

Optimal Placement of Auto Reclosers for Distribution System Considering Reliability in Attapeu Province Laos PDR

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Abstract. *In this paper, the method for selecting the optimal location of auto reclosers in distribution system considering system reliability is proposed. The Monte Carlo simulation (MCS) technique is utilized for evaluating the reliability of the distribution system. The MATLAB program is used to create the MCS model. In the MCS model, the exponential distribution function is used to generate time to failure (TTF) and time to repair (TTR) of each component in the distribution system in order to model the operation status profile of each component. The three reliability indices consisting of the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and the energy not supplied (ENS) are taken into account in the process of optimal location evaluation of auto recloser. Moreover, the benefit-cost analysis of auto recloser installation considering the life cycle cost of the auto recloser and the system reliability is presented. Finally, in order to demonstrate the effectiveness of the proposed method, the IEEE Roy Billinton Test System BUS-4 (IEEE RBTS BUS-4) and the 22 kV distribution system of Electricite Due Laos in Attapeu province, Laos PDR is utilized. From the simulation results, it can be concluded that the auto reclosers should be located around the center of the distribution system.*

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1. Introduction

The electric power system can be separated into four sections including generation system, transmission system, distribution system, and load or consumer. The distribution system is a considerable part of the electric power system because it directly takes responsibility to the customers. It

was reported that 80% of all interruptions in electric power system came from failures in the distribution system [1]. The radial distribution system in Attapeu province, Laos PDR has one major defect that in case that the transmission line connecting between transmission and distribution systems fails, the consumer would not get any power from the main system because there is no alternative path to feed the electric power to the distribution system. Moreover, in the case of transformer or substation in the transmission system failure also, the electric power cannot be supplied to the distribution system as well. The consumers in the distribution system are not supplied until the aforementioned transmission line and substation are restored. For the outage in the distribution system, the most outages are the “line to line fault”, “the line to a ground fault” and “lightning”.

In the literature review of reliability evaluation, the basic principle of reliability assessment of the distribution system was presented by research works [2]–[6]. The basic technique of reliability assessment can be classified into two methods consisting of the analytical method and the simulation method. The analytical method was extensively used, [5]–[8], but it is difficult to be used in the actual system which is very complicated. For the simulation method, it can also be known as the Monte Carlo simulation method which was considerably used for reliability evaluation in the last few decades. This method performs risk analysis by building models of possible results by substituting a probability function for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions. Consequently, this method can predict many failure events of the distribution system; while, the analytical method cannot predict. Therefore, the simulation method is more suitable for a large or complex system that has many failure events [9]–[13]. The Monte Carlo simulation method uses the exponential distribution function to generate the profile of each component in the distribution system by using its failure rate and repair time. In order to improve system reliability, an automatic

protective device such as auto recloser was selected [14]. The stability and reliability of the distribution system are enhanced by installing the auto recloser [15].

According to the previous research works, there is no consideration of cost and benefit analysis of auto recloser installation during finding the suitable auto recloser location. Moreover, this research tries to test the reliability evaluation method with the actual and complex distribution system when considering auto recloser installation.

Thus, this paper proposes the method for solving the optimal placement of auto reclosers in order to improve the reliability of the Attapeu distribution system, Lao PDR. The Monte Carlo technique is used to evaluate the system reliability. Moreover, the benefit-cost analysis was achieved from the optimal placement of auto reclosers. The objective function includes the benefit of reliability improvement obtained from auto reclosers installation minus the investment cost and the operation-maintenance cost of auto reclosers.

2. Methodology

2.1 Reliability Indices

There are three the basic parameters in the distribution system reliability assessment including the failure rate λ (interruptions/year), the interruption duration r (hours/interruption), and the annual unavailability U (hours/year), [16] - [17] as shown below.

$$\lambda = \sum_{i=1}^N \lambda_i \tag{1}$$

$$r = \frac{U_i}{\lambda_i} \tag{2}$$

$$U = \sum_{i=1}^N \lambda_i U_i \tag{3}$$

; where, N is the total amount of the components in the distribution system. i is the index of load point.

This research considers the three important system reliability indices consisting of SAIFI, SAIDI, and ENS. These indices can be expressed as shown below:

1) System average interruption frequency index: SAIFI (interruptions/customer/year) can be presented in equation (4) [16]-[17].

$$SAIFI = \frac{\sum_i \lambda_i N_i}{\sum_i N_i} \tag{4}$$

; where N_i is the number of consumers at load point i . 2)

System average interruption duration index: SAIDI (hours/customer.year) can be calculated as shown in equation (5).

$$SAIDI = \frac{\sum_i U_i N_i}{\sum_i N_i} \tag{5}$$

3) Energy not supplied: ENS (kWh/yr.) can be calculated by equation (6).

$$ENS = \sum L_{a(i)} U_i \tag{6}$$

; where $L_{a(i)}$ is the average load (kW) at load point i . The average load can be described in equation (7) and (8).

$$L_a = L_p f \tag{7}$$

$$L_a = \frac{E_d}{t} \tag{8}$$

; where, t is the number of hours in a year. E_d is the energy demand in a period of interest (kWh). L_p is the peak load (kW) and f is a load factor.

2.2 Reliability Worth

The yearly energy not supplied cost (ENSC) for each load point in the distribution system is evaluated by the equation (9), shown in [16] - [17].

$$ENSC = \sum_{i=1}^N C_i \times ENS_i \tag{9}$$

; where C_i is the cost of the outage of load point i .

The costs of auto recloser are separated into two types including the maintenance and investment costs. The investment cost is a once cost that consists of construction, monitoring device, installation costs, etc., as shown in [18]. The investment costs calculation can be expressed as shown in equation (10).

$$INVC = C_{RE-INV} \times N_{RE} \tag{10}$$

; where, $INVC$ is the total investment cost of auto recloser (\$). N_{RE} is the number of new auto reclosers installed in the system. C_{RE-INV} is the purchase and installation cost of an auto recloser (\$).

The yearly maintenance cost consisting of annual electrical repair, mechanical and renovation costs can be calculated by equation (11) in, [18]:

$$MAINC = C_{RE-MAIN} \times N_{RE} \tag{11}$$

; where, $MAINC$ is the total maintenance cost of an auto recloser (\$/year). $C_{RE-MAIN}$ is the yearly maintenance cost of an auto recloser (\$/year).

In this research, the benefit during its lifetime for the auto recloser installation is presented. The lifetime that considered in this paper is 20 years. Hence, the objective function can be written by equation (12):

$$CF = ENSC - MAINC - INVC \quad (12)$$

; where, CF is the income of the distribution system company (\$) achieved from the installation of the auto recloser.

2.3 Monte Carlo Simulation

The Monte Carlo simulation method simulates the fault occurrence in distribution systems due to the reality that the fault occurrence is random. The behavior of the distribution system components was predicted by the probabilistic technique from the Monte Carlo simulation method. The up and down sequential operation status of each component in the distribution system can be provided by the Monte Carlo simulation. The time to failure (TTF) which is the time period that takes the component to failure as described in [16], [19], and [20] can be randomly predicted by the equation (13).

$$TTF = -\frac{1}{\lambda} \ln(n) \quad (13)$$

; where, n is a random amount (range from 0 to 1).

The time to repair (TTR) is the time required to repair or replace a failed component. Also, it is estimated randomly by the following equation (14).

$$TTR = -\frac{1}{\mu} \ln(n) \quad (14)$$

; where, μ is the repair rate of the system component.

In equations (13) and (14), both TTF and TTR are derived from the exponential distribution. To predict the operation history of each distribution system component, TTF and TTR of each component are created for the whole simulation periods (e.g. 1 year) in sequential order. In Fig. 1, the sample of component operation history is presented. In order to get a correct result, Monte Carlo simulation has to be operated for a large number of scenarios; therefore, simulation time should be expanded (e.g. 1,000 years or more) depending on the desired accuracy. In this research, the simulation time is defined to be 5,000 years which is achieved by the test. The flow chart of the simulation procedure by the Monte Carlo method is presented in Fig. 2.

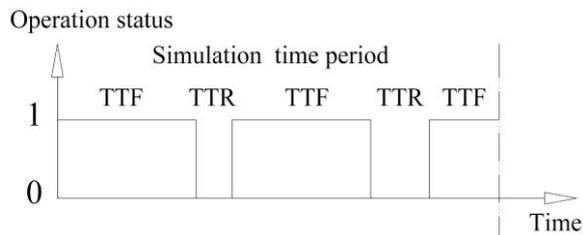


Fig. 1 TTF and TTR of the component

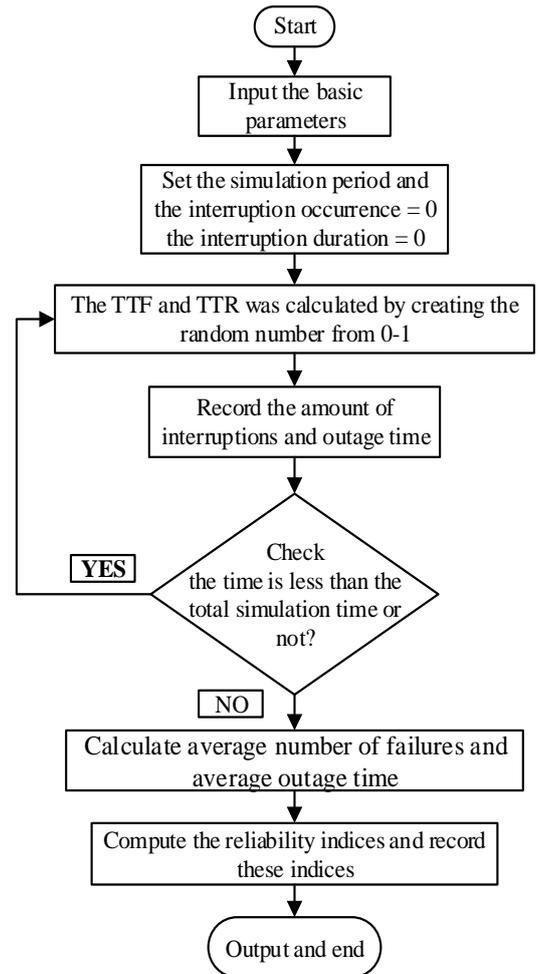


Fig. 2 Flowchart of Monte Carlo simulation procedure

2.4 Proposed Method for Finding the Optimal Position of Two Auto Reclosers

Because of the fact that the average distribution line length in the system of Attapeu province, Laos PDR is long. Therefore, only one auto recloser is not enough to protect the interruption or failure of the system. Hence, this research used two auto reclosers in order to comprehensively protect the system. This section presents the proposed technique to find the optimal placement of two auto reclosers considering the reliability indices of the distribution system. Fig. 3 presents the process to find the lowest values of the system reliability consisting of ENS, SAIFI, and SAIDI when auto recloser is installed.

3. Numerical Results and Discussion

In this section, the effectiveness of the proposed method is performed via testing on the Institute of Electrical and Electronics Engineers Roy Billinton Test System (IEEE RBTS BUS-4) and the distribution system of Attapeu province, Lao PDR on Feeder 01 as presented in the following subsections.

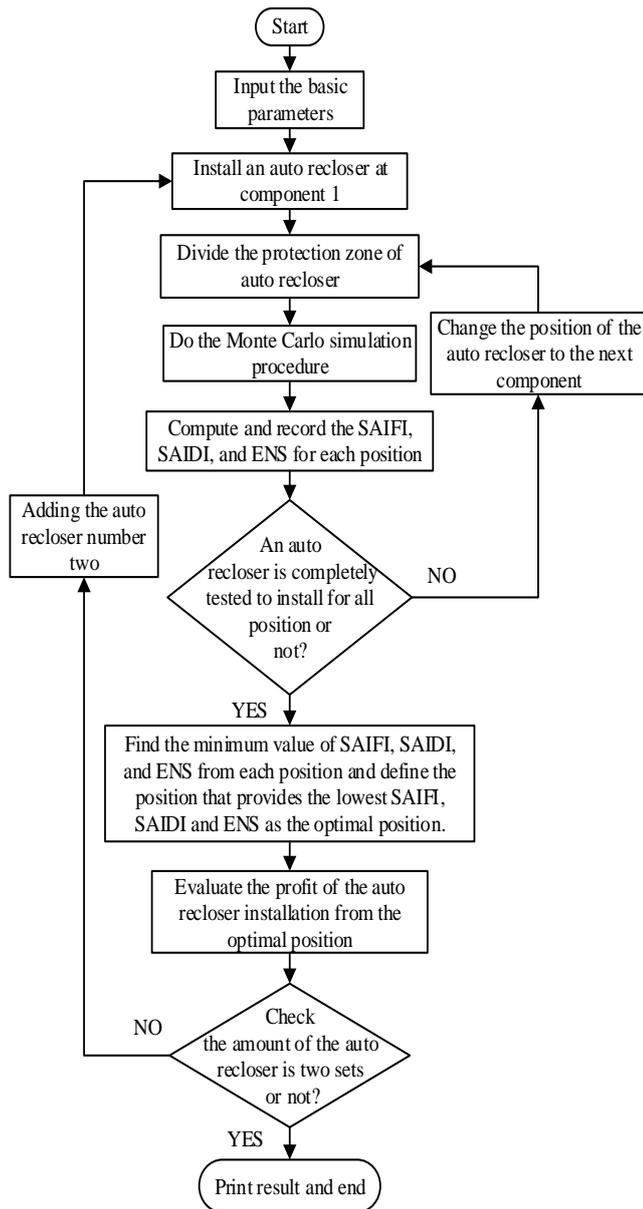


Fig. 3 The flowchart for explaining the optimal placement of two auto reclosers.

3.1 Testing on IEEE RBTS BUS-4

The IEEE RBTS BUS-4 consists of 7 feeders, 36 load points, 67 lines, 4 switches, 76 disconnecting switches, and 36 fuses as shown in Fig. 4 [6]. This system is widely used for testing the reliability evaluation method in the distribution systems because it completely provides all information such as repair time and the failure rate of each component.

In order to analyze the impact of system component on system reliability, the simulation can be separated into four cases as explained below.

Case A: considering only failure rate and repair time of transformers without alternative supply, fuses and disconnecting switch.

Case B: considering only failure rate and repair time of transformers with alternative supply, fuses and disconnecting switch.

Case C: same as Case B but installing one auto recloser in the distribution system.

Case D: same as Case C but installing two auto reclosers in the distribution system.

Firstly, to test the accuracy of the MCS, Cases A and B of the IEEE RBTS BUS-4 are selected. The accuracy of the Monte Carlo simulation method is tested by comparing its result with the result from the analytical method. The comparison result is presented in Table 1.

Index	Case A in overhead line of BUS 4		
	(A) [6]	(S)	Difference (%)
SAIFI (int./cus.yr.)	0.682	0.668	2.01
SAIDI (hrs./cus.yr.)	24.640	24.173	1.93
ENS (kWh./yr.)	374,085	366,568	2.05

Index	Case B in overhead line of BUS 4		
	(A) [6]	(S)	Difference (%)
SAIFI (int./cus.yr.)	0.300	0.299	0.19
SAIDI (hrs./cus.yr.)	3.470	3.401	2.02
ENS (kWh./yr.)	54,293	53,258	1.94

Table 1 The comparison results of system reliability achieved from the analytical (A) and simulation (S) methods for the IEEE RBTS BUS-4

Because of the fact that the Feeder 04 of IEEE RBTS BUS-4 has the greatest number of customers compared with other feeders. It can be implied that the effect of auto recloser installation to reliability will be higher than other feeders. Consequently, this paper selects this feeder to be tested the performance of the proposed method. The Feeder 04 of IEEE RBTS BUS-4 can be seen at the frame in Fig. 4. The results of all four cases are presented in Table 2.

Firstly, for case A, the result shows that this case has the lowest system reliability because when a fault occurs in the line, the substation circuit breaker will operate which causes the interruption through the feeder. Secondly, in Case B, the system reliability can be improved by operation of a protective device consisting of fuses, disconnecting switch and alternative supply. Thirdly, the result in Case C shows that the suitable location of an auto recloser is component 39 because it provides the minimum SAIFI, SAIDI, and ENS. Finally, Case D which installs two auto reclosers. To find the optimal placement of two auto reclosers in the system, the proposed optimal placement of the auto recloser shown in Fig.3 is used. The result shows that the optimal placement of the auto reclosers is components 36 and 39 because two installed auto reclosers can provide the lowest SAIFI, SAIDI, and ENS.

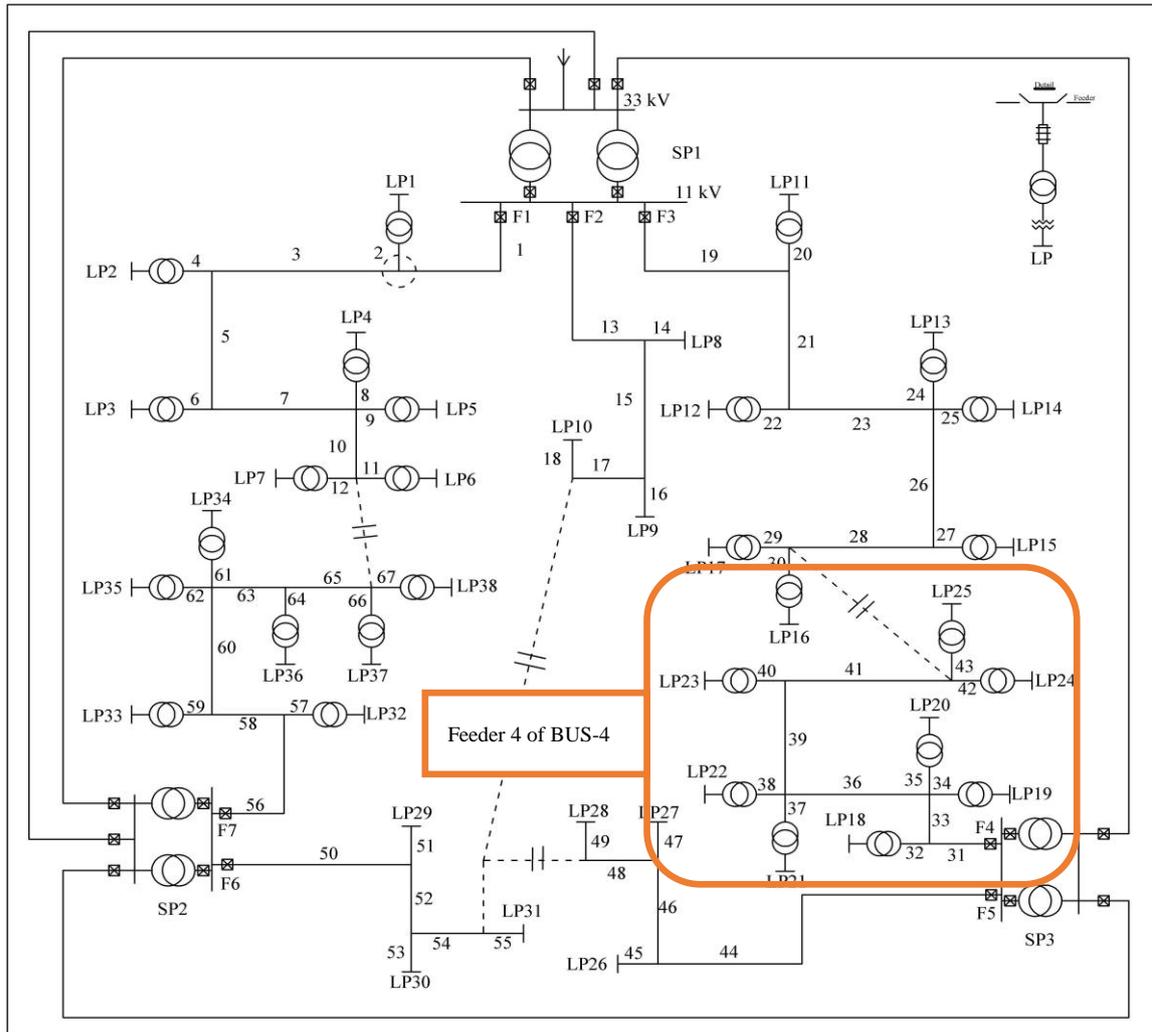


Fig. 4 Single line diagram of the IEEE RBTS BUS-4

Case	Considered Index	Optimal location of auto recloser when considering index	Index value (A) [6]	Index value (S)	Difference (%)
Case A	SAIFI (int./cus.yr.)	-	0.729	0.727	0.303
	SAIDI (hrs./cus.yr.)	-	27.05	26.92	0.484
	ENS (kWh./yr.)	-	108,450	107,948	0.465
Case B	SAIFI (int./cus.yr.)	-	0.308	0.312	1.282
	SAIDI (hrs./cus.yr.)	-	3.48	3.37	3.120
	ENS (kWh./yr.)	-	13,930	13,524	3.002
Case C	SAIFI (int./cus.yr.)	Component 39	-	0.420	
	SAIDI (hrs./cus.yr.)	Component 39	-	2.11	
	ENS (kWh./yr.)	Component 39	-	9,192	
Case D	SAIFI (int./cus.yr.)	Component 39 and 36	-	0.349	
	SAIDI (hrs./cus.yr.)	Component 39 and 36	-	1.751	
	ENS (kWh./yr.)	Component 39 and 36	-	8,036	

Table 2 The comparison of system reliability indices in Feeder 04 of the IEEE RBTS BUS-04 (overhead line case)

3.2 Testing on Feeder 01 of the Distribution System in Attapeu province, Lao PDR

Besides, in this research, Feeder 01 of the distribution system in Attapeu province Lao PDR as shown in Fig.5 is selected for testing the proposed method. The number of consumer in the Feeder 01 is 8,809 users, overall line length is 267.1 km, the failure rate of the transmission line is 0.172 interruptions/yr.km and the repair time of the transmission line is 0.75 hr/km. The distribution system in Attapeu province, Lao PDR is presented in Fig.5. There are 142 load points, 275 lines, 2 load break switches, 1 disconnecting switch, and 161 fuses.

In this research, the lifetime of an auto recloser is defined as 20 years, the price of an auto recloser consisting of the purchase and installation costs is 30,000 USD [21], [22]. The annual maintenance cost is 5 percentages of the purchase and installation costs. The currency exchange rate in May 2019 is 8,628 KIP per 1 USD. Finally, because of the fact that the outage cost in Lao PDR is concealed; therefore, this research assumed the electricity tariff rate in 22 kV distribution systems of Electricite Due Laos as the outage cost. The electricity tariff rate is 0.0857 USD/kWh.

The simulation results of the Feeder 1, distribution system of Attapeu province, Lao PDR are presented in

Table 3. The results are compared only Case B, Case C, and Case D because the actual system of Attapeu province, Lao PDR has the protection devices. The results in Case C show that the suitable location of an auto recloser number is component 195 because it provides the minimum SAIFI and SAIDI. However, if the energy not supplied is the main concern, the suitable location of an auto recloser should be component 193. In addition, for the Case D which installs two auto reclosers into the system, the result shows that the optimal placement of the second auto recloser is component 68 because two installed auto reclosers can provide the lowest SAIFI, SAIDI, and ENS comparing to Case C. The locations of auto recloser that can significantly reduce the SAIFI, SAIDI, and ENS for all three cases are presented in Fig. 6, Fig. 7, and Fig. 8, respectively. It can be seen from Fig. 8 that the minimized energy not supplied of Feeder 01 has appeared when two auto reclosers are installed at components 68 and 193.

In Table 4, the benefit from the best location of two installed auto reclosers in the distribution system of Attapeu province, Lao PDR is presented. It can be seen that the obtained benefit of the distribution system in Attapeu province, Lao PDR by the two auto reclosers installation is about 492,391 USD when considering throughout the auto recloser lifetime.

Test	Considered index	Optimal location of auto recloser when considering index	Result (s)
Case B	SAIFI (int./cus.yr.)	-	46.062
	SAIDI (hrs./cus.yr.)	-	34.628
	ENS (kWh./yr.)	-	716,426
Case C	SAIFI (int./cus.yr.)	Component 195	27.995
	SAIDI (hrs./cus.yr.)	Component 195	21.075
	ENS (kWh./yr.)	Component 193	416,520
Case D	SAIFI (int./cus.yr.)	Component 195 and 68	21.871
	SAIDI (hrs./cus.yr.)	Component 195 and 68	16.468
	ENS (kWh./yr.)	Component 193 and 68	359,138

Table 3 The reliability results of Feeder 01 of the distribution system in Attapeu province, Lao PDR

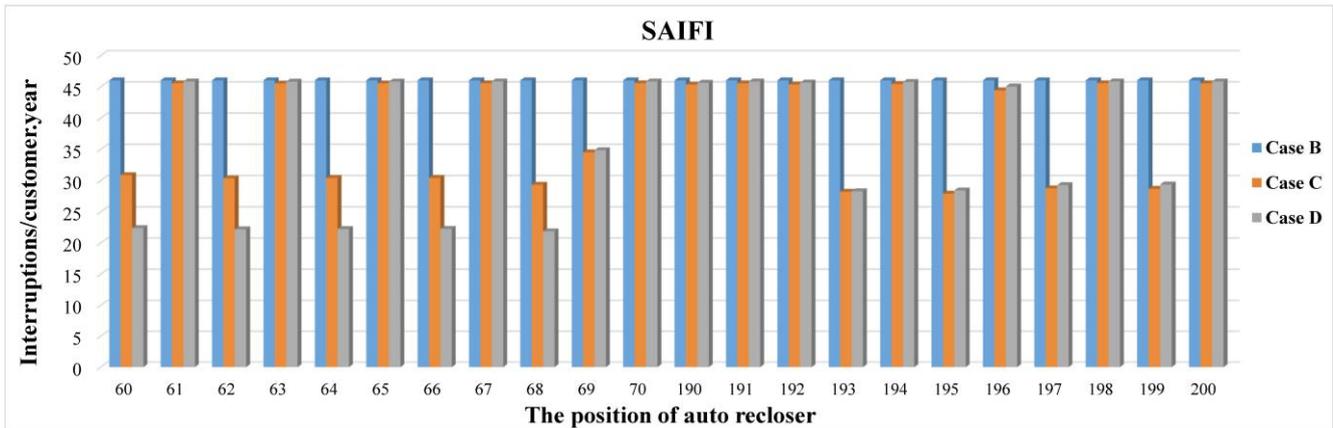


Fig. 6 The calculated SAIFI when installing an auto recloser for each location in Feeder 01 of the distribution system, Attapeu province, Lao PDR

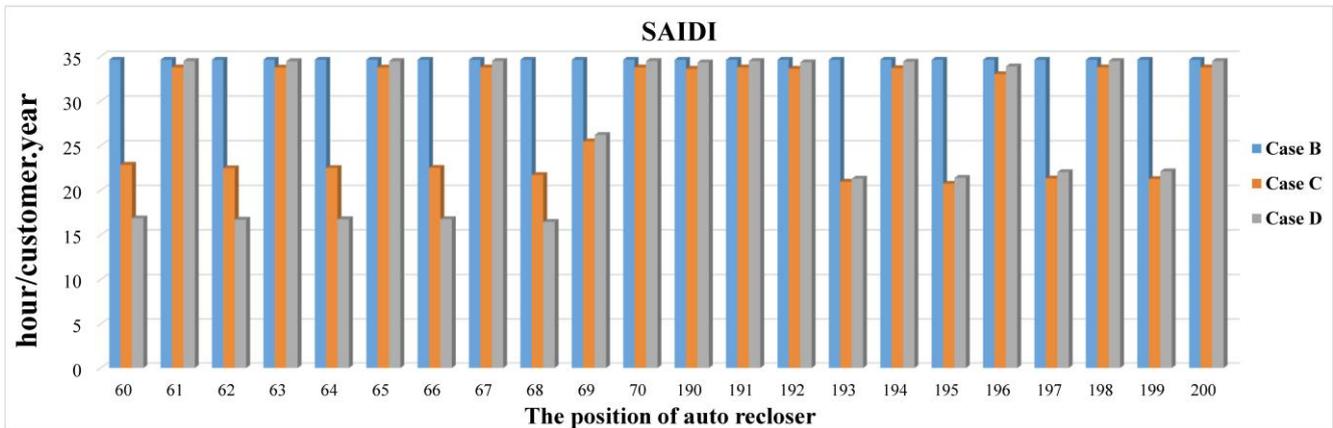


Fig. 7 The calculated SAIDI when installing an auto recloser for each location in Feeder 01 of the distribution system, Attapeu province, Lao PDR

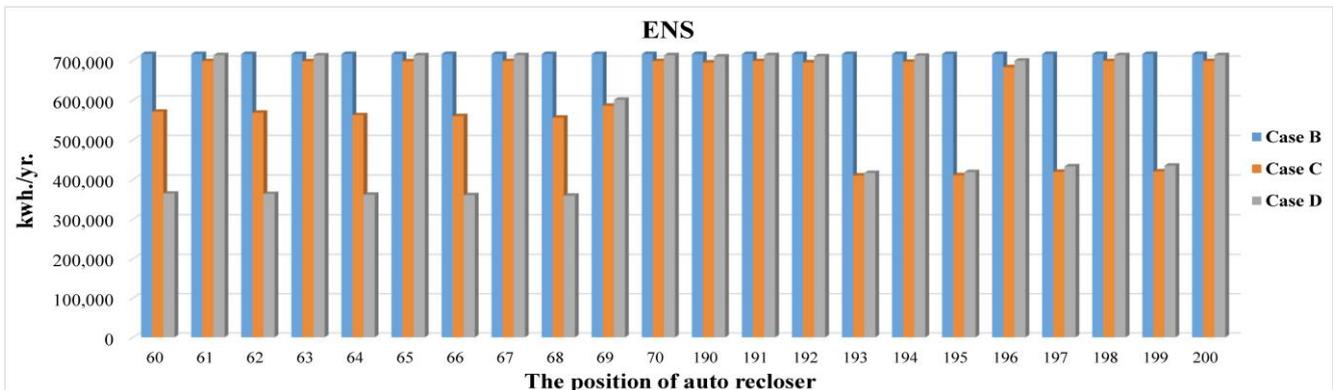


Fig. 8 The calculated ENS when installing two auto recloser for each location in Feeder 01 of the distribution system, Attapeu province, Lao PDR

Detail	Quantity	Unit
ENS without auto recloser (1)	716,426.69	kWh./yr.
ENS after installing two auto reclosers (2)	359,138.93	kWh./yr.
ENS reduction (1)-(2)	357,287.76	kWh./yr.
ENS reduction for 20 years	7,145,755.24	kWh./yr.
Benefit from ENS reduction for 20 years, (Outage cost is 0.0857 USD/kWh)	612,391	USD
The investment cost of two auto reclosers (30,000\$/unit) [21], [22]	60,000	USD
Maintenance cost (5% of investment cost) for 20 years	60,000	USD
The profit of distribution system company	492,391	USD

Table 4 The benefit of Feeder 01 of the distribution system in Attapeu province, Lao PDR when installing two auto reclosers

4. Conclusions

This paper presents the method for selecting the optimal location of auto reclosers in distribution system considering system reliability. The Monte Carlo simulation method is used to evaluate the reliability of the distribution system. It can be seen from the comparison results between the Monte Carlo simulation method and analytical method that the accuracy of the Monte Carlo simulation method is high. In the test results, the reliability of the distribution system can be increased by installing an auto recloser at the proper location which can increase the utility profit as well. For the Feeder 01 of the distribution system of Attapeu province, Lao PDR, the profit can be maximized when installing two auto reclosers at component 68 and 193 because they can mostly reduce the energy not supplied. After two mentioned auto reclosers are installed, the SAIFI, SAIDI, and ENS of the system can be reduced by about 52.52%, 52.44%, and 49.87%, respectively. Moreover, from the research results, it can be concluded that the optimal placement of two auto reclosers should be around the center of the system. This sum up can assist the determination of the system planner to choose the suitable location of two auto reclosers in order to improve the system reliability which results in the increase of utility profit as well.

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Biography

Visanousanh Thepmahavong was born on December 05, 1988. He received B. Eng. degree in Faculty of Engineering, National University of Laos, Lao PDR in 2012. After that, in 2013, he has joined and worked at Electricite Due Laos, Khammouane province Lao PDR. After that, in 2015, he was moved to working in Electricite Due Laos, Attapeu province Lao PDR. He is now studying on the master's degree in electrical engineering, Khon Kaen University, Thailand by using the supports scholarship from EGAT and EDL.

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Apirat Siritaratiwat received the B.Eng. degree in Electrical Engineering from Khon Kaen University, Thailand, in 1992. Then, he worked at the industry for a few years, after that he joined the Department of Electrical Engineering, Khon Kaen University in 1994. In 1995-1999, he studied the Ph.D. degree at the University of Manchester, U.K. Currently, he is working at the KKU-Seagate Cooperation Research Laboratory, Department of Electrical Engineering, Faculty of Engineering, Khon Kaen University. He has done many types of research with more than 100 publications in ESD/EOS and EMI area. Also, he is one of the pioneer researchers in the area of magnetic recording heads in Thailand and has done a lot of works with HDD industries.

Rongrit Chatthaworn was born on August 16, 1986, at Khon Kaen, Thailand. He received B. Eng. degree in Electrical Engineering, Khon Kaen University, Thailand in 2009 (1st class honor) and M. Eng. degree in Electrical Engineering, Chulalongkorn University, Thailand in 2011. In 2015, he obtained the Ph.D. degree in Electrical Engineering, Chulalongkorn University, Thailand. At present, he is a lecturer at Khon Kaen University, Thailand. His research interests include power system planning, energy management system, renewable energy and power system reliability.