 10%.

Keywords: *Quality indices, interruption time, reconnection frequency, simulation, three-phase recloser.*

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I. Introduction

Currently in the 21st century, electrical power systems (EPS) have undergone a paradigm shift oriented towards the intelligent electrical network [1],that includes generation, transmission lines, automatic control systems, communication protocols, distribution subsystem and countless management systems for the different energy resources, which are accompanied by technical standards, high-level technologies and systems Adaptable to various areas of the electrical industry, reliability and safety are a very important factor in the different electrical power distribution systems[2],therefore, the proper functioning of protection and distribution equipment establishes the quality of the service offered, within the control and monitoring system it is of great help to be able to define the different electrical variables as they are; the intensity of current, load of the demands, the power factor, and the different powers such as: active (W), reactive (VAR) and apparent (VA), as well as the voltage level, the detection capacity of faults[3].The National Electricity Corporation, through the Public Company CNEL EP, has the fundamental objective of providing electric service to the public by commercializing electric energy through its distribution networks, within the assigned place, under the exclusivity of the regime regulated and controlled by the state, they must be able to satisfy the demand in a given area to all its consumers[4].The Company CNEL EP has made investments in terms of civil infrastructure, electrical sub-transmission system, technology, distribution and public lighting, all this investment has been made in ten provinces, which, grouping; the policies, the maintenance, the commercial, and the different operation plans, in addition to the incorporation of qualified technical personnel, has allowed to improve the quality of the service and greatly reduce energy losses, the Company has a wide service coverage, with the intended to meet user needs.

For years, in three-phase electrical distribution systems, a number of methods and implementation of electrical equipment have been carried out with computerized systems that are sufficiently reliable with optimal stability, minimizing the possibility of accidental interruptions of service, caused by derivative faults that occur due to the lack of maintenance and other factors that have caused them, therefore, the respective analyzes have been studied, with the aim of reducing the times and frequencies TTIK - FMIK of interruption of the energy supply, developing optimal alternatives in the incorporation of devices and technology integrated into the electrical distribution system [5].

The objective of this article is to improve the indices of the quality of the electrical service (ICSE) by reducing the times of interruption of services by means of three-phase reclosers located in the middle of the distribution circuits at the end of the electrical circuit, caused by power outages. tree branches in wintertime or lightning that have caused poles to fall, generating power outages. To demonstrate the improvement, a simulation of three-phase reclosers in electrical distribution networks coordinated by simulations in the CYMDIST program is used, seeking to reduce the times and frequencies of TTIK - FMIK reconnection.

II. Description of SCADA systems in circuits with reclosers

Numerous research works have been carried out with the aim of proposing techniques in order to (ICSE) in electrical power systems, according to Magallan[3]With the implementation and installation of different automatic reclosers, which are monitored and governed by the main SCADA system, energy distribution is guaranteed at 80% functionality in an electrical power system. As indicated by Ortega and Bustamante [6]the methodology to link the communication network to the SCADA owned by Electrical CompanyAzogues C.A., consists of the implementation of protection devices known as electrical reclosers, where OSM automatic reclosers are used due to their great versatility and robustness to support the environment, the protocols of communication that they used was the IEC 870 DNP3 and ModBus for the SCADA system and the different remote units, to improve the electrical service provided to the capital Azogues and its surroundings, in order to achieve an effective distribution, the design of the implementation of the communications system that links the new electrical devices purchased by the electrical distributor; emphasizing resources and infrastructure, managing to install eight teams in the rural areas of the city, for which they used fiber optics through radio link.

A postgraduate study on an implementation issue applying SCADA in Barrio 10 de Agosto was carried out by Gusque. F [7], was based on an analysis of various electrical service failures specifically in the Atahualpa neighborhood of Santa Elena, the authors used a methodology based on different quantitative designs capable of collecting information through descriptive data in order to analyze the consequences generated by the faults present in the SEP, the results acquired in the processing of the data collected, determined the existence of a high rate of failures and lack of electrical service, which directly affects the commercial activity of the sector, for which it was proposed as a solution the implementation of the SCADA system, to assist the application of a certain reliable and continuous electric power distribution service that will be able to identify a fault caused instantly, reducing the times to the restitution of the electric service[8].

For its part, the study carried out by Vique[9]evaluates the grounding systems related to the decrease of the ICSE, those that are outside a range stipulated in the IEEE 80 standard, whose value is 10 (the quality index does not have units because it is a relationship between kVA) to protection against atmospheric phenomena, as well as, the quality indices in frequency of medium interruption, the FMIK parameter is the one that shows the number of times that the average kVA suffers an interruption or disconnection of the electrical service in a defined period [10],and the total time of an interruption TTIK indicates the average time that the average kVA was not in service during a defined period described in the equations; (1) and (2) respectively.

$$FMIK = \frac{\sum_i kVAfsi}{kVAinst} \qquad (1)$$

Where, kVAfsi is the value of nominal kVA that are out of service in each of the interruptions "i" and kVAinst is the value of nominal kVA that has been installed.

$$TTIK = \frac{\sum_i kVAfsi * Tfsi}{kVAinst} \qquad (2)$$

Where, kVAfs is the number of nominal kVA that are out of service when interruptions "i" occur, Tfsi is the time that is out of service for interruption "i" and kVAinst is the number of nominal kVA installed.
From the simulation carried out in this investigation, the performance of a grounding system under the conditions of atmospheric discharges with a value of 27.37 kA was determined, obtaining a stabilization result of 0.07 seconds, according to the authors' analysis. They indicate that it is necessary to carry out studies to complement the corona effect, carry out thermographic tests of the different insulators and finally a visual inspection. Theresearchof Herrera M.[10]manages to improve the reliability of a radial type feeder which is based on the novel methodology of Markov Chains [11], and the technique used for the reconfiguration of the distribution network system, applying this technique manages to perfect the FMIK and TTIK indices, in the same way Escudero, Rojas and Quizhpi[12]evaluate the reliability of a feeder for Electrical CompanyAzogues with the use of Montecarlo.

III. Materials and methods

For the materials and methods in this research, it was based on the reference of the data in the period of the year 2021 and the first quarter of 2022 of the public Company CNEL EP of the canton Milagro - Guayas of the feeder system located along the Colon Street (connected to the SCADA System). For software simulation, a recloser is incorporated to improve quality index indicators (TTIK and FMIK).

The collection of data and information is summarized below.

1. Report of electrical service interruptions from CNEL EP Milagro on the dates of January 2021 to March 2022, specifically the data (TTIK and FMIK indices) of interruptions of the feeder of Colon Avenue are filtered.
2. PMP 450i access point and subscriber module installation and configuration manuals.
3. Monitoring of failures reported through the SCADA system by means of screenshots during the investigation period.
4. Simulation involved in the planning of the electrical distribution system by means of the CYMDIST software.
5. Analyze the TTIK and FMIK indices in a feeder, and thus be able to verify and check the results with those of real time in the measurement equipment.

The equipment that is incorporated into the system is the PMP 450i and its information is accessed through an Ethernet interface in real time. In turn, it is connected to the Remote Automated Control SCADA System based on the "SCADA/OMS-MWM/DMS SOFTWARE", through the TCP/IP communications protocol[13].

3.1. Reliabilityindicators and indices

Access point and subscriber module (subscriber) PMP 450i

Cambium Networks PMP 450i is an outdoor fixed wireless platform that provides spectral efficiency and scalability to 900 MHz's. It allows frequency propagation to suit the needs of broadband deployments, SCADA and backhaul of sensor data and data. including video surveillance applications. With features like 100+ Mbps subscriber capability on a 20 MHz channel and the access point is now 802.3at compliant and includes an AUX port, while the subscriber can reuse the 30 VDC power supplies common to the PMP 100 platform PMP 450 Download 3G / 4G, Figure 1 shows the emitter and receiver of the recloser signal used in this work.

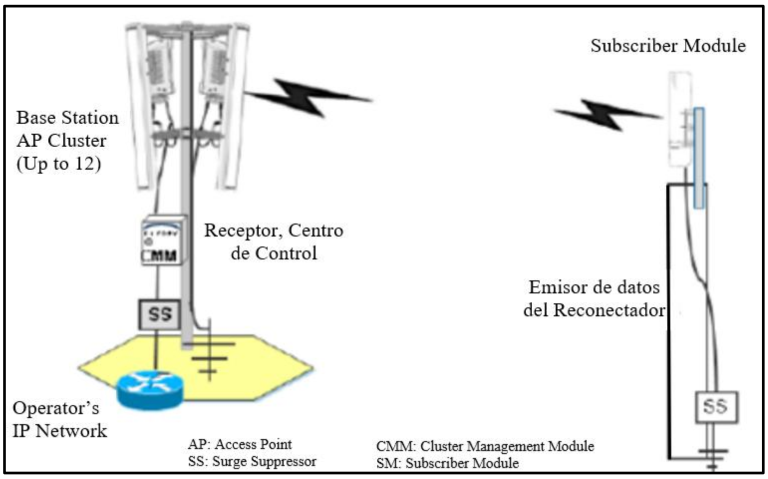


Figure 1: Description of the link used in the proposal.

3.2. Sectorization and location

The location of the recloser will be in the section of the feeder of Avenida Colon crossed by Avenida Colon and P. J. Montero del Canton Milagro.

3.3. Required Parameters

It is known that any Electric Company that focuses on the distribution of electrical energy at a residential level must comply with the system's disconnection limits, taking into account the frequency and disconnection times, as described in [14],the following table shows the indices or values which are admitted by CONELEC, in the feeders; urban and rural.

Table1: Limits established by CONELEC.

Index	Limit FMIK	Limit TTIK
Net	4.0	8.0
Urban feeder	5.0	10.0
Rural feeder	6.0	18.0

3.4. Historical consolidation of frequency and duration index

Tables 2, 3 and 4 present the consolidated consumption and faults based on the two semesters of the year 2021 and the first of the year 2022, taken from the historical data base of the behavior of the header reclosers of the main feeder of the Calle Colon, the faults that have occurred are shown based on the FMIK and TTIK, the times of reestablishment of the chargeability of the flow and energy supply of the feeder of the substation authorized by the Electric Company. With which the information from the historical database of the electrical system is analyzed.

Table2: Frequency and duration indices for the first half of 2021.

Month	January	February	March	April	May	June
FMIK	5	1	4	0.048	1	2
TTIK	5.03	1.06	5.02	0.08	0.63	3.58

Table3: Frequency and duration indices for the second half of 2021.

Month	July	August	September	October	November	December
FMIK	4	1	0	1	0	0
TTIK	0.9	0.053	0	0.75	0	0

Table 4: Frequency and duration indices for the first half of 2022.

Month	January	February
FMIK	1	2
TTIK	0.13	2.06

3.5. Mainfeedermonitoring

From the monitoring, the behavior of the main feeder of Colon Street is presented due to slight or permanent failures that occurred without the timely restoration until its corrective maintenance both in the middle and at the end of the circuit as shown in Figure 2.

Figure 2: Monitoring of faults in real time in the SCADA system.

3.6. Test point location on the simulator

After considering the input parameters, we proceed with the simulation and add the recloser in the middle of the circuit and integrate it into the SCADA system, through the CYMDIST application where fault simulations are carried out from a control system and incorporation of the equipment. CNEL Milagro has the 13.8 kV feeder on Avenida Colon, it is located and presents the coordinates of the point where the single-phase fault was simulated (-2.14259, -79.59103) as shown in Figure 3.

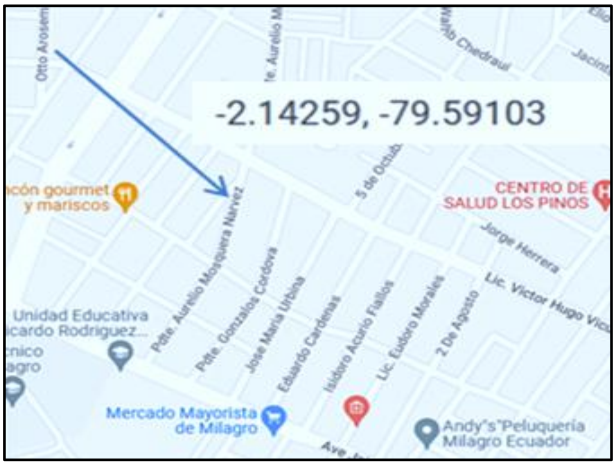
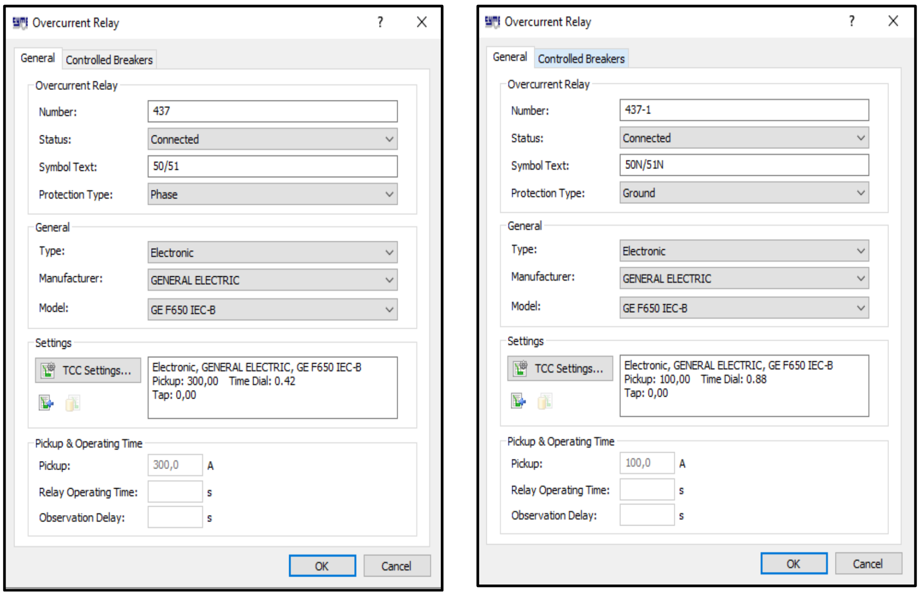


Figure 3: Recloser Location Coordinates.

The simulation is executed by means of the IEC 60909 method, as can be seen in Figure 2, to obtain and analyze the different times in the operation of the protection elements, near the Victor Hugo Vicuña Street recloser.

Figures 4 (a) and (b) show the General tab of the simulator in the "Overcurrent Relay" option where the most important data is entered, such as the recloser model that is GEF650 IECB manufacturer General Electric with a starting current or relay operation of 300 A for phase protection and 100 A for earth protection.



a) Phases: Pickup: 300 A, Curve: IEC-B, TD=0.42, Instant: Off.

b) Grounded: Pickup: 100 A, Curve: IEC-B, TD=0.88,Instant: Off.

Figure4: Data entry in "Overcurrent Relay".

Tables 5 and 6 work with shunt faults, short circuits, and load imbalances.

Table 5: Simulation of the header and half-span switch.

Phases:	**Grounded**:
Pickup: 300 A	Pickup: 100 A
Curve: IEC-B	Curve: IEC-B
TD=0.42	TD=0.88
INSTANT: OFF	INSTANT: OFF

Table 6: Results of the simulation of the Victor Hugo Vicuña Street switch.

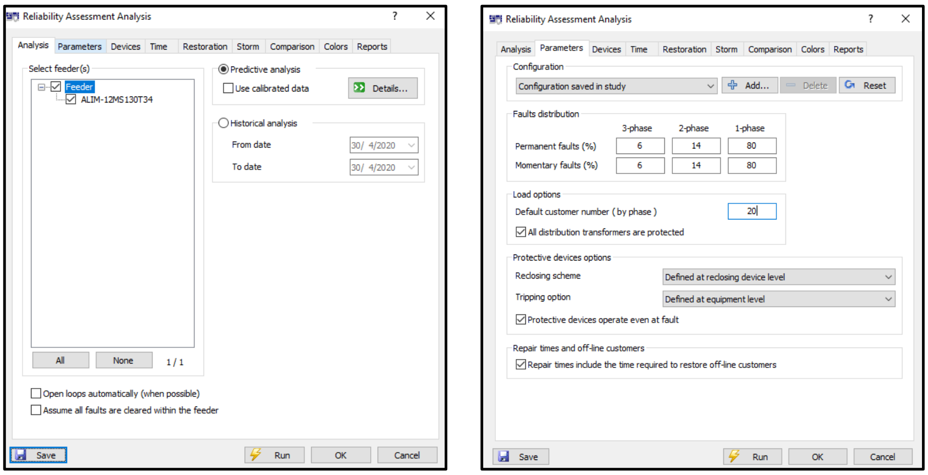
Phases:	**Grounded**:
Pickup: 150 A	Pickup: 90 A
Curve: C3	Curve: C2
TD=1.2	TD=0.45
INSTANT: OFF	INSTANT: OFF

We proceed with the configuration with the "Schweitzer 651R" model since it lends itself to communications-assisted protection schemes; “Integrate the SEL-651R” and communication networks may be best known as they are; Ethernet, DNP3, which is a protocol widely used in the electrical field or area, ModBus or the most widely used worldwide, which is IEC 61850, all these protocols manage to access their communications in a reliable and agile way, the protocol parallel redundancy (PRP) is also operative and apart from being chosen as a standard option in various controls of the "SEL-651R" recloser, it is known that the Ethernet ports are copper or fiber, another feature of this protocol is the switching by network error that are present in the interruptions that occur in the systems of the different electrical substations.

3.7. Simulation with CYMDIST

Based on the bibliography [15], in number 3.4. the respective "Reliability Assessment Analysis" (RAM) module of the CYMDIST software was used to simulate the technical service quality indices FMIK (TIEPI) and TTIK (NIEPI), at the Avenida Colon feeder, in the scenarios with and without a half-span recloser (Victor Hugo Vicuña Street). Next, we proceed to enter the necessary data of the RAM module, to obtain the results.

Then it is observed in Figure 5 (a) "Analysis" and (b) the "Parameters" tab, where the failure rate data was entered; monophasic, biphasic and triphasic, given that CNEL Milagro does not acquire these values, it was taken from reference books and publications, so there is an estimate of percentages of; 6%, 14% and 80% for triphasic, biphasic and monophasic faults respectively.



a) Reliability assessment analysis screen. b) Parameters for reliability evaluation.

Figure 5: Data entry in “Reliability Assessment Analysis”.

With the information provided by the Geographic Information System, where they indicate that for urban feeders CNEL Milagro has an average of 20 transformers per phase. In the "Devices" tab, we will enter the values for the "Failure Rate" column, in order to fill in the values of the "Major Repair Time" and "Minor Repair Time" columns, since CNEL Milagro does not have all the values to calculate this data, the rest of the columns will maintain their default values, the maximum duration time for purely momentary interruptions lasts approximately 180 seconds, and therefore we will only consider exclusively constant failures or known as permanent failures that have a duration greater than 180 seconds for what the regulation committee CONELEC 004/01 indicates[6], since the times for the displacement and the interruption times are already added in the repair time, the default parameters are left in the “Parameters”.

After this, we obtain the values of the indices in all the elements along the Avenida Colon feeder, where we will focus on its head, in the two scenarios: With and without the mid-span recloser of Victor Hugo Vicuña Street.

IV. Results and Discussion

Below is the screen of the results of the various quality indices without the recloser, where it is expected to reduce the parameters as shown in Table 6, column without FMIK recloser (TIEPI) with a value of 4,659 hours /year and TTIK (NIEPI) with a value of 0.632 interruptions/year which is not optimal and could be improved by adding the recloser, and in Table 6, column with recloser, the FMIK (TIEPI) is shown with a value of 4,198 hours/year and TTIK (NIEPI) with a value of 0.577 interruptions/year, which is optimal since the recloser is connected to the Transmission Line. The operation time of the half-span recloser of Victor Hugo Vicuña Street with a single-phase fault of 1920 amps, the fault clearance time is 0.3408 seconds. And the operation time of the main switch of Avenida Colon with the same single-phase fault, the fault clearing time was 0.6528 seconds.

Table 6: Results of the quality indices without and with the ALIM-12MS130T34 feeder recloser.

Parameters	WithoutRecloser	WithRecloser
SAIFI (System AverageInterruption Frequency)	0,665 inter/cust-yr	0,612 inter/cust-yr
MAIFI (Momentary Average Interruption Frequency Index)	0,153 inter/cust-yr	0,227 inter/cust-yr
SAIDI (System Average Interruption Duration Index)	4,891 hr/cust-yr	4,446 hr/cust-yr
CAIDI (Customer Average Interruption Duration Index)	7,353 hr/cust-inter	7,268 hr/cust-inter
ASAI (Average Service Availability Index)	0,999442	0,999493
ENS (Energy Not Supplied)	1859,1 kWh/yr	1687,2 kWh/yr
AENS (Average Energy Not Supplied)	0,313 kWh/cust-yr	0,284 kWh/cust-yr
LEI (Load ExposureIndex)	28809,09 cust-km	28809,09 cust-km
Line length	30,31 km	30,31 km
Cable length	0,89 km	0,89 km
Number of Cust, Served	5942	5942
CEMI (Customers Experiencing Multiple Interruptions)	0,00%	0,00%
CELID (Customers Experiencing Longest Interruption Duration)	27,50%	26,79%
TIEPI (Time InterruptionEquivalent of Power Installed)	4,659 hr/yr	4,198 hr/yr
NIEPI (Number InterruptionEquivalent of Power Installed)	0,632 inter/yr	0,577 inter/yr

As seen in Figures 6 and 7, the simulation results show that, for a 1920-amp fault, the reconnection time is 0.34 seconds, while with the same configuration the reconnection time is 0.65 seconds.

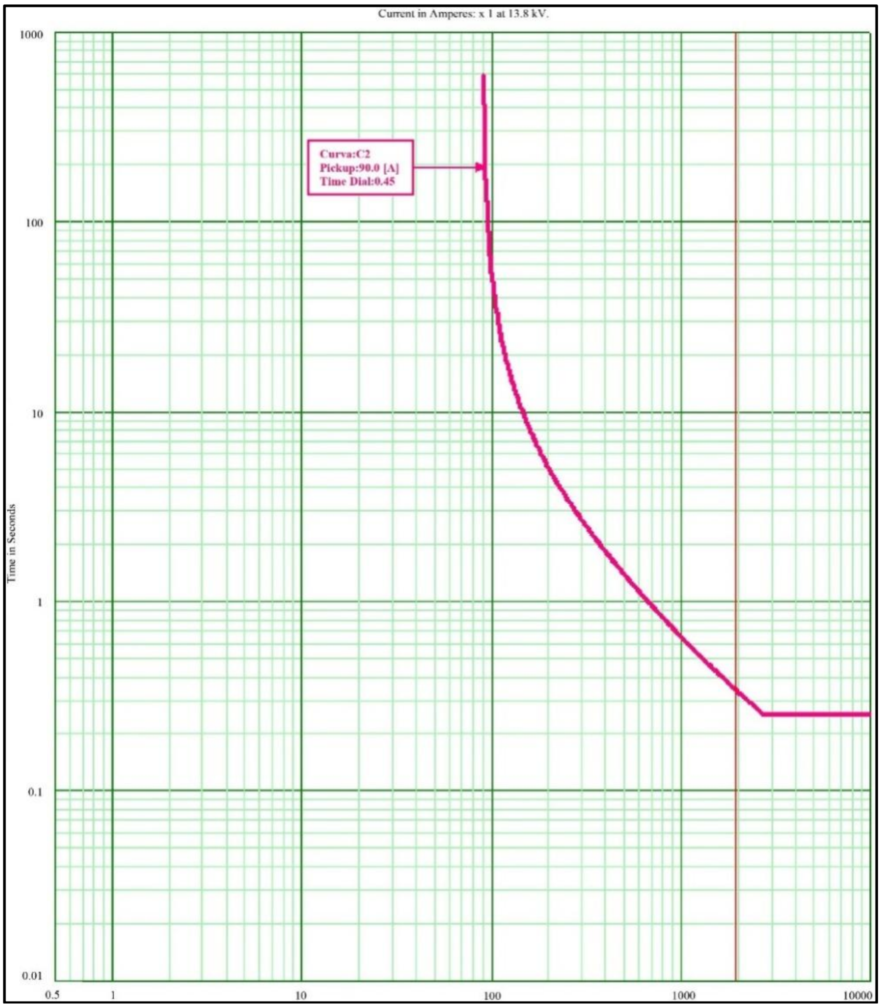


Figure 6: Result of the simulation of the curve of the mid-span recloser of Victor Hugo Vicuña Street.

This means that the option with the shortest reconnection time must be chosen and corresponds to changing the location of the recloser, which must be at the coordinates (-2.14259, -79.50103) of Victor Hugo Vicuña Street and not on Colon Avenue.

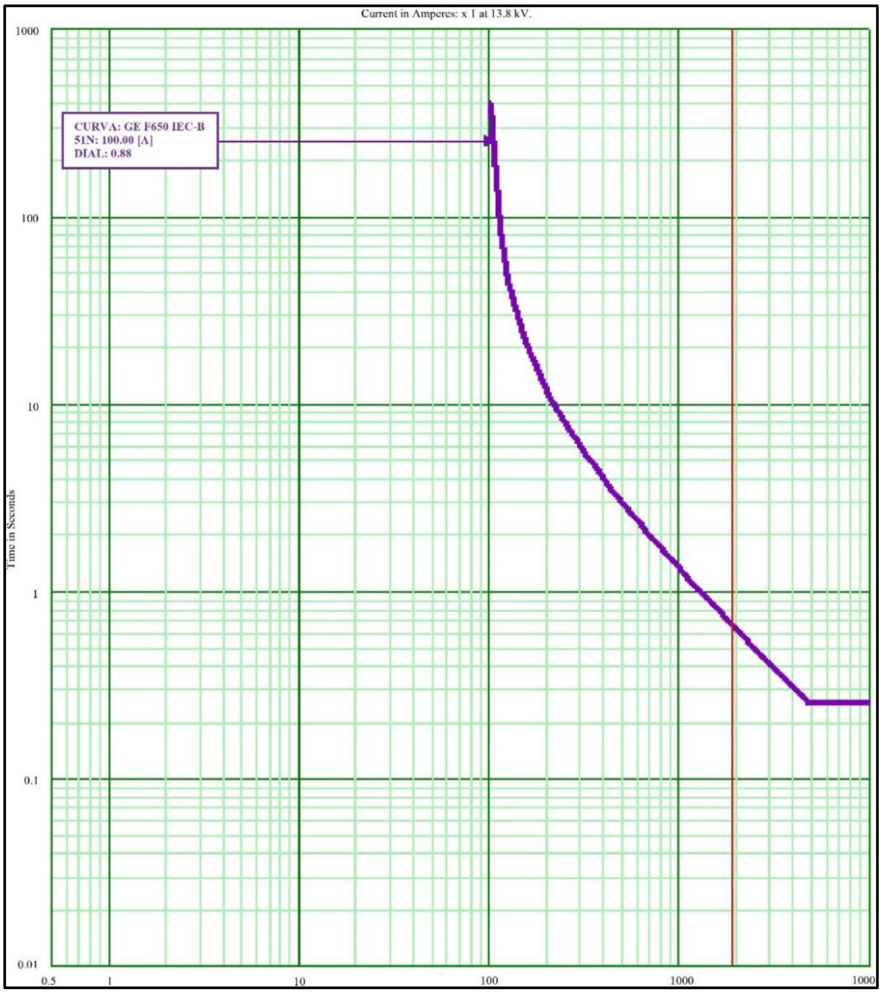


Figure 7: Result of the simulation of the operating time curve of the head switch of Avenida Colon.

a) Before b) After

Figure 8: Implementation of the recloser.

Figure 8 shows the before and after implementation of the recloser under study where the respective analysis and improvement in the quality of service for the community that uses the feeder was carried out.

V. Conclusions

In the proposed work, the three-phase reclosers in distribution networks of Avenida Colon and Calle de Victor Hugo Vicuña were simulated, using the SCADA system of the CYMDIST simulator provided by the Company CNEL EP and through radio link improved the quality indices of electrical service which were the FMIK and TTIK, the operating time for a single-phase fault, will be cleared more quickly by the Victor Hugo Vicuña street half-span recloser, because it is closer to the fault , thus keeping the principle of selectivity, which the protections must comply with; In addition, the half-span recloser, when operating, will disconnect less load than the entire load of the feeder, thus monitoring a correct electrical supply. The recloser must be connected in the path of the feeder in the coordinates of Victor Hugo Vicuña street and not in Colon avenue, as can be compared with the output results of the CYMDIST "Reliability Assessment Analysis" simulator, it is observed that before connecting the recloser, the reliability indices are FMIK (TIEPI): 4,659 hours/year and TTIK (NIEPI): 0.632 interruptions/year and after simulating the recloser on Victor Hugo Vicuña street, the indices are FMIK (TIEPI): 4,198 hours/year and TTIK (NIEPI): 0.577 interruptions/year, which concludes that the indices have improved by 10% and a correct maintenance plan is provided with the new values obtained.

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