



Particle Swarm Optimization-Based Recloser Placement for Reliability Improvement in the Kuala ULP Distribution System

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Abstract: In an electric power distribution system, one of the things that needs to be considered is the reliability of the electric power system. Currently, the location of the recloser is very important for the reliability of the power system. The parameters used for network reliability are the SAIFI and SAIDI values. The SAIFI and SAIDI values can be determined based on the failure time and failure rate in one year. The smaller the SAIFI and SAIDI values, the better the reliability. The purpose of this study is to determine the best recloser position on the MG 03 ULP Kuala feeder grid, Langkat Regency. The method chosen in determining the research location uses particle swarm optimization (PSO) by implementing MATLAB R2021a software. The simulation results show that the reliability before and after reinstallation has changed. SAIFI and SAIDI before reintegration are 1.2495 hours/customer/year and 3.3555 times/customer/year, respectively.

Keywords: SAIFI, SAIDI, Particle swarm optimization, Recloser, MATLAB R2021a.

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INTRODUCTION

The availability of energy supply is crucial to meet human needs. Therefore, it must be possible to transmit and distribute electricity supply in accordance with technical and economic requirements. Technical requirements must be adequate and safe according to the given reliability standards (Anderson, n.d.; Gonen, n.d.). One way to improve system reliability is to quickly repair damage and isolate the fault area so that the impact on the affected area is minimal. A protection system coordination strategy in the distribution system is needed to overcome these failures (Atwa & El-Saadany, n.d.).

Most of the disturbances in the electricity network are in the distribution network, especially in the 20 kV voltage network (Doloksaribu, n.d.; Goenadi, n.d.). One way to improve system reliability is to install, add or relocate optimal fuses or remove equipment. Solutions for optimal placement of reliability devices can be solved with artificial intelligence-based methods (Pasopoulos, Konstantinos, & Vrahatis, n.d.). Research requires an analysis that takes into account the closing function to overcome temporary

disturbances. The method to improve the reliability index of the distribution network is the Particle Swarm Optimization (PSO) method.

This research also refers to PT.PLN (Persero) ULP Kuala Langkat Regency. Which will be the place of my research, because the area still often experiences disturbances in the distribution system, causing prolonged power outages with natural construction that is still natural so that it often causes disturbances in the distribution network, one example of short circuit disturbances, overload disturbances and voltage drop disturbances. This study aims to install reclosers on the Mengduku feeder which is planned to be installed in 2022. Therefore, this study will determine the location of the recloser placement, but using a different method from previous studies (Atwa & El-Saadany, n.d.; No.59, n.d.-a). The recloser placement simulation in this study uses the Particle Swarm Optimization method with the help of Matlab R2021a software.

Optimization is the process of finding the best solution or optimal value for an optimization problem. Optimization problems sometimes seek a maximum or minimum value. Optimization is the process of finding best practices to achieve optimal and ideal results by making the best use of existing resources. Simply put, optimization is a series of processes to optimize existing resources. Optimization is not only used in the business world but also in other fields, including education (Goenadi, n.d.; Gunantara, n.d.).

In electric power distribution, a recloser, or autorecloser, is a circuit breaker equipped with an automatic mechanism that can close after a fault occurs, namely a trip recloser used in SUTM to detect and overcome if a momentary fault occurs. The Entec EVRC 2 A Recloser construction is designed for 110/220 V AC voltage for low voltage distribution lines. The Entec EVRC 2 A consists of an insulated epoxy frame, a metal tank, and a cubicle for control (Gonen, n.d.). The following are the dimensional and standard specifications of the Entec EVRC 2 A Recloser:

Tabel 1. Standar Entec EVRC 2 A

Standard Parameters Enter EVRC 2A	Specification Values
Voltage	27 kV
Frequency Rating	50/60 Hz
Continuous Current Rating	630 A
Short Circuit Current Rating	12.5/16 kA
Rated Making Current	32.5 kA (peak value)
Power Frequency Withstand Voltage	
dry	60 kV (1min)
wet	50 kV (10sec)
Rated impulse withstand voltage	150 kV BIL
mechanical operation life	10,000 operations
auxiliary power supply	AC 110/220 V
control circuit voltage	external power
protection current transformer (CT)	DC24 V
ratio	1000:1 A
Weight	
main tank	160 kg
control cubicle	84 kg

Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is one of the evolutionary computing techniques, where the population in PSO is based on algorithmic search and begins with a random population called particles. Unlike other evolutionary computing techniques, each particle in PSO is also associated with a velocity. The particles move through the search space with dynamic velocities adjusted according to their historical behavior. Therefore, particles have a tendency to move to better search areas after going through the search process. Standard Procedure for Applying the PSO Algorithm:

1. Initialize a population of particles with random positions and velocities in a d-dimensional search space.
2. Evaluate the desired optimization fitness function in the d-dimensional variable for each particle.
3. Compare the particle's fitness evaluation with its Pbest value. If the current value is better than the Pbest value, then Pbest is set equal to that value, and Pi is equal to the location of particle Xi in the d-dimensional space.
4. Identify the particle in the neighborhood with the best results so far.
5. Update the particle's velocity and position.

Return to step 2 until the criteria are met, usually stopping at a sufficiently good fitness value or reaching a maximum number of iterations. Like other evolutionary algorithms, the PSO algorithm is a population-based search based on random particle initialization and interactions between particles in the population. In PSO, each particle moves through the solution space and has the ability to remember its previous best position, which persists across generations (Pasopoulos et al., n.d.; Suyono, n.d.).

METHODS

This methods section explains the data collection procedure, mathematical reliability modeling, and the steps of the PSO algorithm used to determine the optimal recloser point.

The research began with data collection at PLN ULP Kuala Langkat, including existing SAIDI/SAIFI values and Single Line Diagrams. The next step was simplifying the network into linear sections to facilitate mathematical calculations. The research flow systematically followed the procedures presented in Figure 1.

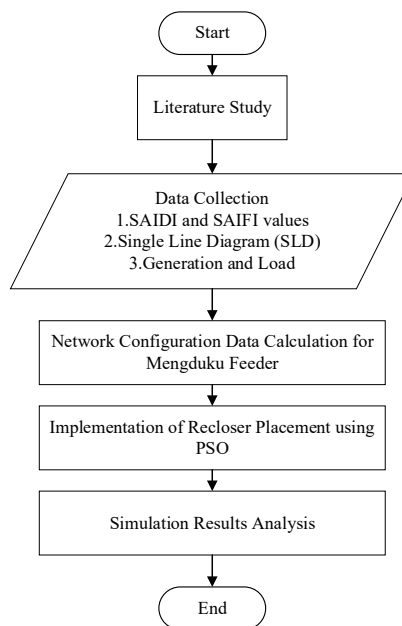


Figure 1. Research Flow

1. Data Collection

This stage involved data collection at the Kuala Langkat ULP. This data collection method was obtained through two research data sources: primary and secondary data. Primary data, or primary data, is data obtained directly by the researcher from the original source without intermediaries. Secondary data, on the other hand, is data obtained by the researcher through literature studies, studying theories such as data processing, including calculating a reliability index before and after recloser placement (Brown, n.d.), optimizing recloser placement using the PSO method, and journals related to and supporting the research discussed. Next, the Matlab software application was used to conduct programming simulations for determining recloser locations.

2. Recloser Placement Calculation and Analysis

In this stage, the collected data was simulated in Matlab software to determine the correct recloser placement using the PSO method.

3. Testing Calculation Results

In this stage, the SAIDI and SAIFI values were tested after recloser placement. The test is followed based on SPLN Standard 68-2: 1986, namely the SAIDI value standard of 21.9 hours/ Customer/Year SAIFI 3.2 Times/ Customer/Year, if the calculated value is below the standard, it is considered that the placement of the recloser is correct and complete (No. 59, n.d.-b; No. 68-2, n.d.).

The main object of this research is the Mengduku feeder. The component data used includes failure rates and repair times for the SUTM, recloser, and PMT, as shown in Table 2.

Table 2. Component Failure Rate and Time-Out Data

Component	λ (Failures/year)	r (Hours/Year)
SUTM	0.0082	0.446
Transformer	0	0
Fuse Cut Out	0.0027	0.051
Recloser	0.005	0.03
PMT	0.019	0.482
LBS	0.013	0.179

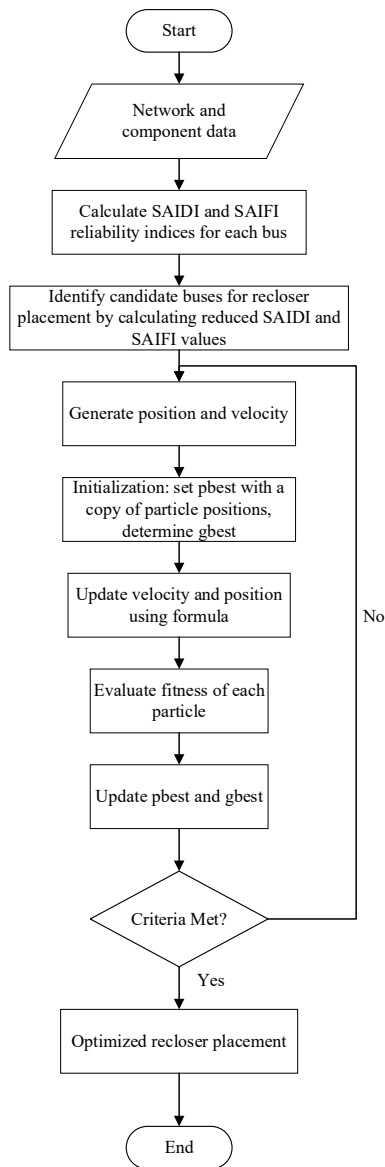


Figure 2. Recloser Placement Process Flowchart

The first step is to simplify the Mengduku feeder network into a linear section, namely by combining the lateral section with the main section. This method is used to simplify the mathematical equation so that it is simpler and more efficient, in addition to that, in principle, the recloser is placed in the main section. Simplification of the network using this series-parallel combination method can be like the following equation.

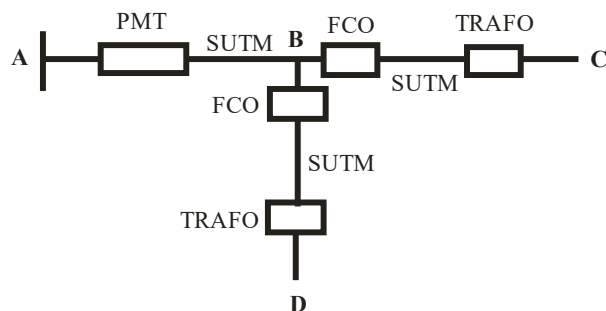


Figure 3. Example of a Mixed Electrical Network of Series and Parallel Elements

1. To make it easier to solve the problem, you can start by simplifying the series components and then simplifying the parallel components (Brown, n.d.; Gonen, n.d.).

$$\lambda_{AB} = \lambda_{PMT} + \lambda_{SUTM}$$

$$r_{AB} = \frac{\lambda_{PMT} \cdot r_{PMT} + \lambda_{SUTM} \cdot r_{SUTM}}{\lambda_{PMT} + \lambda_{SUTM}}$$

$$\lambda_{BC} = \lambda_{FCO} + \lambda_{TRAFO} + \lambda_{SUTM}$$

$$r_{BC} = \frac{\lambda_{FCO} \cdot r_{FCO} + \lambda_{TRAFO} \cdot r_{TRAFO} + \lambda_{SUTM} \cdot r_{SUTM}}{\lambda_{FCO} + \lambda_{TRAFO} + \lambda_{SUTM}}$$

$$\lambda_{BD} = \lambda_{FCO} + \lambda_{TRAFO} + \lambda_{SUTM}$$

$$r_{BD} = \frac{\lambda_{FCO} \cdot r_{FCO} + \lambda_{TRAFO} \cdot r_{TRAFO} + \lambda_{SUTM} \cdot r_{SUTM}}{\lambda_{FCO} + \lambda_{TRAFO} + \lambda_{SUTM}}$$

$$\lambda_{BC//BD} = \lambda_{BC} \cdot \lambda_{BD} \cdot (r_{BC} + r_{BD})$$

$$r_{BC//BD} = \frac{r_{BC} \cdot r_{BD}}{r_{BC} + r_{BD}}$$

Then the failure rate and exit time values at point A are obtained as follows:

$$\lambda_A = \lambda_{AB} + \lambda_{BC//BD}$$

$$r_A = \frac{\lambda_{AB} \cdot r_{AB} + \lambda_{BC//BD} \cdot r_{BC//BD}}{\lambda_{AB} + \lambda_{BC//BD}}$$

2. After obtaining a simple combination, the failure rate and exit time values for each section can be calculated. This data is then used to find the SAIDI and SAIFI values for each section and the entire system. Using the formula:

$$SAIFI = \frac{\sum \lambda_k M_k}{M}$$

Where:

- $f(x)$ = Fitness Evaluation
 λ_{TTR} = System Failure Rate Reviewed From Three-Phase TTR Transformer
 r_{TTR} = System Exit Time Reviewed From Three Phase Transformer TTR
 tLP = Load Point

3. The SAIDI and SAIFI data are then entered into a program to find the x and y values. The x value is the SAIFI value reduced by the placement of reclosers in each section, while the y value is the SAIDI value reduced by the placement of reclosers in each section. The fitness evaluation used in solving this system is:

$$SAIDI = \frac{\lambda_{TTR1} \cdot r_{TTR1} \cdot tLP_1 + \dots + \lambda_{19} \cdot r_{19} \cdot tLP_{19}}{tLP_1 + \dots + tLP_{19}}$$

$$SAIFI = \frac{\lambda_{TTR1} \cdot tLP_1 + \dots + \lambda_{19} \cdot tLP_{19}}{tLP_1 + \dots + tLP_{19}}$$

$$f(x) = \frac{1}{SAIDI \cdot SAIFI}$$

Where:

- $f(x)$ = Fitness Evaluation
 λ_{TTR} = System Failure Rate Reviewed From Three-Phase TTR Transformer
 Γ_{TTR} = System Exit Time Reviewed From Three Phase Transformer TTR
 tLP = Load Point

The use of the above function aims to minimize the SAIDI and SAIFI values so that the best reliability modeling is obtained.

4. The following is the programming algorithm used in this final assignment:
 - a. Enter network data, consumer data, and component reliability data
 - b. The network configuration and the number of reclosers invested are constraints that must be considered to determine system reliability.
 - c. For each failure at each load point, determine the system reliability index. For each failure at a load point, do the following:
 - 1) Calculate the load point reliability index.
 - 2) Repeat for each failure and for each load point.
 - 3) To determine the system reliability index, sum all load point reliability indices.
 - 4) Change the recloser location according to the network configuration and proceed to step 1.
 - 5) Repeat for each possible recloser location.
 - 6) Determine the optimal solution by comparing the reliability indices obtained at each possible recloser location.

RESULTS

The test begins by determining the failure rate and exit time values of each section, by determining the initial values of the recloser failure rate, transformer failure rate, SUTM failure rate, FCO failure rate, PMT failure rate, recloser exit time, transformer exit time, SUTM exit time, FCO exit time, and PMT exit time. In the initial setting of the failure rate and exit time values have been set with a value of 0.005 failures/year for failure rate, 0.03 hours/failure for recloser exit time, 0 failures/year for transformer failure rate, 0 hours/failure for transformer exit time, 0.0082 failures/year for SUTM failure rate, and 0.446 hours/failure for SUTM exit time, 0.0027 failures/year for FCO failure rate, 0.051 hours/failure for FCO exit time, 0.019 failures/year for PMT failure rate, and 0.482 hours/failure for PMT exit time, 0.013 failures/year for transformer failure rate, 0.179 hours/failure for transformer exit time. then these parameters are used to calculate the SAIFI and SAIDI values for each section.



Figure 4. Recloser Placement Point Results

Meanwhile, for table 4.6 the test results above can be said that the bus that has the largest SAIFI (x) reduction value is bus 18 with a reduced number of 0.2487 disturbances/customer year and automatically reduces the SAIFI system from 5.5829 disturbances/customer.year before the recloser is placed, the SAIFI system after the recloser is installed (SAIFI systemAR) becomes 5.334229501 disturbances/customer.year after the recloser is installed in this section. Meanwhile, the SAIDI (y) reduction value that has the largest value is on bus 12 with a total of 0.0921 hours/customer.year which reduces the SAIDI system value to 1.989641343 hours/customer.year from the previous 2.0818 hours/customer.year.

Looking at the reduction value and system in one feeder, the recloser can be placed at bus 18 position with the assumption that this section has the largest reduction value that is able to reduce the SAIFI SAIDI system, while bus 12 is not selected because the SAIDI system value on bus 18 is still below the specified limit (SPLN 59 / 1985 for overhead line repair time $r = 3$ hours) with a value of 1.990841343 hours/customer year. In addition, it is also due to the number of customers who are burdened on bus 18 being more efficient than bus 12 with a number of 2206: 2598 so that if a disturbance occurs and results in a blackout, section 18 has a smaller risk and impact than bus 12. So it can be seen in Figure 11 determining the placement of the recloser on bus 18. Testing on this system is the same as the placement carried out by PLN, on the Mengduku PLN ULP Kuala feeder which prefers bus 18 because this section is also the location of the connecting substation (GH TURANGI) so it is assumed that it can reduce the impact if a disturbance occurs at the connecting substation.

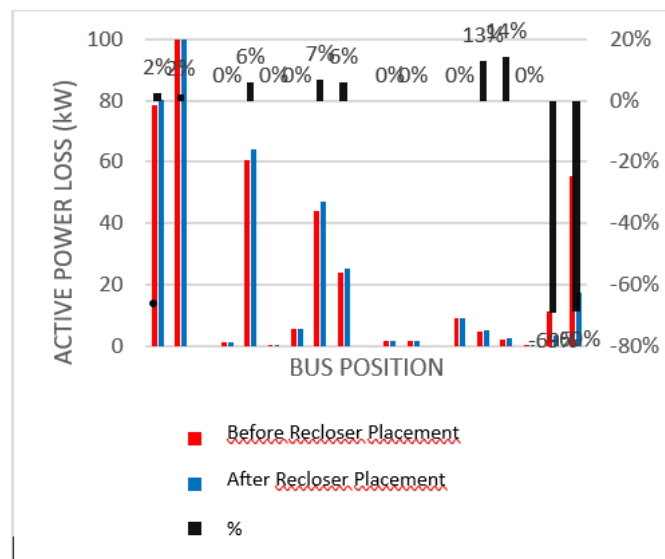


Figure 5. Comparison of Active Power Losses Before and After Recloser Placement

Based on Figure 4.4, we can see a comparison of the active power losses of the system before and after optimization with the addition of a recloser. Where the blue graph is the graph before optimization and the orange graph is the graph after the recloser is installed. Before optimization, the largest power loss occurred between bus 18 and bus 19, namely 55.2 kW after optimization, after optimization it decreased to 17.1 kW.

DISCUSSION

The findings of this study demonstrate that the implementation of the Particle Swarm Optimization (PSO) method for recloser placement significantly improves the reliability performance of the Mengduku feeder at PT PLN ULP Kuala. The optimization results showed a considerable reduction in the SAIFI and SAIDI indices after the placement of the recloser on bus 18. These findings indicate that the application of intelligent optimization algorithms in distribution systems can effectively minimize outage frequency and outage duration experienced by customers. Reliability improvement is an important indicator in electric power systems because continuity of service directly affects customer satisfaction and operational efficiency in distribution networks. The results obtained in this study are consistent with the theory proposed by Electric Power Distribution Reliability, which states that reliability enhancement can be achieved through optimal sectionalizing and protection coordination.

The decrease in SAIFI values after optimization indicates that the number of interruptions experienced by customers can be reduced significantly through appropriate recloser placement. Before optimization, the system experienced a higher disturbance frequency, while after PSO implementation, the disturbance frequency decreased substantially. This result confirms that the recloser functions effectively as an automatic protective device capable of isolating temporary faults rapidly before they propagate to larger network sections. According to Electric Power Distribution System Engineering, the use of automatic reclosers is one of the most effective approaches for improving distribution system continuity because most disturbances occurring in medium-voltage distribution networks are temporary disturbances.

In addition to reducing SAIFI values, the optimization process also succeeded in lowering SAIDI values, indicating shorter outage durations experienced by customers. The reduction of outage duration occurs because the recloser can isolate faulted sections faster and restore unaffected sections more efficiently. The results of this study align with previous research conducted by Yasser M. Atwa and Ehab F. El-Saadany, who explained that optimal protection coordination and switching devices significantly contribute to improving reliability indices in distribution systems, especially in networks experiencing high disturbance rates.

The selection of bus 18 as the optimal recloser placement location demonstrates that PSO can identify network sections with the highest contribution to reliability improvement. The algorithm successfully analyzed the reduction in SAIFI and SAIDI values across different buses and selected the most effective placement alternative. This supports the argument that heuristic optimization methods are highly suitable for solving complex distribution system problems involving multiple variables and constraints. The PSO method has advantages in computational simplicity, fast convergence, and the ability to avoid local optimum solutions compared with conventional optimization methods. As explained by Particle Swarm Optimization researchers Pasopoulos and Vrahatis, PSO is highly effective for engineering optimization problems involving nonlinear and multidimensional search spaces.

The reliability improvement obtained in this research is also influenced by the characteristics of the Mengduku feeder network. The existence of a connecting substation near bus 18 makes this location strategically important because disturbances occurring in this area potentially affect a larger number of customers. Therefore, placing the recloser at this point provides better system protection and minimizes the propagation of disturbances throughout the feeder. This finding supports the reliability planning principles proposed in the SPLN reliability standards, which emphasize the importance of strategic protection coordination in medium-voltage distribution systems.

Another important finding of this study is the reduction of active power losses after recloser installation. The comparison graph shows that power losses between bus 18 and bus 19 decreased significantly after optimization. This condition indicates that reliability

improvement not only affects service continuity but also contributes to operational efficiency in the distribution network. Lower power losses imply more efficient power delivery and reduced energy waste during system operation. According to distribution engineering theory, reducing outage duration and improving network sectionalization can indirectly improve voltage profiles and reduce technical losses in the system.

The implementation of PSO in this study also demonstrates the growing importance of artificial intelligence approaches in modern power system engineering. Conventional analytical methods often face difficulties when dealing with complex distribution networks containing multiple operational variables. In contrast, PSO provides adaptive search mechanisms capable of identifying optimal solutions efficiently. Similar findings were reported by H. Suyono, who explained that PSO-based optimization techniques can significantly improve electrical system performance due to their capability to adapt dynamically during the optimization process.

From a practical perspective, the results of this study provide important recommendations for PT PLN and other power utilities regarding the planning of protective devices in distribution networks. The optimization approach used in this research can be adopted as a decision-support tool for determining optimal recloser placement in other feeders experiencing similar reliability issues. Moreover, the use of MATLAB R2021a proves that simulation-based approaches are highly effective for evaluating system reliability before implementing actual field installations. Consequently, utilities can reduce planning errors and improve investment efficiency in network protection infrastructure.

This study also contributes theoretically to the development of reliability optimization research in electrical distribution systems. Previous studies mainly focused on reliability analysis without integrating intelligent optimization algorithms comprehensively. The integration of PSO with reliability indices such as SAIFI and SAIDI in this study provides a more systematic framework for evaluating protection system performance. Furthermore, the combination of reliability modeling and optimization techniques offers a promising approach for future smart grid development, where automation and intelligent protection coordination become essential components of modern electrical networks.

Despite the positive findings, this study still has several limitations. The optimization process focused only on one feeder and one type of protection device, namely the recloser. Future studies should consider integrating other protective devices such as sectionalizers, load break switches, and distributed generation systems into the optimization model. In addition, the study used deterministic reliability parameters, whereas real distribution systems may experience stochastic variations due to weather conditions, load fluctuations, and equipment aging. Therefore, future research can develop probabilistic or hybrid optimization models to produce more comprehensive reliability assessments.

The results of this study confirm that the Particle Swarm Optimization method is highly effective for determining optimal recloser placement in electrical distribution systems. The significant reduction in SAIFI, SAIDI, and active power losses indicates that intelligent optimization approaches can improve both reliability and operational efficiency simultaneously. The findings strengthen the role of computational intelligence methods in supporting the modernization of electrical power distribution systems and provide valuable insights for utilities seeking to enhance service quality and system stability.

CONCLUSION

The placement of reclosers on the Mengduku feeder, using the Particle Swarm Optimization (PSO) method, obtained optimal placement, namely on bus 18, obtained SAIDI and SAIFI values of 0.024 hours/customer/year and 0.479 times/customer/year.

Whereas before the placement of the recloser, the SAIDI and SAIFI values obtained were 1.2493 hours/customer/year and 2.6703 times/customer/year.

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